Final Report to

RPSEA

Research Partnership to Secure Energy for America

Environmentally Friendly Drilling Systems Program
Project Number 08122.35.FINAL

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RPSEA EFD PROJECT 08122-35

FINAL REPORT

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ABSTRACT

Though industry has made great strides in protecting the environment while increasing natural gas production in the U.S., producers face continual challenges to effectively produce more natural gas in environmentally sensitive areas. The Houston Advanced Research Center (HARC) and its partners offer options to address environmental issues of O&G operations in environmentally sensitive ecosystems. The Environmentally Friendly Drilling (EFD) program combines new low-impact drilling technologies, integrates light weight drilling rigs with reduced emission engine packages, addresses on-site waste management, optimizes the systems to fit the needs of a specific development sites and provides stewardship of the environment. Additionally, the EFD program includes industry, the public, environmental organizations, and elected officials in a collaboration that addresses concerns on development of unconventional natural gas resources in environmentally sensitive areas. Partners have regional expertise that they are able to bring together in a synergistic manner to address the needs across the country.

The RPSEA EFD program leverages on-going research in order to move technologies closer to field application and subsequent commercialization. The program includes (a) commercialization of technology to treat and reuse produced water, (b) development of Alternate Rig Power to reduce operating costs and emissions, and (c) identification and testing of improved technologies and equipment that will reduce the footprint of access roads and well pads, to optimize EFD technologies in E&P activities. Various applications supported in the U.S. DOE NETL "Microhole Technology" were brought within the RPSEA EFD collaboration. To inform the public of the industry's environmental advancements in technology, the RPSEA EFD program developed a computer based model to select complementary environmentally friendly technologies for E&P operations along with an EFD Scorecard to measure performance. The model and the scorecard are important tools that allow industry and regulators to measure performance. The Scorecard concept engages all stakeholders, including industry, academia and environmental organizations, in identifying technologies and systems that can be used to recover unconventional natural gas reserves with the lowest possible environmental footprint. The Model and the Scorecard are based on the principles of what gets measured gets done and what gets identified gets dealt with.

Technology Transfer activities included the human dimension of technology incorporation in societal areas. Educating and informing was directed toward the industry, regulators and the public.
The outcome of the RPSEA EFD program is expected to result in greater access, reasonable regulatory controls, lower development cost and reduction of the environmental footprint associated with operations for unconventional natural gas. The RPSEA EFD program will increase the public's and regulatory agencies' acceptance to operate in environmentally sensitive areas, and add significant reserves to the U.S. unconventional natural gas inventory.

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EXECUTIVE SUMMARY

Industry has made great strides in protecting the environment while increasing natural gas production in the U.S. However, producers face daunting challenges to effectively produce more natural gas in environmentally sensitive areas. The Houston Advanced Research Center (HARC) and its partners offer options to address environmental issues associated with O&G operations in environmentally sensitive ecosystems. The Environmentally Friendly Drilling (EFD) program combines new low-impact technologies that reduce the footprint of drilling activities, integrates light weight drilling rigs with reduced emission engine packages, addresses on-site waste management, optimizes the systems to fit the needs of a specific development sites and provides stewardship of the environment. In addition, this project includes industry, the public, environmental organizations, and elected officials in a collaboration that addresses concerns on development of unconventional natural gas resources in environmentally sensitive areas.

The RPSEA EFD effort is based on a previously co-funded U.S. DOE/industry joint industry partnership (JIP) program led by Texas A&M University and HARC that created a government, industry, public partnership to reduce the environmental footprint of drilling systems in sensitive ecosystems. The 2005-2008 EFD program identified critical technologies appropriate for low impact systems, created industry led research projects, and developed techniques for selecting low impact systems for a given project site. The first EFD program showed that the industry could achieve more than 90% reduction in the impact on the environment if low impact technology was combined into a complete system.

The partnership established in the 2005-08 EFD program provided the foundation of this RPSEA EFD program. It offered an organizational structure that both identified new technologies and transferred those and existing technologies to areas of development that must incorporate new practices to address environmental concerns. Regional U.S. partners managed the RPSEA EFD program and optimized technologies to fit the needs of their locale. Partners in each region worked to incorporate such systems into operations in the Rockies, in the Southwest desert, and in the Appalachia region of the U.S. Partners routinely came together to present work progress to each other and to the sponsors/advisors.

HARC was the prime contractor with Dr. Richard C. Haut acting as the project director/principal investigator. In addition to HARC, the RPSEA EFD team included Texas A&M University (TAMU) and its Global Petroleum Research Institute (GPRI), Sam Houston State University, University of Arkansas, the University of Colorado, Utah State University, the University of Wyoming, West Virginia University, Argonne National Laboratory, Los Alamos National Laboratory and TerraPlatforms, L.L.C. A JIP provided cost share. The JIP included BP, CSI Technologies, Devon Energy, Gulf Coast Green Energy, Halliburton, Huisman, KatchKan USA, M-I SWACO, Newpark Mats and Integrated Services, Chesapeake, Shell, Hess, Chevron, Tenaris, NOV, WyoComposites, Basin Engineering, Scott Environmental and ExxonMobil. The Nature Conservancy and the Natural Resources Defense Council (NRDC) provided in-kind contributions. In the Northeast, the New York State Energy Research Development Authority (NYSERDA) helped promote the program.

The RPSEA EFD program leveraged on-going research in order to move technologies closer to field application and subsequent commercialization. The program included (a) commercialization of technology to treat and reuse produced water, (b) development of Alternate Rig Power to reduce operating costs and emissions, and (c) identification and testing of improved technologies and equipment that will reduce the footprint of access roads and well pads, to optimize EFD technologies in E&P activities. Various applications supported in the U.S. DOE NETL "Microhole Technology" were also brought within the RPSEA EFD collaboration.

To inform the public of the industry's environmental advancements in technology, the RPSEA EFD program developed a computer based model to select complementary environmentally friendly technologies for E&P operations along with an EFD Scorecard to measure performance. The model and the scorecard are important tools that allow industry and regulators to measure performance. The Scorecard concept engages all stakeholders, including industry, academia and environmental organizations, in identifying technologies and systems that can be used to recover unconventional natural gas reserves with the lowest possible environmental footprint. The Model and the Scorecard are based on the principles of what gets measured gets done and what gets identified gets dealt with.

Technology Transfer activities included the human dimension of technology incorporation in societal areas. Educating and informing were directed toward the industry, regulators and the public.

REPORT DETAILS

Experimental Methods

The Environmentally Friendly Drilling Systems (EFD) team focused on technologies for developing unconventional energy sources that can be used in environmentally sensitive areas to maintain our standard of living and preserve our quality of life. The objective was to identify, develop and transfer critical, cost effective, new technologies that can provide policy makers and industry with the ability to accelerate development of US domestic reserves in a safe and environmentally friendly manner.

The EFD program addresses:

- New low-impact technologies that reduce the footprint of drilling activities
- Light weight drilling rigs with reduced emission engine packages
- On-site waste management
- Site access
- Systems to fit the needs of specific development sites and provides stewardship of the environment
- Education

The program included participants from environmental organizations, academia, state and federal agencies, government laboratories, and industry. The partnership identified new technologies and transferred them to areas that must incorporate new practices to address environmental concerns. Regional partners optimized technologies to fit the needs of their locale. Partners routinely came together to discuss progress with the sponsors/advisors.

Technology Transfer activities included the human dimension of technology incorporation in societal areas. Educating and informing was directed toward the industry, regulators and the public. The outcome of the ongoing program is expected to result in greater access, reasonable regulatory controls, lower development cost and reduction of the environmental footprint associated with operations. To inform the public of the industry's environmental advancements in technology, the program developed an EFD Scorecard to measure performance concerning environmental tradeoffs. A computer based model to select complementary environmentally friendly technologies assists industry in deciding the most appropriate technologies to be applied. The program may increase the public's and regulatory agencies acceptance to operate in environmentally sensitive areas, create jobs and add significant reserves to the U.S.

The EFD program included a University/National Laboratories Alliance to fund and transfer critical new technologies that accelerates development of domestic reserves in a safe and environmentally friendly manner. The research was aimed specifically at identifying and developing safe and environmentally friendly technologies.

Results and Discussions

Systems Engineering Design Methodology – Low Impact Well Design Optimization

A web-based decision optimization tool using the causal deterministic approach was developed by Texas A&M University. The Bayesian Network (BN) model with causal probabilistic approach for drilling systems is operational and found at: http://stochasticgeomechanics.civil.tamu.edu/efd/

The Systems Engineering Design Methodology is currently specific for the coastal margins of Texas. This task, led by Dr. Medina-Cetina, an expert in Geotechnical Engineering generalized the methodology and provided a framework into which play specific information (regional requirements for environmental compliance, etc.) could be placed. This enabled the RPSEA regional partners to more quickly and efficiently "stand-up" an equivalent information site. Team members collaborated with stakeholders in workshops in order to deploy an information site using this framework. The process was documented so that it could be linked to the EFD Scorecard system.

An engineering report describing a prototype systems model has been provided to regional centers to use in developing low impact well designs for specific unconventional gas resource plays and is attached in the Appendix. Additionally, a report defining the link between the Environmentally Friendly Drilling Scorecard and the Systems Engineering Design Methodology for the RPSEA EFD Partners is included.

Best Practices Database

The Natural Resources Law Center (NRLC) at University of Colorado Law developed a free-access, searchable, database and supporting website for best management practices (BMPs). This version, launched in March 2009, focuses on the Intermountain West (CO, MT, NM, UT, WY). It includes federal, state, and local regulatory requirements as well as voluntary practices currently in use, required, and/or recommended for protection of surface resources. This version is accessible at: http://www.oilandgasbmps.org/

A white paper has been completed that summarizes the needs and barriers for the region and is available in the Appendix. This includes a discussion on the application of EFD technologies to the region. The NRLC contributed to a series of workshops in order to transfer EFD technologies to regional stakeholders. Throughout the project, NRLC worked to expand the database/website to a broader community of partners in order to refine and expand its functionality and add BMP data. Additional website support materials were also developed.

Dissemination and Decision Support

The University of Arkansas, sponsored by the US Department of Energy through the Low Impact Natural Gas and Oil (LINGO) Program, developed the Fayetteville Shale Information Web and the Fayetteville Shale Infrastructure Placement Decision Support System. The information site enables readers to learn about the natural gas resources available in the Fayetteville Shale formation in Arkansas and explains the steps followed by natural gas development companies, from gaining access to the land through sending the gas to the marketplace. For each step in the process, the site provides information about the state and federal regulatory requirements that developers must follow. The site also describes some of the technologies that can be used to minimize the environmental impacts of natural gas development and provides current interactive maps showing the locations of active drill sites and permitted sites.

The decision support system is also an online map-based resource but is targeted at operators, regulators and other primary stakeholders. The system provides several decision support tools to:

1. Help reduce the possibility of negative environmental impact from infrastructure (drill pads, gather lines, reserve pits and access roads placement and,
2. Promote more effective communication between regulators and operators to expedite the permitting process.

Designed with input from Chesapeake Energy, Southwestern Energy Company, Arkansas Oil and Gas Commission, Arkansas Department of Environmental Quality, US Fish and Wildlife Service, and many others collected through several joint and individual meetings, the system implements a geographic information system (populated with the best and most current geographical data) shared by operators and regulators. In this system a producer can interactively place infrastructure features and let advanced sediment transport models predict the effect on nearby regulated waterways. The web-enabled decision support tool and the supporting queries are constructed in ArcGIS Server 9.3

The Fayetteville Shale Information site contains information specific to the natural and regulatory environment in Arkansas and was developed with critical support and contributions from all stakeholders in the play. The existing site provided a framework into which play specific information (natural resources, regulations, drilling activities, etc.) could be placed. This enabled local stakeholders to more quickly and efficiently “stand-up” up an equivalent informational site. The EFD team worked with stakeholders from the Haynesville play to deploy an information site using this framework and documented the process so that it could more easily be deployed elsewhere. The website is found at: http://lingo1.cast.uark.edu/HaynesvillePublic/

The Decision Support System developed for the Fayetteville Shale worked closely with researchers at the Global Petroleum Research Institute at Texas A&M University to integrate additional environment impact models, in particular the SWAT and APEX assessment tools, into the existing ArcGIS Server deployment. This served to expose these advanced environmental impact models to a wider range of researchers, operators and regulators.

Western Mountain State Studies

The University of Wyoming (UW), in collaboration with the Bureau of Land Management, Heartland BioComposites (now WyoComp) and major upstream gas production companies, has developed a layered mat, roll-out road system design using composite building materials to minimize the impact of oil field access to roads to well pads using the most sustainable approach possible. The concept came from the need to minimize soil disruption and wildlife fragmentation in Jonah Field and Pinedale

Anticline Production Area (PAPA) of the upper Green River Valley, Wyoming. UW's submission won first prize in TAMU 2008 Disappearing Roads competition. Field trials of the scale model system were conducted at the Pecos Desert Research test Center and were incorporated for the RPSEA project with recycled materials. Testing procedures and engineering evaluations have been developed in detail along with an expanded economic feasibility study. A white paper summarizing the needs and barriers for the region that includes a discussion of the application of EFD technologies to the region is included in Appendix.

Public Perception

The EFD Team established rapport with members of the general public, community leaders, representatives of oil and gas associations, regulatory agency personnel, non-governmental organization representatives, and other interested individuals who are expected to be affected by energy development in the Uinta Basin through face-to-face meetings and teleconferencing. Empirically examine stakeholders' level of familiarity with environmentally friendly energy exploration and production practices.

Stakeholders' level of agreement that environmentally friendly energy exploration and productions practices can be used in environmentally sensitive areas that are currently off-limits or highly restricted should such areas be opened up for development was empirically examined.

Workshops were held to establish dialogue among members of the general public, community leaders, representatives of oil and gas associations, regulatory agency personnel, non-governmental organization representatives, and other interested individuals in the Uinta Basin of Utah with respect to the acceptance and assimilation of environmentally friendly energy exploration and production practices drawing upon the empirical data collected.

The EFD team conducted a study of the familiarity with and use of a range of environmentally-friendly natural gas exploration and production practices in the Uintah Basin (UB) of northeastern Utah. The primary goals were to (1) document the use of EFD practices in the UB; (2) understand the drivers that have led to increased use of EFD practices, (3) identify remaining barriers to EFD use in this region. It was also important to raise awareness of EFD practices among key actors in this area, and to better understand public concerns and priorities related to natural gas exploration and development. The key outcomes included publishing a detailed white paper summarizing the research findings, organizing a workshop in the UB that brought together local stakeholders and outside experts (from the EFD national team) to talk about opportunities to reduce the environmental footprint of local natural gas exploration and development, and presentations at national meetings and conferences.

This was begun by introducing the project to representatives from the natural gas industry, local community, and public land management agencies at regularly scheduled quarterly meetings of the UB oil and gas working group in the spring of 2010. The team identified a set of key informants to represent a diverse array of topical and organizational experience and perspectives. A total of 26 key informant interviews were conducted in summer and fall 2010. Results of the interviews were summarized in written narrative reports and analyzed using standard qualitative analysis techniques and software. Interviews were combined with secondary data to write a white paper on the "Opportunities and Barriers to Reducing the Environmental Footprint of Natural Gas Development in Utah's Uintah Basin" (published in April 2011). The results were also presented at the UB workshop in October, 2010, and at several professional meetings.

Eastern Mountain State Studies

The Marcellus shale is one of the most promising gas plays in the U.S. There are barriers and challenges in the development of this play, in particular with site locations, logistics and water issues. The first step was to identify and define the issues and problems. The RPSEA EFD Team collaborated with the West Virginia University (WVU) to initiate an environmentally friendly E&P systems program. WVU is the lead organization for the Eastern U.S. Petroleum Technology Transfer Council (PTTC).

The first objective was to identify the needs and barriers associated with unconventional natural gas production in the Eastern mountain states. While this area of the U.S. is the oldest oil and gas producing area in the country, new horizontal drilling and massive, multi-stage hydraulic fracturing technology is entirely new and must be adapted to the specific requirements of the area. The need for light weight drilling rigs, access to well sites, and the use of water resources must be addressed before the shale can be developed. This objective is detailed in the white paper entitled, "Challenges Facing Developers of the Marcellus Shale Play" found in the Appendix. Additionally, workshops were held in order to transfer technology for the Marcellus Shale to appropriate stakeholders.

National Laboratories Advisors

This project brought to end users research and technical expertise in Environmentally Friendly Drilling (EFD) technologies, including geophysical methods, sensors, micro-drilling, risk assessment, modeling and cost analyses, and produced water treatment and reuse. This work was led at LANL by Dr. E.J. (Jeri) Sullivan. LANL has extensive experience in environmental production issues from current work with Carbon Sequestration and Southwest Regional Partnership projects, DOE-funded produced water treatment for small producers, and advanced sensor and geophysical work for large E&P companies, including oil-shale and tight-gas production research. LANL also brought to the project an experienced staff of technology-transfer professionals who worked with Dr. Sullivan in identifying both available and developing technologies at LANL, and who assisted the EFD partners with technology development, contracts, and commercialization. The National Laboratories supplied high-level research capability in environmental science, chemistry, materials, and engineering, and the ability to develop innovative solutions and technologies quickly.

Argonne provided technical, analytical, and outreach support to the EFD Program. Argonne supported the EFD Program's mission by increasing public awareness of the role that environmentally friendly technologies and practices can play in reducing the environmental footprint of unconventional gas exploration and development through participation in a number of conferences and webinars. Analytical support to EFD as new issues surrounding hydraulic fracturing emerged was provided.

Argonne conducted a survey to identify a wide range of technologies, best practices, and active research areas that have the potential to significantly reduce the environmental footprint of oil and gas development. The survey identified a range of commercial or near commercial technologies in areas such as: produced water management, well pads construction and drilling operations, and waste reduction and pollution monitoring. It also identified a number of emerging best practices in the areas of life cycle water management and air emissions reductions. Finally it summarized ongoing research efforts likely to result in either new technologies or improved processes that will reduce the environmental footprint of future unconventional natural gas exploration and development activities. This effort has resulted in a final summary report which is currently under review and is expected to be published by Argonne and available on the EFD website soon.

Application for Semi-Arid Ecosystems

The EFD team met with operators concerning the application of EFD technologies in semi-arid ecosystems. To develop the environmental cost/benefit methodology, a workshop was held with appropriate representation from the project team and various environmental organizations. The project team also held workshops to show how Systems Engineering Design Methodology and the EFD Scorecard can be used to identify low impact systems.

The various meetings and workshops led to the finalization of the draft prototype EFD Scorecard. Dry-runs, including drilling the well on paper exercises, were performed to test the prototype. Field trials were then planned and scheduled to test the prototype.

The Nature Conservancy invited the EFD System program to perform noise surveys and performance measurement of various drilling and production equipment that is in use at the Texas City Prairie Reserve. The noise survey involved using a hand held GPS, a sound level monitor and a simple measuring device. The EFD team performed the measurements and compared the results to the prairie chicken distribution maps provided by the Nature Conservancy.

Prototype Small Footprint Drilling Rig

A review of rig technologies was developed and published. Huisman agreed to provide a LOC 400 rig at reduced rates for demonstrating its ability to drill with minimal environmental impact for less cost and with safer operations. M-I SWACO provided engineering time and cash to integrate waste minimization technology at the rig site. The various projects making up the microhole project were integrated into the Systems Engineering Model and the alternate power project was developed so that the entire rig operations can be powered at lower cost with lower emissions than conventional operations.

As part of the EFD management Team, Tom Williams was directly involved in ensuring the success of the program. Tom assisted in arranging and leading meetings with sponsors, partners and other stakeholders.

The overall success of the EFD project depended upon sponsors. Tom assisted in these activities. In addition, Tom worked with HARC and other EFD team members to coordinate and facilitate a prototype test of a low impact rig operation. Tom oversaw other EFD team members to identify alternatives to reduce the footprint associated with hydraulic fracturing operations including offsite operations and innovative fracturing technologies such as novel process involving: minimal pumping equipment, low volumes of frac fluid and materials that are environmentally green and non-damaging.

Tom also provided a review of the prior environmental projects sponsored by the US Department of Energy and work with the EFD team to determine which are relevant to the EFD effort.

Air Emissions Studies

The project developed guidelines concerning the mitigation of oxides of nitrogen (NOx) for a drilling site and published them on the www.efdsystems.org website. The team also developed a baseline audit of operating practices during fracturing operations that form the source of emissions and become the starting point of efforts to measure, the mitigate those emissions. These efforts are industry controlled rather than government mandated.

The Center for Applied Technology (TCAT), Texas A&M University System, led a team to collect air emissions data and develop a methodology for estimating/measuring emissions from a natural gas hydraulic fracturing operation. The study site was located at a ranch near Laredo in the Eagle Ford Shale Play. The emissions profiles developed as part of this study can be applied to other similar sites and further refined as additional data becomes available. These studies can also help to ensure that future air quality regulations are based on the best possible data.

Reduced Fracturing Footprints

The production for the majority of tight gas, coalbed methane and gas shales require fracturing, most from horizontal drilling completed with frac jobs. The wellsite footprint from the completion and stimulation can exceed the drilling rig footprint, not to mention the added road and water requirements.

This project identified alternatives available to reduce the footprint including offsite operations and innovative fracturing technologies such as a novel process involving: minimal pumping equipment, low volumes of frac fluid and the use of materials that are environmentally green and non-damaging.

The ReadyFrac process is a novel stimulation process based on U. S. Patent No. 6,949,491 in which solid pellets of a degradable polymer impregnated with proppant are placed into a well, allowed to degrade to a highly viscous liquid, and injected into the formation at low rate creating a hydraulic fracture. This process is limited in size by well geometry, depth and temperature range for polymer degradation. Even so, it is anticipated that ReadyFrac can be applied in wells requiring fracture past damage and produce more productive reservoirs since perfect transport fluids result from the degradation process, no residue remains to damage the formation face or proppant pack, and significantly higher proppant concentrations achievable via this process should improve fracture conductivity.

CSI Technologies, LLC worked with the inventor, Claude E. Cooke, Jr., for several years to develop this concept for commercial application. Significant progress has been achieved in the areas of controlling polymer degradation, manufacturing, and application processes. However, numerical modeling of the treatment or resulting productivity increase requires substantially more work in order to predict fracture geometry and resulting reservoir behavior.

Differences between the ReadyFrac process and conventional hydraulic fracturing operations include:

- The ReadyFrac fluid forms *in situ* in the well across from the perforations. Thus, no initial high-rate injection of thin fluid initiates the fracture. Instead, the fracture is initiated with very viscous fluid injected at a very low rate (1 bpm).
- Resulting fracture geometry will be extremely important since job size is limited to small treatment volumes. Traditional growth boundaries may not work in this application.
- Productivity increase resulting from higher-conductivity, undamaged proppant beds is difficult to predict with current fracturing models.
  CSI is working with a University to develop algorithms and numerical models required to simulate the process.

Hart Energy interviewed the EFD management team to highlight the EFD project in the August, 2012 Hart Energy's Techbook Supplement to Hart's E&P. The article printed a list of the goals accomplished since the project's inception. This commentary offered further clarification on the practices introduced and evaluated throughout the program, providing details on the founders and defining the relationship between industry, academia, the general public and the EFD Team.

Measuring Effectiveness of Environmentally Friendly Drilling

This collaborative effort between Sam Houston State University and TAMU had two aspects:

Public Perception –Factsheets and other outreach educational materials pertaining to environmentally friendly energy exploration and production practices were developed, printed and disseminated.

Social Impact – A review of potential social impacts was documented.

In addition, the RPSEA EFD team organized workshops to develop ecosystem specific scorecards. Input from environmental organizations, industry, universities and government agencies, was used to optimize the scorecards for the specific areas.

The EFD team conducted a series of studies aimed at measuring the effectiveness of an Environmentally Friendly Drilling program. Focus groups, interviews, and household surveys were used to collect data in multiple study sites around the United States where energy development is an integral part of the local society. These sites included communities within Texas, Utah, New York, and Pennsylvania. While the results from these studies pertaining to public perception and social impacts are detailed in the papers in the Appendix, highlighted here are two of the more pertinent findings/recommendations:

First, in each study, the findings revealed that over 8 in 10 individuals believed that natural gas operators must adopt and use more environmentally friendly drilling practices. And, the data from one of the Texas studies revealed that an overwhelming majority of citizens are in favor of eliminating or relaxing governmental regulations that limit oil and natural gas development exploration and production in environmentally sensitive settings as the energy industry adopts and uses a more environmentally friendly approach to development.

Second, based on these studies, it is proposed that energy operators must make a more concerted effort to communicate openly with the public and enhance involvement at the community level. Local residents need to be informed about local energy developments.

Technology Transfer Efforts

The Houston Advanced Research Center (HARC) designated 2.5% of the amount of the award for funding technology transfer activities. Throughout the project, HARC worked with RPSEA to develop and implement an effective Technology Transfer Program at both the project and program level. In addition, HARC provided information requested by RPSEA to support the quantitative estimation of program benefits.

Presentations – List is included in Appendix. Coordinated presentations and articles with project team members in order to inform and educate industry, academia and the public. Members of the EFD engaged in technology transfer activities at the 16th International Symposium on Society and Resource Management (ISSRM), June 6-10, 2010.

Outreach to Regulatory Agencies – Established a dialogue and held seminars/forums with the Bureau of Land Management (BLM), the Interstate Oil and Gas Compact Commission (IOGCC), the Texas Railroad Commission (RRC), various Oil & Gas Commissioners in the Intermountain states, in the Appalachian states, and elsewhere. Argonne Lab, HARC, and Terra Platforms lead the effort.

Collaborate with Others – Collaborated with API, PTTC, International Association for Society and Natural Resources (IASNR) and other organizations. HARC and Terra Platforms lead the effort. The University/National Laboratories Alliance helped coordinate the activities of regional partners in the program.

Outreach in the Rocky Mountains and Desert Southwest – Addressed regional issues related to development of private and public lands including the Uinta, Piceance and other plays in the West. Utah State, University of Colorado, SHSU, University of Wyoming, and HARC lead the effort.

Outreach in Northeast – Informed and educated public and industry concerning EFD practices that may be used in the Marcellus Shale development. PTTC, Argonne National Lab, and TAMU lead the effort. A key focus was produced water management.

Native American Outreach –Workshops were held with Native Americans to inform and educate them of applicable EFD systems.

Outreach in the Upper Midwest – Created a communication network with industry, state and federal officials. TAMU lead the effort.

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12. Haut, R.C., Williams, T., Theordori, G., Slutz, J.: "Balancing Environmental, Societal and Energy Production Issues," extended abstract presented at the Australian Petroleum Production and Exploration Association (APPEA) 2011 Conference, 10-13 April 2011.

13. Gentry, B., Jackson-Smith, D., Belton, L., Theodori, G.: "Assessing Opportunities and Barriers to Reducing the Environmental Footprint of Natural Gas Development in Utah's Uintah Basin," white paper published on www.efdsystems.org, April 2011.

14. Stuver, S., Burnett, D. B., Haut, R. "*Reducing Water Needs in Energy Production and Lowering Environmental Footprint of Oil and Gas Development*," Report to City of San Antonio, Texas. April, 2011.

15. Burnett, D.B., McDowell, J., Scott, J.B., Dolan, C.: "Field Site Testing of Low Impact Oil Field Access Roads: Reducing the Environmental Footprint in Desert Ecosystems," paper SPE-142139-PP presented at the SPE Americas E&P Health, Safety, Security and Environmental Conference, Houston, TX, 21-23 March 2011.

16. Haut, R.C.: "We Can Minimize Negative Side-Effects of Shale Drilling", Houston Chronicle, 12 February 2011.

17. Burnett, D. B. *"Advanced Membrane Filtration Technology for Cost-Effective Recovery of Fresh Water from Oil and Gas Produced Brine,"* U.S. Department of Energy National Environmental Technology Laboratory 27279-NETL, 2011.

2009 – 2010

1. Haut, R.C., Burnett, D., Williams, T., Theodori, G.: "Balancing Environmental Tradeoffs Associated with Low Impact Drilling Systems to Produce Unconventional Natural Gas Resources," paper CSUG/SPE-1337430-PP presented at the Canadian Unconventional Resources & International Petroleum Conference, Calgary, Alberta, Canada, 19-21 October 2010.

2. Haut, R.C., Bergan, J.F., Judy, J., and Price, L.: "Living in Harmony – Gas Production and the Attwater's Prairie Chicken," paper SPE-133652-PP presented at the SPE Annual Technical Conference and Exhibition, Florence, Italy, 19-22 September 2010.

3. Veil, J.A., Puder, M.G, Bruno, M., and Fleming, C.: "Regulatory Considerations," chapter in Society of Petroleum Engineers Monograph Vol 24, Solids Injection of Exploration and Production Wastes, N. Nagel and J. McLennan, eds., September 2010.

4. Produced Water Volume Estimates and Management Practices," manuscript accepted September 21, 2010 for publication in upcoming issue of SPE Production and Operations.

5. Veil, J.A., Clark, C.E.: "Produced Water Volume Estimates and Management Practices," manuscript accepted September 21, 2010 for publication in upcoming issue of SPE Production and Operations.

6. Pickett, A.: "Technologies, Methods Reflect Industry Quest to Reduce Drilling Footprint," American Oil & Gas Reporter, July 2010, pp. 71-81.

7. Haut, R.C. and Fischer, M.W.: "Cooperative Efforts Lead to Safer Operations," Hart's E&P, January 2010, pp. 32-33.

8. Redden, J.: "Drilling Advances: Is Green Drilling on the Horizon?" World Oil, December 2009, Vol. 230 No. 12.

9. "Environmentally Friendly Drilling Program to Reduce Impact of Operations on Ecosystems," NETL E&P Focus, Winter 2009 Oil & Natural Gas Program Newsletter.

10. Haut, R.C. and Dishaw, R.: "Shoulder/Thread Verifier System Uses Thermal Imaging to Detect Potential Connection Problems," Drilling Contractor, November/December 2009, pp. 68-73.

11. Clark, M. and Hotby, Q.: "Prevention Technology Can Help Drilling, Service Rigs to Minimize Environmental Footprint at the Source," Drilling Contractor, November/December 2009, pp. 74-79.

12. Mutz, K. and Haut, R.: "Best Practices Database Reduces Impact of Drilling, Production," April, 2010.

13. Theodori, Gene L., Mona E. Avalos, David B. Burnett, and John A. Veil. (forthcoming). "Public Perception of Desalinated Water from Oil and Gas Field Operations: A Replication" Journal of Rural Social Sciences.

14. Theodori, Gene L. and Douglas Jackson-Smith. 2010 (September). "Public Perception of the Oil and Gas Industry: The Good, the Bad, and the Ugly," paper SPE-134253 presented at the 2010 Society of Petroleum Engineers Annual Technical Conference and Exhibition. Florence, Italy.

15. Theodori, Gene L. 2009. "Paradoxical Perceptions of Problems Associated with Unconventional Natural Gas Development." Southern Rural Sociology 24(3): 97-117.

16. Theodori, Gene L., Brooklynn J. Wynveen, William E. Fox, and David B. Burnett. 2009. "Public Perception of Desalinated Water from Oil and Gas Field Operations: Data from Texas." Society and Natural Resources 22(7): 674-685.

17. Anderson, Brooklynn J. and Gene L. Theodori. 2009. "Local Leaders' Perceptions of Energy Development in the Barnett Shale." Southern Rural Sociology 24(1): 113-129.Yu O.K., Medina-Cetina Z, Briaud, J.L. and Burnett, D. (2009), "Towards a Probabilistic Selection of Environmentally Friendly Drilling Systems," 16th International Petroleum and Biofuels Conference, Houston TX, 3-5 November.

18. Al-Yami A.S., Schubert J., Medina-Cetina Z. and Yu O-Y, (2010), "Members Drilling Expert System for the Optimal Design and Execution of Successful Cementing Practices," Proceedings of the IADC/SPE Asia Pacific Drilling Technology Conference and Exhibition, Ho Chi Minh City, Vietnam, 1–3 November 2010.

19. Yu O.K., Medina-Cetina Z. and Briaud J.L. (2011), "Towards an Uncertainty-Based Design of Foundations for Onshore Oil and Gas Environmentally Friendly Drilling (EFD) Systems," Proceedings of the Geo-Frontiers Conference, Dallas TX USA, March 13-16.

20. Yu O.Y., Medina-Cetina Z., Geikema S., Briaud J.L. and Burnet D., (under review), "Causal vs. Non-Causal Selection of Environmentally Friendly Drilling Systems," Journal of Economics and Management of the Society of Petroleum Engineering SPE.

21. Yu O.Y., Medina-Cetina Z., Geikema S., Briaud J.L. and Burnet D., (under review), "Risk-Based Selection of Environmentally Friendly Drilling (EFD) Systems," Journal of Systems Engineering.

22. Burnett, D.B, Yu, O.Y., and Schubert, J.J., "Well Design for Environmentally Friendly Drilling Systems: Using a Graduate Student Drilling Class Team Challenge to Identify Options for Reducing Impacts," SPE/IADC 119297, Prepared for presentation at the SPE/IADC Drilling Conference and Exhibition held in Amsterdam, The Netherlands, 17-19 March 2009.

Presentations

2012

2012-07-16 Utica Shale Appalachian Basin Research Consortium (focus on industry-government collaborations) presented to representatives from the Shenhua Group; within the DOE Fossil Energy Global Knowledge Network program.

2012-07-16 Preliminary Results on the Effect of Land-Use Land-Cover Methods of Classification and Data Resolution on SWAT Model Predictive Ability. Poster presented at the 3rd Biennial Colloquium on Hydrologic Science and Engineering of the Consortium of Universities for the Advancement of Hydrologic Science Inc. (CUAHSI), Boulder, CO.

2012-06-19 Environmentally Friendly Drilling: Air & Waste Management Association Annual Conference & Exhibition, San Antonio, TX.

2012-06-18 "Assessing Opposition and Support for Energy Development in Environmentally Sensitive Areas." Presented at the 18th International Symposium on Society and Resource Management in Edmonton, Alberta, Canada.

2012-06-06 Best Management Practices for Oil and Gas Development. Presentation made at The Institute for Energy Law 3rd Law of Shale Plays Conference in Fort Worth, TX.

2012-06-05 BMPs on Public Lands: Protecting Water and Wildlife. Public Lands Committee session, Developing North America's Oil and Gas Resources, Interstate Oil and Gas Compact Commission, Midyear Summit, Vancouver, B.C.

2012-06-04 The EFD Technology Integration Program: IOGCC, Vancouver, B.C.

2012-06-03 Developing North America's Oil and Gas Resources. Presented at the Interstate Oil and Gas Compact Commission, Midyear Issues Summit (Public Lands Committee) in Vancouver, B.C.

2012-05-24 Ukraine Shale Gas: Environmental and Regulatory Assessment presentation at the Regional Shale Gas Workshop in Poland, Ukraine and Kyiv.

2012-05-01 An ArcGIS-Server based framework for oil and gas E&P decision support. PowerPoint resented at the ESRI Petroleum User Group (PUG) Meeting, Houston, TX.

2012-04-27 "Public Reaction to Shale Gas Development." Presentation delivered at the Center for Research Excellence in Science and Technology—Research on Environmental Sustainability in Semi-Arid Coastal Areas (CREST-RESSACA) Environmental and Energy Sustainability Conference. Houston, TX.

2012-04-25 Assessing Opposition and Support For Shale Gas Development. Presented at SPE Reducing Environmental Impact of Unconventional Resource Development workshop, San Antonio, TX.

2012-04-25 Energy and the Environment: Application of Framing Theory to Gas Shale Development. Presented at SPE Reducing Environmental Impact of Unconventional Resource Development workshop, San Antonio, TX.

2012-04-24 An ArcGIS-Server based framework for oil and gas E&P decision support. PowerPoint presented at the Mid-America GIS Consortium Biennial Meeting, Kansas City, MO.

2012-04-24 The Industry Must Apply Best Practices for Shale Gas Development. Presented at SPE Reducing Environmental Impact of Unconventional Resource Development workshop, San Antonio, TX.

2012-04-24 Produce Water Analytical Field Trials and Methodology Development. Presented at SPE Reducing Environmental Impact of Unconventional Resource Development workshop, San Antonio, TX.

2012-04-23 Emissions from Oil and Gas Sites are at Risk of being Overestimated. Presented at SPE Reducing Environmental Impact of Unconventional Resource Development workshop, San Antonio, TX.

2012-04-23 Advanced Geoprocessing with Python. Workshop presented at the Mid-America GIS Consortium Biennial Meeting, Kansas City, MO.

2012-04-10 "Water Management in Oil & Gas Unconventional Developments: A Sociological Perspective." Plenary presentation delivered at the 2012 American Association of Drilling Engineers Fluids Technical Conference and Exhibition. Houston, TX.

2012-03-20 Modeling the Effects of Non-Riparian Surface Water Diversions on Flow Conditions in the Little Red Watershed. PowerPoint presented at the 2012 Fayetteville Shale Symposium, Fort Smith, AR.

2012-03-11 *Reading and Writing Spatial Data for the Non-Spatial Programmer*. Poster presented at the PyCon U.S., Santa Clara, CA.

2012-02-17 Ukraine Shale Gas: Regulatory and Environmental Review: Washington, DC

2012-02-07 Creating A Company's Environmental Culture to Improve Performance in the Energy Industry: IADC Health, Safety, Environmental & Training Conference & Exhibition, Houston, TX.

2012-02-05 "A Big Fracing Mess: An Examination of Public Perception of Hydraulic Fracturing." Presented at the annual meeting of the Southern Rural Sociological Association, Birmingham, AL.

2012-01-24 Fact-based Regulation for Environmental Protection in Shale Gas Resource Development: Ground Water Protection Council UIC Conference, Austin, TX.

2012-01-18 Natural Gas Research and Resources at CU Boulder. "Drawing the Blueprint for a Sustainable Natural Gas Future." Presented at the Museum of Nature and Science in Denver, CO.

2011

2011-12-13 Environmentally Friendly Drilling Programs. Presentation given at the Oklahoma Unconventional Resources Forum, Tulsa, OK.

2011-12-07 Low Impact O&G Activity; Environmentally Friendly Drilling Systems. Presentation given at the Crisman Institute for Petroleum Research Forum, College Station, TX.

2011-11-30 Intermountain Oil and Gas Best Management Practices. Presentation given at the RPSEA Onshore Production Conference: Technological Keys to Unlocking Additional Reserves, Golden, CO.

2011-11-07 Reducing Environmental Footprints by Providing Unbiased Science for Policy and Cost Effective Operations. Presentation given during panel discussion at the World Shale Gas Conference & Exhibition, Houston, TX.

2011-11-01 Shale Gas – The Energy-Water Nexus. Presented as part of the webinar series Hydraulic Fracturing: Fresh Facts & Critical Choices sponsored by the Clean Water for America Alliance and the American Water Resources Association.

2011-11-02 Providing Science and Solutions to Shale Development. Presentation given during special environmental panel discussion at the SPE Annual Technical Conference and Exhibition, Denver, CO.

2011-10-27 Balancing Environmental Tradeoffs – Clearing the Air. Presentation given at the Colorado Oil and Gas Association Western Slope Annual Meeting, Grand Junction, CO.

2011-06-28 Testimony given to the Secretary of Energy/Energy Advisory Board/Natural Gas Subcommittee. Washington, DC.

2011-06-06 Examining the Effects of Unconventional Natural Gas Development on Community Attachment, Satisfaction, and Action: Data from the Barnett Shale. Presentation given at the 17th International Symposium on Society and Resource Management, Madison, WI.

2011-06-06 Produced Water Management and Disposal: Toward Beneficial Reuse Practices. Presentation given at the 17th International Symposium on Society and Resource Management, Madison, WI.

2011-05-18 Public Perception and Reaction to Shale Gas Development. Presentation given at the East Texas Energy Expo, Center, TX.

2011-05-13 Creating a Company's Environmental Culture to Improve Performance in the Energy Industry. Presentation given at the IADC Environmental Conference & Exhibition, Trinidad.

2011-05-11 Public Perceptions of Marcellus Shale Knowledge Gaps: Preliminary Findings and New Questions. Paper presented at the Marcellus Shale Multi-State Academic Research Conference. Altoona, PA.

2011-05-08 EPA Technical Workshops Office of Research and for the Hydraulic Fracturing Study: Chemical & Analytical Methods.

2011-04-28 Reducing Environmental Footprint in Shale Gas Development – Emerging Technologies. Presentation given at the SPE ATW Workshop, Pittsburgh, PA.

2011-04-19 Environmentally Friendly Drilling Systems. Program review given at RPSEA forum in Denver, CO.

2011-04-19 Shale Gas – The Energy-Water Nexus. Presented at the American Water Resources Association spring specialty conference, Baltimore, MD.

2011-03-29 Balancing Environmental Tradeoffs Associated with Natural Gas Production. Presentation given at Cornell University.

2011-02-06 This is All New to Us: Rural Residents' Views on Gas Drilling and Water Resources in an Emerging Energy Hotspot. Paper presented at the Annual Meeting of the Southern Rural Sociological Association. Corpus Christi, TX.

2011-02-01 Environmentally Friendly Drilling Systems Program. Presentation given at the USEA Luncheon Forum, Washington, DC.

2011-01-27 Environmentally Friendly Drilling Systems Program. Presentation given at the SPE Hydraulic Fracturing Forum, The Woodlands, TX.

The following presentations were made by Texas A&M during 2011:

2011-12-08 Burnett, D. B., Environmentally Friendly Drilling: How Texas A&M can Save America, Texas A&M Crisman Institute

2011-11 Burnett , D. B., "Eagle Ford Shale: Impact of Gas Shale Development on South Texas Counties, Texas A&M Agri-Life Extension Service

2011-11 Burnett, D. B. "Produced Water "Desalination: Science and Solutions", Drilling Engineering Association, Houston, Nov., 2011

2011-11 Burnett, D. B., McLeroy, K. E., "Technology for Management and Re-Use of Produced Water," Nieva, Colombia

2011-09 Burnett, D. B., McLeroy, K. E. Lowering the Environmental Footprint of E&P Operations: by the Land, Sea(water), and Air, Brigham Energy, Austin, TX

2011-09 Burnett, D. B., "Treatment and Re-Use of Frac Flowback Brine and Produced Water," U. of Wyoming Hydraulic Fracturing Forum Ruckelehouse Energy Institute, Laramie, WY.

2011-08-17 Burnett, D. B., Nathan, V., " Drilling the Eagle Ford Shale: Science and Solutions", presented to Friends of the Shale, Laredo, TX

2011-08 Platt, F. M., Burnett, D. B., Report on Field Trials of Mobile Filtration Unit. Texas A&M Membrane/Filtration Short Course Texas, College Station, TX

2011-07 Burnett, D. B., McLeroy, K. E. "Environmentally Friendly Drilling: South Texas Brine Management Practices," ConocoPhillips, Houston

2011-07 Burnett, D. B. Lowering the Environmental Footprint of E&P Operations: by the Land, Sea(water), and Air, Chesapeake, Energy, OK City OK

2011-06 Higgins, M. E., Burnett, D. B., Societal Issues Related to Leasing Fort Worth Nature Center for (Barnett Shale) Drilling , International Symposium for Society and Resource Management, Madison, WS.,

2011-06-02 Burnett, D. B., McLeroy, K. E. "Lowering the Environmental Footprint of E&P Operations: by the Land, Sea(water), and Air. The Environmentally Friendly Drilling Systems Program, Duke University Nichols School of the Environment

2011-05 Burnett, D. B., "Desalination as an alternative to off-site disposal in conventional oil, Global Water Intelligence

2011-04 Burnett, D. B. Lowering the Environmental Footprint of E&P Operations: By the Land, Sea(water), and Air" Calgary CA.

2011-04 Burnett, D. B., Reducing Environmental Footprint in Gas Shale Operations, SPE Advanced Technology Workshop, Pittsburgh, PA.

2011-04-07 Burnett, D. B., TAMU *Mobile desalination and disappearing roads, Texas A&M Agri-Life Extension Services Workshop, Ft. Stockton, TX*

2011-04-06 Burnett, D. B., TAMU *Mobile desalination and disappearing roads, Texas A&M Agri-Life Extension Services Workshop, Midland, TX*

2011-04-05 Burnett, D. B., TAMU *Mobile desalination and disappearing roads, Texas A&M Agri-Life Extension Services Workshop, Ozona, TX*

2011-04 Burnett, D. B., Texas A&M Membrane/Filtration Short Course Texas, College Station, TX

2011-02 Haut, R. S. Stuver, S., Burnett, D. B., Reducing Water Needs in Energy Production and Lowering Environmental Footprint of Oil and Gas Development", Alamo Area Council of Governments, San Antonio

2011-01-27 Burnett, D. B., Vavra, C.J., Platt, F. J., McLeroy, K. E. Membrane Treatment to Optimize Beneficial Re-Use of Oil Field Brines, SPE Summit Environmental Issues Related to Hydraulic Fracturing, The Woodlands.

2011-01-12 Burnett, D. B., Vavra, C. J., Platt, F. M., Reducing Water Needs in Energy Production and Lowering Environmental Footprint of Oil and Gas Development , presentation to Cleanwater Solutions, LTD., College Station, TX.

2009 – 2010

2010-11-16 Geospatial Decision Support for Reducing Environment Impact in Natural Gas Shale Operations, Managing Fayetteville Shale Play Development Workshop. Workshop held in Fayetteville, AR.

2010-10-28 Decision-Support System for Pad Siting, West Slope Colorado Oil & Gas Association Environmental Summit, Grand Junction, CO.

2010-10-27 Reducing Environmental Impacts in the Fayetteville Shale Play using Geospatial Decision Support, A Spatial Quest: Twenty Years of Mapping the Natural State, Arkansas GIS User's Forum, Hot Springs, AR.

2010-10-25 Natural Gas in the New Energy Economy, Panel discussion part of Clean Energy Day, University of Colorado, Boulder, CO.

2010-10-22 Natural Gas Development and Social Well-Being. Presentation delivered at the Pennsylvania State University, Department of Agricultural Economics and Rural Sociology, M.E. John Lecture Series. University Park, PA.

2010-10-14 Geospatial Decision Support for Reducing Environment Impact in Natural Gas Shale Operations, Opportunities and Obstacles to Reducing the Environmental Footprint of Natural Gas Development in the Uintah Basin. Workshop held in Vernal, UT.

2010-10-14 Intermountain Oil and Gas BMP Project, Presented at the Opportunities and Obstacles to Reducing the Environmental Footprint of Natural Gas Development in the Uintah Basin Conference, Vernal, UT.

2010-10-10 *Minimizing the Surface Footprint for Unconventional Gas,* Presented at the 2010 GCAGS/GCSSEPM Annual Meeting, San Antonio, TX.

2010-09-26 *Water Availability and Management in Shale Gas Operations*, Presented at the Ground Water Protection Council Water/Energy Sustainability Symposium, Pittsburg, PA.

2010-09-22 Public Perception of the Oil and Gas Industry: The Good, the Bad, and the Ugly. Presented at the 2010 Society of Petroleum Engineers Annual Technical Conference and Exhibition. Florence, Italy.

2010-09-01 Water Modeling in the Fayetteville Shale, 17th International Petroleum & BioFuels Environmental Conference, San Antonio, TX.

2010-08-31 *Water Availability and Management in Shale Gas Operations*, Presented at the 17th International Petroleum and Biofuels Conference, San Antonio, TX, August 31-September 2, 2010.

2010-08-31 *The Regulatory Environment*, presented at the 17th International Petroleum and Biofuels Conference, San Antonio, TX, August 31-September 2, 2010.

2010-08-12 *'Deep in the Heart of Texas' Barnett Shale Perceived and Objective Community Level Impacts of Unconventional Gas Development*, Presented at the annual meeting of the Rural Sociological Society, August 12-15, Atlanta, GA.

2010-08-10 Findings for the Publics' Willingness to Adopt Desalination (Purification) of Oilfield Brine. Presented at the 6th Annual Practical Short Course on Water Desalination, Process and Wastewater Issues & Technologies. College Station, TX

2010-07-12 Assessing Opportunities and Barriers to Improving the Environmental Footprint of Oil and Gas Development in Utah. Presented at the Utah Governor's Energy Forum. Salt Lake City, UT.

2010-07-08 *Water Management Technologies & Regulatory Requirements for Different Locations and Environments,* Workshop presented at the 2010 Summer Meeting of the IOGA of New York, Findley Lake, NY.

2010-07-07 *The Inextricable Linkage between Water and Energy,* Presented at the 2010 Summer Meeting of the IOGA of New York, Findley Lake, NY.

2010-07-07 Exploration and Production of Oil and Natural Gas in Environmentally Sensitive Areas: Views from the Public. Presented at the 15th International Symposium on Society and Resource Management. Vienna, Austria

2010-06-24 *Water and Energy Relationships with a Focus on Oil and Gas Produced Water,* Presented at the 10th Biannual Research Review Meeting, National Science Foundation Industry/University Cooperative Research Center for Multiphase Transport Phenomena, East Lansing, MI.

2010-06-17 *Minimizing the Surface Footprint for Unconventional Gas,* Presented at the 2010 Global Unconventional Gas Forum Amsterdam, Netherlands.

2010-06-15 *Water & Energy - Inexorably Entwined Dance Partners, but without Perfect Choreography,* Seminar presented to staff at the Oak Ridge National Laboratory, Oak Ridge, TN.

2010-06-13 *Options for Management of Produced Water,* Presented at the Goldschmidt Conference, Knoxville, TN.

2010-06-07 *Opportunities and Barriers to Environmentally Friendly Energy Exploration and Production Practices in the Uinta Basin,* Presented at the 16th International Symposium on Society and Resource Management, Corpus Christi, TX.

2010-05-25 *Produced Water – Nuisance Byproduct or Valuable Resource?* Presented at the University of Wyoming Produced Water Conference, Laramie, WY.

2010-05-24 *Water & Energy - Inexorably Entwined Dance Partners, but without Perfect Choreography*, seminar presented to staff at the National Renewable Energy Laboratory, Golden, CO.

2010-05-20 Disappearing Roads Competition Finals, Texas A&M University.

2010-04-07 *The Environmentally Friendly Drilling Systems Program,* Presented at the RPSEA Unconventional Natural Gas Forum, Golden, CO.

2010-04-06 Conference Keynote Speaker for the AADE Conference, Houston, TX.

2010-03-18 Houston Association of Professional Landmen (HAPL), Petroleum Club, Houston, Luncheon Presentation.

2010-03-03 *Natural Resources and Environmental Issues and Energy Policy: A Sociologist's Perspective,* Presented at the Center for Environmental Research, Education, and Outreach, Washington State University, Pullman, WA.

2010-02-08 Energy Development, Natural Environments and Quality of Life: The Good, the Bad, and the Ugly as Perceived by Texans. Presented at the Annual Meeting of the Southern Rural Sociological Association. Orlando, FL.

2009-11-05 *From the Past to the Future: The Environmentally Friendly Drilling Systems Program,* Presented at the 2009 IOGA Conference, Buffalo, NY.

2009-11-03 *Environmental Stewardship of Natural Gas Operations,* Presented at the 2009 IPEC Conference, Houston, TX.

2009-11-03 *Causal vs. Non-Causal Selection of Onshore Environmentally Friendly Drilling Systems,* Presented at the 2009 IPEC Conference, Houston, TX.

2009-11-03 *Pretreatment Options for Water Based E&P Wastes,* Presented at the 2009 IPEC Conference, Houston, TX.

2009-11-03 *Environmental Benefits of KERS System with Electrical/Diesel Rigs,* Presented at the 2009 IPEC Conference, Houston, TX.

2009-11-03 *Team Challenge: Environmentally Friendly Drilling Using Low Impact Access Practices for Desert Ecosystems,* Presented at the 2009 IPEC Conference, Houston, TX.

2009-11-03 *Public Opinion on Exploration and Production of Oil and Natural Gas in Environmentally Sensitive Areas,* Presented at the 2009 IPEC Conference, Houston, TX.

2009-11-03 *Constructed Wetland Treatment Systems for Environmentally Friendly Drilling,* Presented at the 2009 IPEC Conference, Houston, TX.

2009-11-03 *A Crystal Ball View of the Energy Industry in 2025: How Environmentalists Hold the Key to America's Future Energy Security,* Presented at the 2009 IPEC Conference, Houston, TX.

2009-10-14 Intermountain Oil and Gas BMP Project, Presented at the Best Practices for Community and Environmental Protection Workshop, Rifle, CO.

Workshops

2012

2012-06-12 EFD Program: Milestone Review held in The Woodlands, TX.

2012-05-17 Best Management Practices for Utica and Marcellus Development Workshop, Morgantown, WV.

2102-05-02 EFD Tour of the Offshore Technology Conference, Houston, TX.

2011

2011-11-10 EFD Program: Managing the Eagle Ford Development Workshop held in Kingsville, TX.

2011-08-17 Eagle Ford Shale Fracturing: Science and Solutions Workshop held in Laredo, TX.

2011-07-26 Lowering the Environmental Footprint of Marcellus Shale Development Workshop held in Morgantown, WV.

2011-05-26 Best Management Practices Workshop held in Boulder, CO.

2011-04-13 Environmentally Friendly Drilling Workshop held at the American Association of Drilling Engineers Conference, Houston, TX.

2011-03-15 Managing the Eagle Ford Development Workshop held in San Antonio, TX.

2009 – 2010

2010-11-16 EFD – Managing Fayetteville Shale Play Development Workshop held at the University of Arkansas, Fayetteville, AR.

2010-10-14 EFD/BMP – Opportunities and Obstacles to Reducing the Environmental Footprint of Natural Gas Development in the Uintah Basin. Workshop held in Vernal, UT.

2010-09-23 EFD Europe Kick-Off Forum held in Florence, Italy

2010-08-24 PTTC-EFD Workshop/Forum held in Pittsburgh, PA.

2010-07-08 *Water Management Technologies & Regulatory Requirements for Different Locations and Environments,* Workshop presented at the 2010 Summer Meeting of the IOGA of New York, Findley Lake, NY.

2010-06-07 *The Eagle Ford Shale,* 16^{th} International Symposium on Society and Resource Management in Corpus Christi, TX.

2010-05-06 Panel Discussion, Natural Gas Solutions Summit, Aspen, CO.

2010-05-05 Panel Discussion, Offshore Technology Conference, Houston, TX.

2009-11-12 *The EFD University/National Laboratory Alliance*, Oak Ridge, TN, Special workshop with employees from the Oak Ridge National Laboratory.

2009-10-14 *Best Practices for Community and Environmental Protection*, Rifle CO, Over 160 participants from academia, industry, environmental organizations, regulators, landowners and others

Exhibits

2011

2011/10/15 *Energy Day*, Houston, TX.

2011/09/24-28 *Groundwater Protection Council Annual Forum,* Atlanta, GA.

2011/05/17-18 *East Texas Energy Expo i*n Center, TX.

2010 – 2009

2010/06/07-10 *16th International Symposium on Society and Resource Management,* Corpus Christi, TX.

2010/05/20 *IADC Onshore Drilling Conference & Exhibition,* Omni Houston Hotel Westside, Houston, TX.

2010/01/26-27 *IADC Health, Safety, Environment & Training Conference & Exhibition,* Omni Houston Hotel Westside, Houston, TX.

Awards

2009-10-05: ***Environmental Partnership/Chairman's Stewardship Award***,
Interstate Oil and Gas Compact Commission.

LIST OF ACRONYMS AND ABBREVIATIONS

API: American Petroleum Institute

ArcGIS: name of a group of geographic information system software product lines produced by ESRI

BCF/D: Billion cubic feet per day

BLM: Bureau of Land Management

BMP: Best Management Practice

CEQ: Council on Environmental Quality

CIAP: Coastal Impact Assistance Program

CITP: Coastal Impacts technology Program

CO: Colorado

CO_2: Carbon Dioxide

CU: University of Colorado

DOE: U.S. Department of Energy

E&P: Exploration and Production

EFD: Environmentally Friendly Drilling Systems Program

FS: Forest Service

GIS: Geographic Information System

GPRI: Global Petroleum Research Institute

HARC: Houston Advanced Research Center

Hp: Horsepower

Hrs: Hours

HSE: Health, Safety, Environment

HVOC: Highly Volatile Organic Compounds

IASNR: International Association for Society and Natural Resources

ISSRM: International Symposium on Society and Resource Management

IOGCC: Interstate Oil and Gas Compact Commission

ISO: International Organization for Standardization

JIP: Joint Industry Partnership

KW: Kilowatt

LANL: Los Alamos National Laboratory

LINGO: Low Impact Natural Gas & Oil Prgrm

MMS: Minerals Management Service

MT: Montana

MW: Megawatt

NEPA: National Environmental Policy Act

NETL: National Energy Technology Laboratory

NGO: Non-governmental organization

NM: New Mexico

NOx: Oxides of Nitrogen

NPC: National Petroleum Council

NRCS: Natural Resources Conservation Service

NRDC: Natural Resources Defense Council

NRLC: Natural Resources Law Center

NYSERDA: New York State Energy Research Development Authority

O&G: Oil and Gas

OCS: Outer Continental Shelf

PAPA: Pinedale Anticline Production Area

PI: Principal Investigator

PTTC: Petroleum Technology Transfer Council

RPSEA: Research Partnership to Secure Energy for America

RRC: Texas Railroad Commission

SCR: Selective Catalytic Reduction

SPE: Society of Petroleum Engineers

SSURGO: Soil Survey Geographic Data Base

TAMU: Texas A&M University

TBD: To Be Determined

tcf: Trillion Cubic Feet

TX: Texas

U.S.: United States of America

USA: United States of America

USGS: United States Geological Survey

UT: Utah

UW: University of Wyoming

WVU West Virginia University

WY: Wyoming

Yds: Yards

APPENDICES

RPSEA EFD Project 08122-35

4.1 System Engineering Design Methodology – Low Impact Well Design Optimization

Lead: Texas A&M University

Prepared for the
Environmentally Friendly Drilling Systems Program
Houston Advanced Research Center

July, 2012

Zenon Medina-Cetina, Ph.D.

07/16/12

Date Signed

System Engineering Design Methodology - Low Impact Well Design Optimization

By:
Zenon Medina Cetina
Patricia Varela

Texas A&M University
Stochastic Geomechanics Laboratory
College Station, Texas, USA. July, 2012.

Introduction

Shale gas developments in the U.S. are presently showing a significant growth due to recent discoveries from rich shale formations such as the Barnett, Marcellus and the Eagle Ford. The expansion of these energy developments is exponential, showing a growing rate even into urban and environmentally protected areas. In order to access these environmentally protected areas (called off-limit areas), the shale gas industry has be conditioned to mainstream the development of low impact Environmentally Friendly Drilling (EFD) technologies. This has generated the need for making available a methodology that can define an optimal single drilling system for a given site. In practice, this effort is known to introduce significant uncertainty due to the inherent subjectivism at the time of selecting components of the drilling system, without having a systematic understanding of the potential technology integration. Moreover, different competing criteria may be imposed from different stakeholders, which exacerbates the optimal selection of a drilling system.

The relevance of the proposed work is to replicate a complex decision-making process that in practice is based on expert judgment, by introducing a decision-making model for the selection of EFD technologies. The aim is to make available a tool that can facilitate the understanding of the system selection process under varying selection criteria. For this purpose, a simplified model is first discussed as a proof of concept, addressing the theoretical and computational elements required for its implementation. Then, a more detailed model is applied to the case study, showing that the new decision-analytic tool can allow for a more rational and transparent decision-making, under environmental, cost, and public perception evaluation criteria. This approach will be extrapolated to other locations when placed within a Geographic Information System. Furthermore, since the proposed model represents a probability template, it will be easily updated as new evidence about the specific drilling site becomes available. It is anticipated that industry, government agencies, environmental organizations, and other oil and gas stakeholders will benefit from the proposed system selection method as a way to identify critical components that require further design and research, which in turn can reduce operating risk in similar processes

Appendix 1 presents the description of a 'System Selection Tool' used to evaluate the best combination of technologies to help decision makers on the task of selecting the proper drilling technologies for a given rig site. Two approaches are described to obtain a value that measures the best technologies combination: a 'Non-Causal' completely deterministic used to make preliminary evaluations with a time saving tool, and a 'Causal Model' that includes the natural dependencies between the system components and two factors integrated as probabilistic variables, such as 'Drilling Depth' and 'Drilling Time'. As expected, the second tool is a more robust and accurate decision making tool to address an optimal drilling system. These tools can be accessed through a web page available for the public, where the user can design a project making a combination of the technologies provided by the tools, and even introduce new technologies to the system (https://stochasticgeomechanics.civil.tamu.edu/efd/).

The 'Big Picture' as defined by Ok Youn (2010) is a Bayesian Decision Network model that gathers most of the activities developed by O&G industry when a site is chosen to drill and to develop a reservoir (Figure 1). This model evaluates the combination of several technologies in 'Decision' nodes (squared) and their correspondent risk in terms of environment impact, cost and public perception. These technologies are grouped in subsets (decision nodes), which at the same time are arranged by subsystems sequentially organized as 'Site and Rig', 'Power' and 'Operations'.

The causal dependencies (oval variables) derived from the deterministic choices made in the decision nodes, are also separated by color according to the addressed factor: 'Cost', 'Environmental Impact' and 'Public Perception'. The consecutive propagation of the information through the model allows making probabilistic inferences about the state of the emissions, the footprint and costs for each subsystem. This probabilistic approach permits to converge into a value of risk that serves as a decision making factor, which is obtained after evaluate a combination of technologies.

To enhance the capability of the tool to guarantee that environmental and societal factors are taken under serious consideration, the model was calibrated with the Score Card System, either correlating or adding technologies to the 'Big Picture'.

Environmentally Friendly Drilling Foundations - System Engineering Design Methodology

The design of a rig site for Oil&Gas operation is a key factor to minimize the land footprint and the direct affectation to the surface. The implementation of an elevated platform that reduces the disturbance of the ground surface in sensitive areas is a solution that requires the use of piles as a foundation alternative. This way, the direct contact between the drilling system and the surface ground is a discrete sequence of piles, instead of a continuous surface affecting the land. Appendix 2 presents this system along with a parametric uncertainty quantification analysis, which aims to measure the probabilistic likelihood of a failure state and the margin of safety for different variables: load, unit weight, ground water level, number of blows on a Standard Penetration Test (SPT), bearing capacity factor and friction angle.

Bayesian Decision Networks (BDN) and Score Card System (SCS)

Each section of the SCS is related to the implementation of a specific technology or method in environmental and societal issues. A cross-verification was implemented consisting in making an evaluation of each question of the SCS to determine if the implementation of such technology was included in the 'Big Picture' model.

The procedure to make the cross-verification consisted on the development of a table that groups the Score Card questions and topics for each technology subset of the 'Big Picture' BDN model. The 'Topic' field from Tables 2 to 6 refers to the particular concerns of the questions, resuming the main idea of the technology required. In the 'Questions SC' column is pointed out the questions related to the Technology Subsets and the topic described. The nomenclature for these fields (Table 1) consists in an alphanumeric combination of the Score Card attribute and the number of the question.

Most of the technologies suggested by the Score Card were already reflected in the system selection tool provided by the 'Big Picture', but some others were recently included in pre-existent subsets, allowing to enhance the capabilities of the model. In other cases, was required the definition of a new subset with its own technologies, that might include the methods and techniques present on the topics described on Tables 2 to 6.

Enhanced Subsets

The previous subsets contain a list of several technologies that can be selected when designers are planning the operation of a drilling site. These technologies were separated in subsets as shown below:

1.1.1. Subsystem: Site and Rig / Subset: Well Design

- Reuse of pre-existing well site
- Several wells per drill site (clusters)

1.1.2. Subsystem: Site and Rig / Subset: Rig Type

- Spill Control System

1.1.3. Subsystem: Site and Rig / Subset: Access Road

- Plan for avoid erosion.
- Armor roadway ditches and leadoff ditches with rock riprap.
- Use of pre-impacted terrains for access routes.

1.1.4. Subsystem: Site and Rig / Subset: Site Preparation

- Low profile structures.
- Design centralized location for hydraulic fracturing and water delivery.

1.1.5. Subsystem: Power / Subset: Conventional Rig Power

- Use Tier IV diesel engines or natural gas.

1.1.6. Subsystem: Operation / Subset: Drilling Technology

- Electric top drive system

1.1.7. Subsystem: Operation / Subset: Drilling Fluid Type

- Use of biodegradable lubricants.
- Water efficiency programs

1.1.8. Subsystem: Operation / Subset: Reserve Pit and Solid Control Equipment

- Limit contact with live water bodies

1.1.9. Subsystem: Operation / Subset: Waste Management

- Recycle and reuse of water
- Plan for water discharge
- Regular and remote monitoring system of wastes.
- Cuttings management plan
- Maximize bulk material and minimize pallets, bags, etc.

1.1.10. Subsystem: Site and Rig / Subset: Air Emission Reduction

- Brine treatment
- Low dust emission infrastructure

- Green completions.

1.1.11. Subsystem: Restoration / Subset: Restoration Systems

- Site survey to plan a restoration system
- Restore elevation, vegetation and topsoil
- Plan planting on the proper season of the year
- Prevent transport of invasive species
- Ensuring wild life and agricultural experts assesment
- Well abandonment plan and update it.

1.1.12. Subsystem: Societal / Subset: Comunication Channels

- Inform stakeholders with water wells, streams, wetlands within 5000 feet of the proposed operation.
- Hold meeting to discuss risk and mitigation efforts.
- Publishing documents and training sessions available to contractors with information on how to reduce the environmental impact.
- Document the Environmental Sensibility.
- Work with community to identify noise management and light effects.
- Provide web site that links to data from sensors.
- Develop dispute resolution plan.
- Implement company policy that addresses unintended consequences and communicate with stakeholders. These have to know whom to contact if/when an issue arises.

1.1.13. Subsystem: Societal / Subset: Safety

- Instruct crews not to harass or feed wildlife.
- Ban pets, hunting and fishing.
- Train crew to identify wildlife.
- Work with local law enforcement to reduce traffic safety hazards.
- Engage regional official to advice on health and safety concerns associated with operations.
- Provide transportation to workers
- Create an emergency response plan
- Implementation of “Incident Reports” and any significant problems with wildlife.

Conclusions

The BDN model proposed is a tool conceived to help designers to combine a series of technologies and to assess the risk associated to it. The proposed decision-making model based on Bayesian Decision Networks allows for the Drilling System Selection considering causal dependencies. The Score Card System, allowed for a simple cross-verification with the system selection tool. The result consists on a series of subsets with enhanced technologies and new subsets adressing environmental and societal issues that strengthens the system selection tool of the BDN model.

References

Ok-Youn Yu (2009). *Systems Approach and Quantitative Decision Tools for technology Selection in Environmentally Friendly Drilling*. Doctoral Dissertation, Texas A&M University. College Station, Texas.

Ok-Youn Yu, Medina-Cetina Zenon, Jean-Louis Briaud (2011). Towards an Uncertainty-Based Design of Foundations for Onshore Oil and Gas Environmentally Friendly Drilling (EFD) Systems. Geo-Frontiers, ASCE. USA, 2011

Houston Advanced Research Center (2010). *SCORECARD Reference Guide*. First Edition. Houston, TX. USA. June 2010.

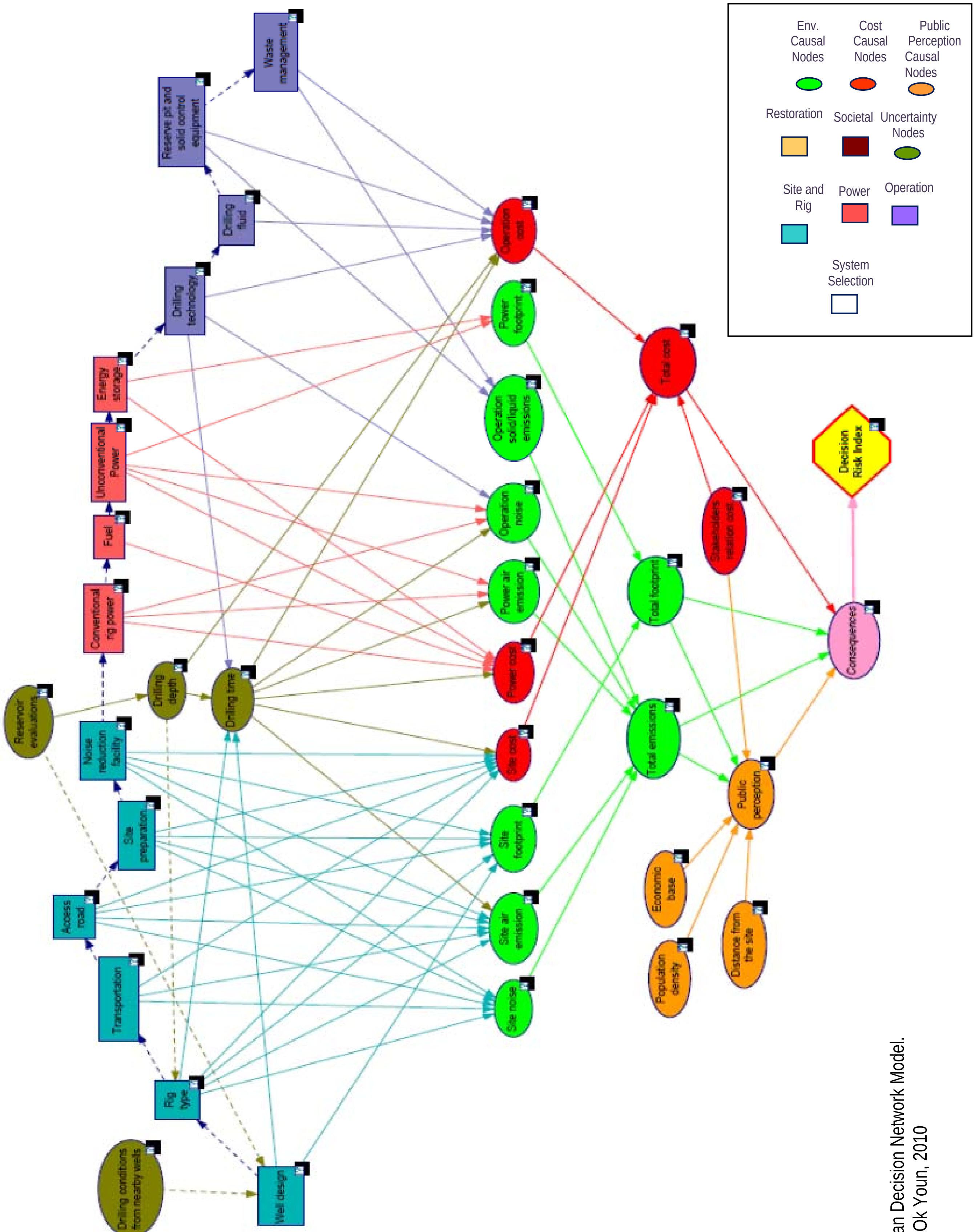

Figure 1. Bayesian Decision Network Model.
The Big Picture. Ok Youn, 2010

Table 1. Nomenclature for Score Card Questions.

SC Attribute	Nomenclature
Air	Air 1 to Air 9
Water	Water 1 to Water 13
Site	Site 1 to Site 17
Waste Management	WM 1 to WM 13
Biodiversity	Bio 1 to Bio 12
Societal	Soc 1 to Soc 14

Table 2. Correlation for Score Card and Site and Rig Technologies.

Technology Subset	Topic	Questions SC
Well Design	Reuse of pre-existing site, pad drilling, maximize number of wells per drill site	Site 1, Site 2, Site 3, Site 4, Site 11, Site 15
Rig Type	Use of spill control system	Site 5, WM 9
Air Emissions Reduction	Dust suppression documented plan, Green Completion practices	Air 5, Air 9
Transportation	Use of vehicles Tier II, III and IV. Use of retrofit technology on Tier I on-road vehicles or on Tier II-I for non-road vehicles.	Air 1, Air 2, Air 3, Air 4
Access Roads	Access roads to avoid erosion, roadway ditches and leadoff ditches. Low impact roads	Bio 5, Bio 6, Soc 2
Site Preparation	Use of low profile structures, plan layout of flow lines, planning for stock tanks	Site 9, Site 14, Site 16, Soc 2
	Establish centralized location for hydraulic fracturing and water delivery	Bio 3
Noise Reduction Facility	Construction of sound/safety barriers. Reduce residual lighting effect	Soc 4, Soc 5

Table 3. Correlation for Score Card and Power Technologies.

Technology Subset	Topic	Questions SC
Conventional rig Power	Use Tier IV diesel engines or natural gas, or connected to the electric grid.	Air 6, Air 7
Unconventional Rig Power	Power from solar or wind sources.	Air 8

Table 4. Correlation for Score Card and Operation Technologies.

Technology Subset	Topic	Questions SC
Drilling Technology	Electric top drive system	WM 7
Drilling Fluid Type	Water efficiency programs and reduction of hazardous materials. Use of environmentally friendly drilling fluids and biodegradable lubricants	Water 11, Water 12, Water 13, WM 2, WM 5, WM 6
Reserve pit and solid control equipment	Waste water management plan, limit contact with live water bodies, reuse of water	Water 1, Water 5
Waste Management	Recycle and reuse of water, plan of water discharge, implement contingency plans	Water 2, Water 3, Water 4, Water 5, WM 10
	Regular and Remote Monitoring and Recycling Programs, Cuttings Management Plan	Water 9, Water 10, WM 12, WM 13, Bio 4, Soc 8
	Closed loop System, Cutting Dryer, Cuttings Management Plan, Bioremediation, Composting,	WM 1, WM 3, WM 4, WM 11, WM 12, WM 13
	Maximize bulk materials and minimize use of pallets, bags, etc. Implementing recycling programs to minimize household waste.	Site 12, WM 8

Table 5. Correlation for Score Card and Restoration Technologies.

Technology Subset	Topic	Questions SC
Restoration Systems	Survey to adapt a restoration plan, harvest organic or native species for further planned restoration, wild life and agricultural expert's assessment, use of local topsoil. Topographic restoration. Clean equipment.	Site 4, Site 8, Site 13, Site 17, Bio 1, Bio 7, Bio 8, Bio 9, Bio 11, Bio 12, Soc 12

Table 6. Correlation for Score Card and Restoration Technologies.

Technology Subset	Topic	Questions SC
Communication Channels	Inform nearby stakeholders, hold meetings, inform risk mitigation efforts, share documentation for reducing footprint, web pages, dispute resolution plan. Work with local law enforcement to reduce traffic hazard. Manage logistics to minimize noise between 11 pm and 5 am	Water 6, Water 7, Water 8, Site 6, Site 7, Site 10, Bio 10, Soc 1, Soc 3, Soc 4, Soc 9, Soc 11, Soc 13, Soc 14
Safety	Security and risk mitigation to workers and regional officials. Training to handle wild life and to reduce footprint for workers and contractors. Transportation for workers. Ban pets, hunting and fishing to contractor's workers. Training of local emergency medical service for specific issues during operation activities or public health issues.	Bio 2, Bio 11, Soc 1, Soc 6, Soc 7, Soc 10

Appendix 1

Integrated Approach for the Optimal Selection of Environmentally Friendly Drilling Systems

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Submitted to the International Journal of Energy and Environmental Engineering

Appendix 2

Towards an Uncertainty-Based Design of Foundations for Onshore Oil and Gas Environmentally Friendly Drilling (EFD) Systems

Ok-Youn Yu1, Zenon Medina-Cetina2, Jean-Louis Briaud2

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Geofrontiers ASCE, 2011 (http://ascelibrary.org/doi/pdf/10.1061/41165%28397%2919)

RPSEA EFD Project 08122-35
4.2 Best Practices Database

Kathryn Mutz
University of Colorado Law
Natural Resources Law Center

Prepared for the
Environmentally Friendly Drilling Systems Program
Houston Advanced Research Center

July, 2012

______________________________ **7 15 12**
Date Signed

Kathryn Mutz

Program Area: 4.2 Best Practices Database

Lead: University of Colorado Law

Description of Task/Milestone(s):

The Natural Resources Law Center (NRLC) at University of Colorado Law is currently developing a free-access, searchable, database and supporting website for best management practices (BMPs). The NRLC has developed a beta version of the database/website in conjunction with project partners and advisors from government, industry, the conservation community, and academia. This test version, launched in March 2009, focuses on the Intermountain West (CO, MT, NM, UT, WY). It includes federal, state, and local regulatory requirements as well as voluntary practices currently in use, required, and/or recommended for protection of surface resources. This version is accessible at: http://www.oilandgasbmps.org/

Key Deliverables:

1. Contribute to a white paper (8-12 pages) that summarizes the needs and barriers for the region including a discussion of the application of EFD technologies to the region.
2. Contribute to a series of workshops (at least two) that will transfer EFD technologies to regional stakeholders.
3. Expand the beta version to a broader community of partners to refine and expand its functionality, add BMP data, and develop additional website support materials. Materials featured on the website will include projects of the EFD team and its alliance partners.
4. Contribute to a paper and presentation at a conference.
5. Work with the other alliance members, to identify various research projects and funding sources for future work.

Summary & Accomplishments:

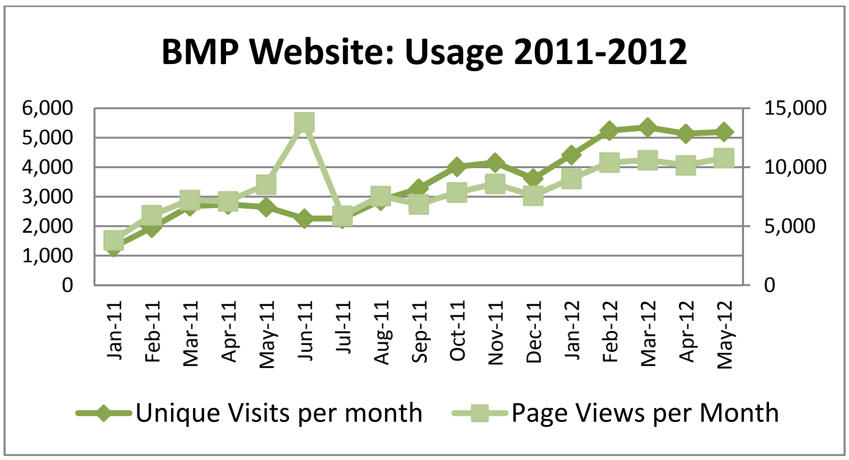
#1. Whitepaper: The BMP Project contributed to discussion of the needs and barriers in the region through:

1. Preparation of a paper for the Society of Petroleum Engineers "BMPs for Minimizing Environmental Impacts: A Resource for Communities, Government and Industry", November 1, 2011; and
2. Contributions to the work of the Operations and Environment Task Group for the National Petroleum Council's report "Prudent Development – Realizing the Potential of North America's Abundant Natural Gas and Oil Resources" (September 2011)

#3. Expand BMP Project website and database: The principal accomplishments of the project were expansion of the materials on the BMP Project website and database and broadening of the user base. Over the course of the Project, every section of the beta version of the database/website was expanded and improved. In additions, project staff added new resource pages on communities, costs and benefits of using BMPs, reclamation, coalbed methane, and hydraulic fracturing. Existing Law and Policy pages (including Federal and State laws and regulations) were expanded to include tribal government rules, case law, and local government rules. Innovative practices/technologies of industry and community-industry collaborative processes were highlighted in case studies.

Project staff investigated the integration of GIS into the website and expansion of the database and website beyond the Intermountain region. While the website incorporates both GIS and materials from beyond the region, a major effort in these directions was rejected as not feasible given existing time and resources.

Usage of the project website/database has increased steadily over the grant period. The following chart demonstrates three to nearly five-fold increases in page views and unique visits per month, respectively, for the website/database in the past 18 months.



This chart demonstrates three to nearly fivefold increase in page views and unique visits per month respectively, for the website/database from January, 2011 – May, 2012.
http://www.oilandgasbmps.org/

The BMP Project staff made or contributed to the following presentations:

K. Mutz, K. Rice, L. Walker, A. Palomaki, and K. Yost. BMPs for Minimizing Environmental Impacts: A Resource for Communities, Government and Industry, Society of Petroleum Engineers Annual Technical Conference and Exhibition, Denver, CO, November 2011 (author and presenter)

K. Mutz. Best Management Practices, Managing the Eagle Ford Development, Kingsville, TX, November 10, 2011

K. Mutz and S. Watterson. Intermountain Oil and Gas Best Management Practices. RPSEA Onshore Production Conference: Technological Keys to Unlocking Additional Reserves, Golden, CO, November 30, 2011

K. Mutz and K. Doran. Natural Gas Research and Resources at CU Boulder. Drawing the Blueprint for a Sustainable Natural Gas Future, Museum of Nature and Science, Denver, CO, January 18, 2012.

D. Hertzmark, G. Thonhauser, R. Haut, K. Mutz, M. Sura, and O.K. Yerli. Ukraine Shale Gas: Environmental and Regulatory Assessment, Regional Shale Gas Workshop – Poland and Ukraine, Kyiv, Ukraine, May 24-25, 2012.

K. Mutz, B. Kramer, and A Palomaki. Best Management Practices for Oil and gas Development, The Institute for Energy Law 3rd Law of Shale Plays Conference, Ft Worth, TX, June 6-7, 2012.

M. Sura. BMPs on Public Lands: Protecting Water and Wildlife, Public Lands Committee session, Developing North America's Oil and Gas Resources, Interstate Oil and Gas Compact Commission, Midyear Issues Summit, Vancouver, B.C., June 3-5, 2012.

K. Mutz. Presentations on project website (www.oilandgasbmps.org) at quarterly meetings of the Environmentally Friendly Drilling Program (August 20 -21, 2009; Woodlands TX and February 23, 2010 (via teleconference))

4.3 - Dissemination and Decision Support

University of Arkansas

Prepared for the
Environmentally Friendly Drilling Systems Program
Houston Advanced Research Center

July 13, 2012

July 13, 2012
Date Signed

Dr. Jackson Cothren

The United States Energy Information Administration (EIA) estimates that in 2009 approximately 25% of the energy used in the United States came from natural gas[1]. This contribution to the national energy budget has been rising steadily from the early twentieth century with technologies such as hydraulic fracturing and horizontal drilling becoming more prevalent. The majority of natural gas consumption can be attributed to the commercial and industrial sectors; mainly in electricity generation[2]. Estimates suggest a substantially imminent growth in the national daily consumption in the coming years. This rise in consumption has not been met with a commensurately equivalent level of production; albeit production has consistently increased over the years. With factors such as an almost unrelenting campaign to wean the country off substantial crude oil dependence, the gradual replacement of crude oil with natural gas, and the recent unfavorable public opinion concerning nuclear energy, the stakes of natural gas in the energy portfolio of the nation are set to be elevated to unprecedented levels. The obvious implication is that production at the wellhead will have to be significantly increased to make up for market demands.

This scenario brings with it the inevitable negative repercussions on the environment regarding various energy production methods. The development of adequate, accurate, seamless and reliable methods of harnessing natural gas in various environmental settings while ensuring an appreciably low impact on the environment therefore becomes a subject of high priority. Also of importance is the need to ensure an increase in natural gas production levels to satisfy the attainment of realistic economic advancement. The various environmental impact scenarios can be categorized under several facets including water quality and quantity, air quality, and ecological impact of native animal and plant species. The perceived environmental impacts have led to the enactment of various regulatory procedures that are meant to minimize the environmental footprints of natural gas related activities. However, most of these procedures lack scientific backing thereby rendering their enforcement ineffective and ultimately hindering the development of an important energy resource. Operators and regulators do not have a common framework within their respective processes that can be mutually harnessed to produce the desired result of ensuring environmental stewardship while meeting the demands for an important resource such as natural gas.

[1] http://www.eia.gov/energyexplained/index.cfm?page=natural_gas_use
[2] http://www.eia.gov/dnav/ng/ng_cons_sum_dcu_nus_a.htm

Software framework for the informational website & Informational website populated with data from one play (Haynesville Shale Play)

Through research and development alongside the U.S. Department of Energy's (DOE) LINGO initiative, the Fayetteville Shale Play (FSP) Low Impact Natural Gas and Oil (LINGO) Program[3] and the Infrastructure Placement and Analysis System (IPAS) were created with the sole purpose of meeting the above stated need for communication between operators, regulators, and the general public.

The LINGO Initiative and RPSEA Follow-on

The LINGO initiative, created by the DOE in 2006, integrates current technologies and practices in ways that minimize adverse environmental impacts from the recovery of oil and natural gas. At the same time, the initiative seeks to boost the economic recovery of oil and gas by addressing environmental concerns that block such recovery. This effort built on this initiative and created a similar site for the Haynesville Shale Play (HSP), providing regulatory and technical information specific to Texas, Louisiana, and Texas.

The HSP public site explains the steps followed by natural gas development companies in drilling and producing gas from a well, from gaining access to the land through sending the gas to market up to abandonment upon the well reaching the end of its productive life (Figure 1). Videos are also available for viewing. For each step in the process, the site provides information about the state and federal regulatory requirements that developers must follow (Figure 1). Links to state and federal regulations are also provided. Also described are technologies that can be used to minimize the environmental impacts of natural gas development (Figure 1). Best management practices (BMPs) are also discussed. Within each topic, links are provided to related information. For example, the Site Preparation section under Minimizing Environmental Impacts contains a related link to the Site Preparation section under Natural Gas Production, allowing users to easily navigate the site and see how all the steps in the well development lifecycle are related.

[3] http://lingo.cast.uark.edu

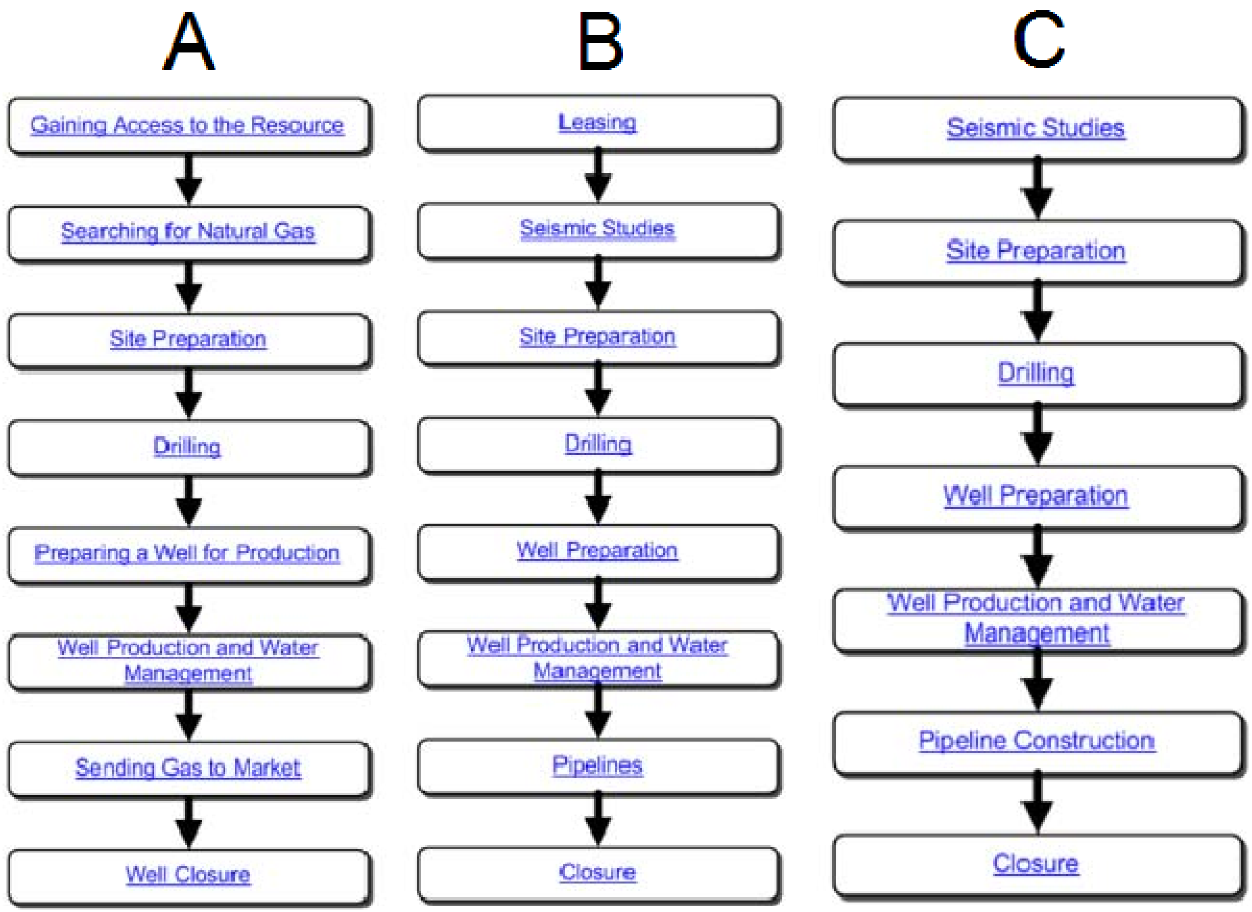


Figure 1: A: Steps in producing gas from a well located in the Fayetteville Shale; B: Regulatory steps that operators must follow during the process of developing a well in the Fayetteville Shale; C: Technologies and practices used to limit environmental impacts of natural gas.

HSP Map Viewer

A map viewer, developed using ArcGIS Server's JavaScript application programming interface (API) and Microsoft Bing Maps API, provides members of the general public with vital information on the Haynesville Shale including drilled well locations, permitted well locations, compressor stations, gas production, and watersheds. Information that can be viewed includes:

1. Well locations: Permit number, status, latitude, longitude, operator, well name, activity start date, permit date (Figure 2)
2. Roads and aerial photography (Figure 2)
3. Compressor stations: permit, permit holder, latitude, longitude
4. Gas production by Public Land Survey System (PLSS) section (Figure 3)
5. Cumulative production: sum of all gas that has ever been produced until a specific date, in Mcf (1,000 cubic feet)
6. Annual production: sum of all gas in a calendar year, in Mcf

7. Estimated gas production: derived via kernel density statistical analysis of the current production values. This prediction is based solely on a kernel density estimate of the production values for a specific year smoothed over with a factor that is iteratively determined based on the size of each dataset (Figure 3)
8. Watersheds: watershed boundaries, number of wells located within watershed, and links to watershed information (Figure 4)

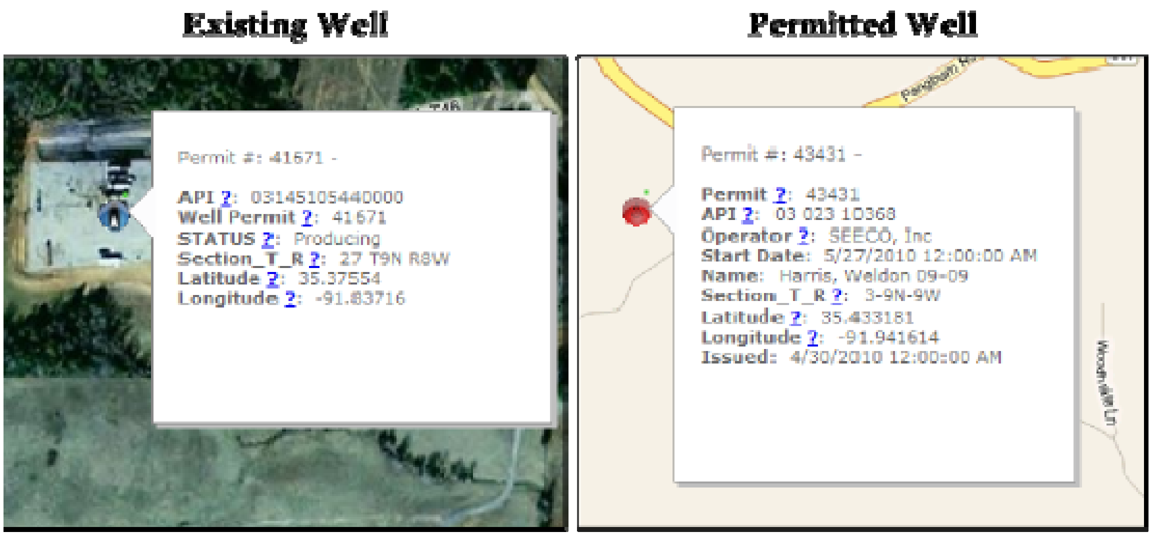


Figure 2: Well information on public viewer.

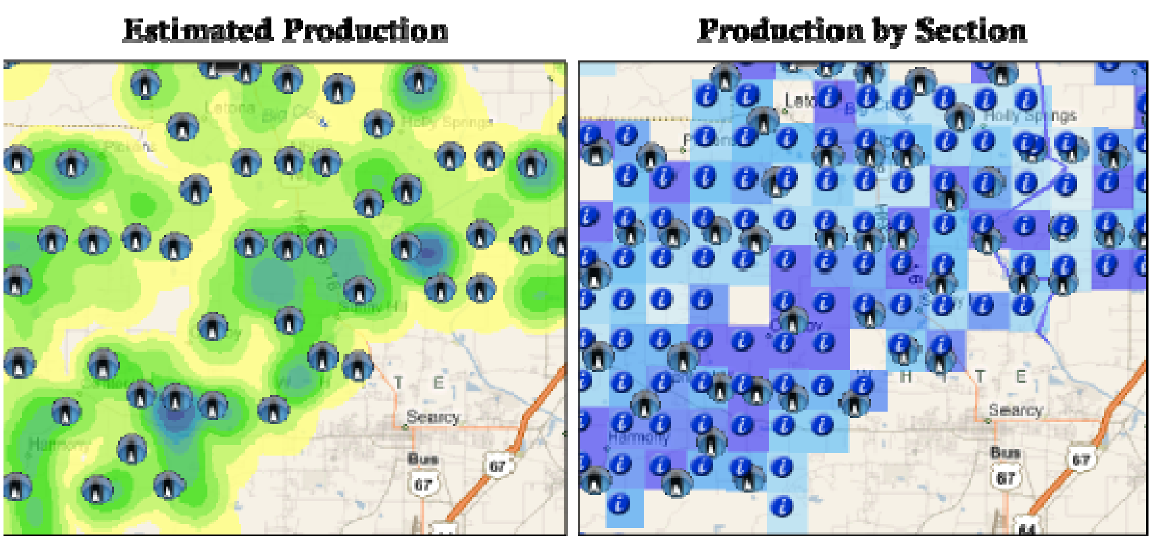


Figure 3: Well production information available on public viewer.

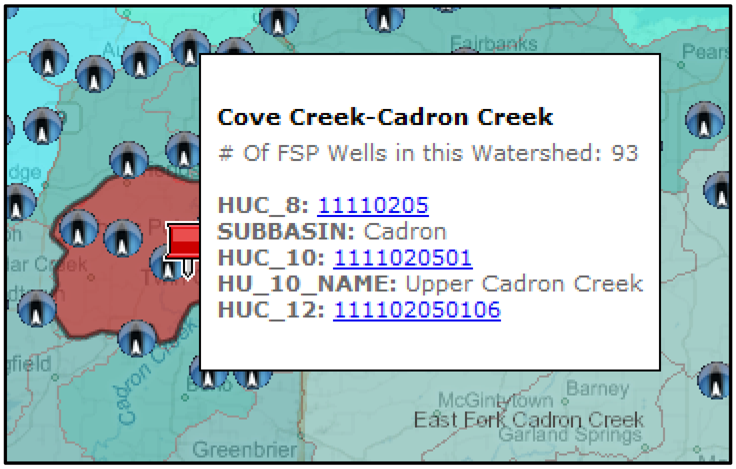


Figure 4: Watershed information available through the public viewer.

HSP Components

The LINGO HSP public map viewer is built on top of Microsoft Bing Maps API version 6. Roads and aerial photography are provided via the API as basemap layers. Existing and recently permitted natural gas well locations, along with well production data, are mined from the Arkansas Oil and Gas Commission, the Texas Railroad Commission, and the Strategic Online Natural Resources Information System websites (see “IPAS Components” section below). Public Land Survey System (PLSS) sections are widely available from a variety of sources; for this project they were acquired from Geostor[4]. Watershed polygons (12-digit HUC) are available from the United States Geological Survey (USGS) through the National Hydrography Dataset (NHD) project[5].

4 http://www.geostor.arkansas.gov/
5 http://nhd.usgs.gov/

Requirements documented for populating and deploying the decision support tool

IPAS is an online application developed by the Center for Advanced Spatial Technologies (CAST) of the University of Arkansas - Fayetteville in collaboration with Argonne National Laboratory. The system provides a secured and centralized resource where operators and regulators can perform pertinent geospatial analysis on a range of environmental issues relating to the oil and gas industry. IPAS can help streamline several critical tasks involved with the placement and permitting of new well drilling pads, gathering lines, and other infrastructure. Operators can use custom tools (Figure 5) to place well pads, gathering lines, or lease access roads on the map. Once the operator is done placing the object, they can run sensitive area, flow model, and slope analyses. Sensitive area analysis runs a geoprocessing service to determine if the planned feature will impact extraordinary resource waters or endangered/threatened species. Protection of water resources is a key concern for everyone involved with development of the Fayetteville and Haynesville Shale play. Approximately fifty percent of the total area falls either directly within subwatersheds containing state-designated Extraordinary Resource Waters or within subwatersheds that are upstream of Extraordinary Resource Waters. To understand the possible impact of a spill from a drilling site, such as the failure of a reserve pit retaining wall, the Fayetteville Shale IPAS provides a spill modeling tool. Run on top of a filled-depression digital elevation model, the spill model will show the spill flow path down to the nearest water body or bodies. This model incorporates the D infinity method of determining direction of liquid flow from one elevation pixel to the next, which allows it to split flow more realistically to multiple paths, if the terrain indicates such. Slope analysis can aid operators in determining if a slope is too steep to place a feature. Proposed locations can be reviewed by multiple users within the same company. Once the operator has completed the feature siting process, they are able, through the IPAS system, to submit the planned feature to a regulatory body for approval. The regulator is then able to log onto IPAS, examine the feature, run the requisite tools and models, and determine whether or not they approve of the planned feature and its location. Once the feature is approved or denied, the submitting operator is notified via email. If changes to the planned feature need to be made, the operator can do so in IPAS, and then resubmit the feature back to the regulatory agency once again for approval. This workflow facilitates streamlined and structured communication between operators and regulators along with built-in logging and accountability.

A primary concern of GIS professionals and others familiar with commonly used spatial data is the misconception, by the general public and others, that the position of a feature boundary on a digital map implies absolute accuracy. In reality, every GIS data layer has a limit to its “spatial accuracy”, typically related to the manner in which the data was collected or created. In IPAS, the boundary of each critical data layer has been converted into a fuzzy “uncertainty zone”, the width of which typically reflects a 95% confidence level of boundary accuracy. Furthermore, the boundary of planned infrastructure features placed using IPAS also reflect spatial uncertainty. In this case, the spatial accuracy of the underlying aerial photography layer (± 6 meters) is added to error related to the user’s viewing scale (approximate the width of two pixels × viewing scale) to determine the width of the uncertainty zone. Whenever the Sensitive Area Analysis is performed, the results reflect whether there is overlap between the “certain” feature and “certain” sensitive area, or perhaps only between the uncertainty zones. The possible outcomes are as follows:

- “certain” feature and “certain” sensitive area = strong likelihood of impact
- “uncertainty zone” of feature and “certain” sensitive area = moderate likelihood of impact
- “certain” feature and “uncertainty zone” of sensitive area = moderate likelihood of impact
- “uncertainty zone” of both feature and sensitive area = slight likelihood of impact

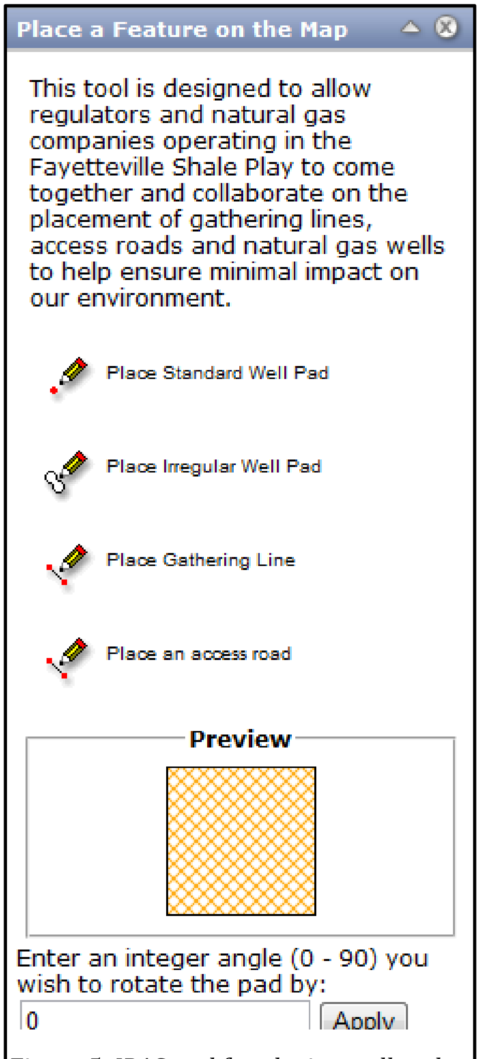


Figure 5: IPAS tool for placing well pad, gathering line, or access road features on the map.

Within the IPAS system, security is paramount. Recognizing the need for protection of private data in this competitive market, IPAS is designed with security and reliability as key concerns. IPAS runs on a dedicated, limited access server located in a climate-controlled server room with full UPS and generator backup and computer-room rated fire suppression system. All web pages utilize Secure Socket Layer (SSL) protocol. Features entered by different producers are stored in totally independent database tables, eliminating possibility of access by other producers. All passwords are fully encrypted on servers and industry best practices for secure web applications are followed.

IPAS is an essential and desired system in that it serves as a single geospatial hub with capabilities which ensure that analyses by both operators and regulators are performed on the same data repository. Since operators and regulators perform the same analyses with a common geospatial analytic algorithm, IPAS helps to remove ambiguities in the results of the respective analyses performed by separate entities. For example; if an operator is interested in placing a well pad in a specific geographic region in the FSP, a sensitive area analysis can be run by the operator to give various impact scenarios on the likelihood (predictive) of impact on environmental factors such as highly erodible soils, extraordinary resource waters sub-watersheds, or potential impacts on the habitats of species such as the least tern and bald eagle. The results of this analysis can either be rejected or accepted. Well characteristic information such as well name, well type (whether horizontal, vertical or directional), drilling mud type, nearest town, as well as any further attributes deemed fit by the operator can be added to the saved analytic result, along with comments. The regulatory body can then review the analysis and also has the capability of performing the same analysis in the system. Based on the results of both analyses, the regulatory agency can adequately make decisions that might either grant the permit or propose a more suitable location.

IPAS presents the advantage of harmonizing the activities of stakeholders while removing regulatory bottlenecks and thereby speeding up the processes involved in both regulator and operator activities related to well permitting.

IPAS Architecture

The IPAS system architecture involves secure and robust components that include ArcGIS Server, ArcGIS Server Web Application Development Framework (ADF) and ASP.NET 2.0, MATLAB and Microsoft .NET executables (Figure 6). The web mapping application runs on Microsoft Windows Server 2003 and provides map images to web clients, performs spatial and attribute queries against existing GIS data, allows clients to import their own GIS data into their web sessions, and keeps a current copy of natural gas-related GIS data. The flexibility afforded to users to import their own data into the system extends the versatility of the system to the user in terms of data gathering.

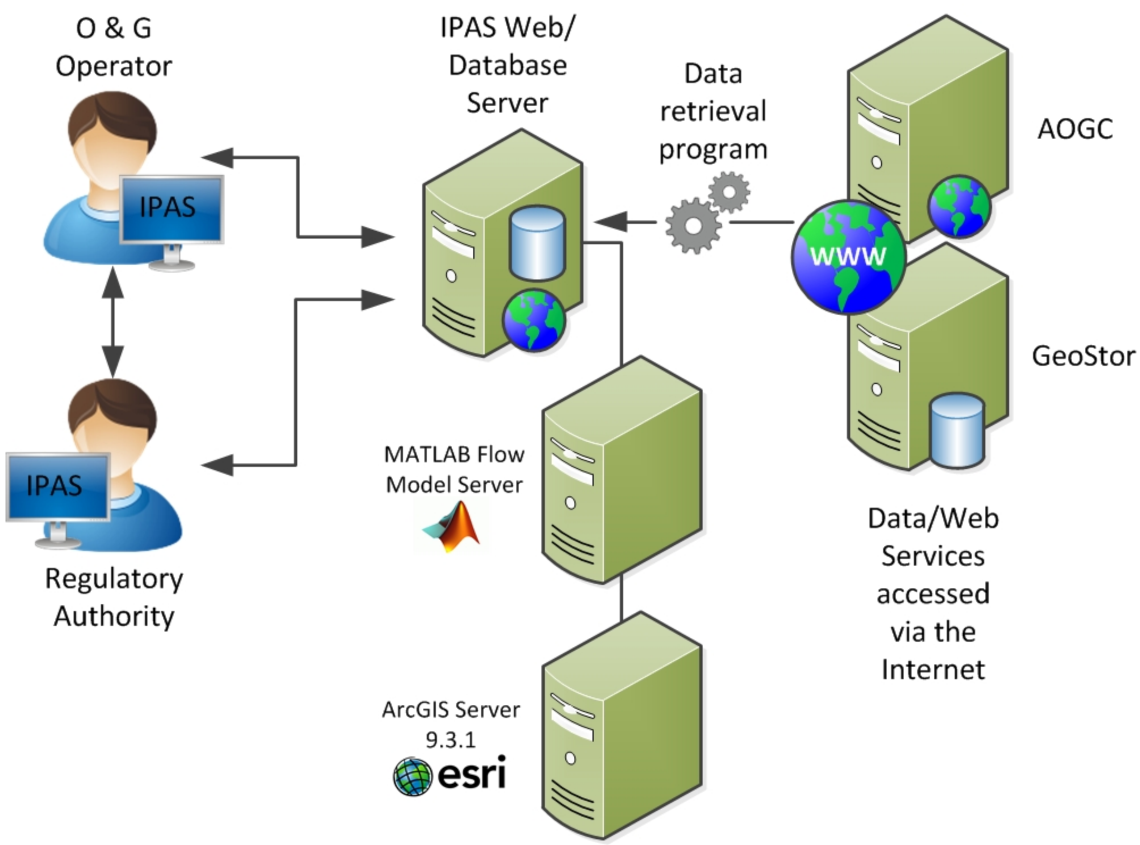


Figure 6. IPAS architecture overview.

IPAS Components

ESRI ArcGIS Server 9.3.1

The IPAS system runs on ESRI's ArcGIS Server 9.3.1[6] for the Microsoft .NET Framework. ArcGIS Server produces images and runs queries against map documents created in ESRI's ArcMap – an industry standard desktop GIS package. These map documents define the symbology, scale dependencies and other properties involved in creating and organizing maps from GIS data. ArcGIS Server also provides a framework for the sensitive area analysis and slope model analysis through the use of geoprocessing services that accept the locations of user sited features as inputs and returns GIS data related to the requested operation.

ArcGIS Server Web ADF and ASP.NET 2.0

Users of the IPAS system interact with a web application written in ASP.NET 2.0 using the ArcGIS Server Web ADF for .NET. The web application manages user login sessions and what data is available to each user, allows users to retrieve and store information from a central database (Microsoft SQL Server 2005) in a secure fashion, and provides a graphical user interface to view, manage and analyze map services from ArcGIS Server. Commands are dispatched from this web application to other components of the software system as users interact with its various functionalities.

MATLAB

The reserve pit spill model is implemented as a MATLAB[7] script compiled into a command line interface program using the MATLAB Runtime. The program calculates possible spill flow path(s) using a DEM (digital elevation model) and the coordinates of a well pad location. Output consists of a georeferenced TIFF image representing the possible spill flow path(s). Through a geoprocessing service, ArcGIS Server renders the output to the client.

Data mining program

A requirement of IPAS is to provide current information on the status and location of natural gas wells, including current permits. Information regarding oil and gas well locations is often proprietary, expensive, and difficult to acquire; therefore, a data mining program (C# .NET 2.0/Python) was created to download and process this information for the FSP. After downloading and processing the data, tables in the central IPAS database are updated as are GIS layers in the IPAS geodatabase.

Information about current active and inactive oil and gas wells including locations is published weekly through and acquired via a web service API[8] of the Arkansas state GIS clearinghouse Geostor[9]. Information about locations in Louisiana is harvested from the public SONRIS site, while locations in Texas are harvested from the Texas Railroad Commission public website.

[6] http://www.esri.com/arcgisserver
[7] http://www.mathworks.com/products/matlab/
[8] http://www.geostor.arkansas.gov/G6/dev/API.htm
[9] http://www.geostor.arkansas.gov

Modifications to the Fayetteville Shale Infrastructure Placement Decision Support System to support the SWAT, APEX or other impact models

Little Red River Watershed Storm-Water Modeling with SWAT

The Soil and Water Assessment Tool (SWAT) model is used to study the impact of shale-gas activities on the hydrology of a watershed in the Fayetteville Shale play, gain better understanding of the dynamics of the watershed and evaluate the cost-effectiveness of alternative data sources and techniques in model evaluation. Particular emphasis in regards to this research is on SWAT model storm-water predictive ability as influenced by input LULC data resolution and methods of classification and subsequently evaluate Best Management Practices (BMPs) implemented to mitigate shale-gas activity impacts on storm-water generation in the watershed.

The approach is to perform LULC classifications using the pixel-based maximum-likelihood and the object-oriented image analysis techniques with high (1m NAIP) and moderate resolution (30m Landsat 5 TM) image data of the Little Red River watershed (LRRW). This will yield four LULC maps resulting from a combination of image data resolution and classification techniques. Hence two 1 m NAIP LULC maps will be produced from the pixel-based method and object-oriented method respectively. In like manner, a 30m Landsat 5 TM LULC map of the watershed classified with the object-oriented method is required. A 30 m LULC data (obtained from Landsat 5 TM NLCD) is already available and has been used to calibrate the first flow model.

Modeling efforts primarily involve setting up, calibrating and evaluating four storm-water flow models with input data from the above-described LULC datasets. The evaluation is done using uncertainty analysis at the 95% prediction uncertainty limit to determine model predictive ability as impacted by input LULC data. Respective predictive abilities of the flow models calibrated with different input LULC data is based on manual calibration and validation results and subsequent automatic calibration and validation results obtained with SWAT-CUP (a SWAT Calibration and Uncertainty analysis Programs software). Hydrologic modeling is inherently plagued with the issue of equifinality. A concept that for any parameter set used to calibrate a model there are several sets of parameters that will produce acceptable model results. This problem becomes particularly important in this research in respect of the four separate models. To account for equifinality a method known as generalized likelihood uncertainty estimation (GLUE) is used. GLUE mainly evaluates model calibrations (based on uncertainty analysis) obtained from a large number of simulations with each simulation having a statistical degree of belief associated with it.

Preliminary results of the 30m LULC model are presented in the appendix section of this report. A total of 27 sub basins and 140 HRUs were delineated. Precipitation and temperature data from 10 weather stations and 2 USGS stream-flow data obtained from 2 sites in the watershed were used for calibration. Current efforts are on classifying NAIP and Landsat 5 TM data using pixel-based method in ArcGIS and object-oriented classification in eCognition software to produce the remaining three LULC maps of the watershed. The storm-water flow model evaluated to have the best predictive ability will be subsequently used to evaluate BMPs being implemented in the South Fork of the Little Red River. This is a sub watershed in the LRRW which seas the bulk of shale-gas activities in the watershed.

Full integration of key SWAT components with IPAS is ongoing under funds provided by NETL (award #DEFC2609FE0000804) and will be completed by March 2013.

Conclusion

No form of harnessing energy has ever been proven to be completely environmentally friendly. Therefore, mitigating and minimizing the possible detrimental effects of such activities on the environment if often a focus. In light of this, systems like LINGO and IPAS are highly desired and ultimately should be regarded as prerequisites for any energy related industrial undertaking; even more so in a sector like oil and gas activities. The unique features and essential functionalities that these two systems present are imperative and highly suited for a geospatial decision support system. Systems such as IPAS allow for operators and regulators to communicate on essential business matters within a secure geospatially-enabled platform.

The LINGO public website and viewer serve to both educate the general public on all phases of oil and gas drilling and production and to provide them easy access to general well location and production information for the Fayetteville and Haynesville Shale plays. With backing by the oil and gas industry, public sites such as LINGO can provide transparency to oil and gas activities and foster a relationship between operators and the general public.

Papers and/or Presentations and other Technology Transfer Efforts:

Abouabdillah, A., Di Luzio, M., Williamson, M., & Cothren, J. (2011, November 8). Modeling Water Resources Management in the Fayetteville Shale Area. Powerpoint presented at the 18th Annual International Petroleum & Biofuels Environmental Conference, Houston, TX.

Asante, K., Cothren, J., & Brahana, J. V. (2012, July 16). Preliminary Results on the Effect of Land-Use Land-Cover Methods of Classification and Data Resolution on SWAT Model Predictive Ability. Poster presented at the 3rd Biennial Colloquium on Hydrologic Science and Engineering of the Consortium of Universities for the Advancement of Hydrologic Science Inc. (CUAHSI), Boulder, CO.

Cooper, C. (2012, April 23). Advanced Geoprocessing with Python. Workshop presented at the Mid-America GIS Consortium Biennial Meeting, Kansas City, MO.

Cooper, C. (2012, March 11). *Reading and writing spatial data for the non-spatial programmer*. Poster presented at the PyCon U.S., Santa Clara, CA.

Cooper, C., Smith, P., Williamson, M., & Cothren, J. (2012, April 24). An ArcGIS-Server based framework for oil and gas E&P decision support. Powerpoint presented at the Mid-America GIS Consortium Biennial Meeting, Kansas City, MO.

Cooper, C., Smith, P., Williamson, M., & Cothren, J. (2012, May 1). An ArcGIS-Server based framework for oil and gas E&P decision support. Powerpoint resented at the ESRI Petroleum User Group (PUG) Meeting, Houston, TX.

Cothren, J. (2012, March 20). Modeling the Effects of Non-Riparian Surface Water Diversions on Flow Conditions in the Little Red Watershed. Powerpoint presented at the 2012 Fayetteville Shale Symposium, Fort Smith, AR.

Cothren, J. and Williamson, M. (2010, October 14). Geospatial Decision Support for Reducing Environmental Impact in Natural Gas Shale Operations. Powerpoint presented at Opportunities and Obstacles to Reducing the Environmental Footprint of Natural Gas Development in the Uintah Basin, Vernal, UT.

Cothren, J., & Di Luzio, M. (2010, November 16). Geospatial Decision Support Systems and Surface Water Balance Modeling with SWAT. Powerpoint presented at the Environmentally Friendly Drilling Workshop. Fayetteville, AR.

Cothren, J., Thoma, G., & Di Luzio, M. (2010, August 31). Water Modeling in the Fayetteville Shale Play. Powerpoint presented at the 17th Annual International Petroleum & Biofuels Environmental Conference, San Antonio, TX.

Cothren, J., Williamson, M., Thoma, G. (2010, October 27). Reducing Environmental Impacts in the Fayetteville Shale Play using Geospatial Decision Support. Powerpoint presented at Arkansas GIS Users 10th Biennial Symposium & Training. Eureka Springs, AR.

Cothren, J., Williamson, M., Thoma, G. (2010, October 28). Decision Support System for Pad Siting. Powerpoint presented at West Slope Colorado Oil & Gas Association Environmental Summit, Grand Junction, CO.

Culpepper, B., Limp, F., Cothren, J., & Williamson, M. (2010, April 26). Geospatial Decision Support in the Fayetteville Shale: The LINGO Project. Powerpoint presented at the 2010 ESRI Southeast Regional User Group Conference, Charlotte, NC.

Gorham, B. (2011, October 11). Lingo Project: Terrestrial Habitat Mapping. Powerpoint presented at the AmericaView Fall Technical Meeting, Cleveland, OH.

Oluwafemi, T. (2010, September 1). Water Accounting in the Fayetteville Shale Play: An Application of the Depth-Averaged Navier-Stokes Equation to Hortonian Overland Flow. Powerpoint presented at the 17th Annual International Petroleum & Biofuels Environmental Conference, San Antonio, TX.

Pai, N. (2011). Geospatial tools and techniques for watershed management using SWAT 2009. (Ph.D., University of Arkansas).

Taiwo, O. (2012). Mathematical modeling of fluid spills in hydraulically fractured well sites. (Ph.D., University of Arkansas).

Taiwo, O., & Thoma, G. (2011, November 8). Mathematical Modeling of Spills in Hydraulically Fractured Well Sites. Powerpoint presented at the 18th Annual International Petroleum & Biofuels Environmental Conference, Houston, TX.

RPSEA EFD Project 08122-35

Program Area: 4.4 Western Mountain States Studies
Lead: Texas A&M University/University of Wyoming Laydown Road (Pecos TX)

Prepared for the
Environmentally Friendly Drilling Systems Program
Houston Advanced Research Center

July, 2012

David Burnett ______ Date Signed: August 1 '12

Western Mountain State Studies

The impact of access roads and drilling pads was identified by the industry as one of the major problems to be managed when conducting oil and gas operations in environmentally sensitive areas. Since 2006, Texas A&M and its partners within the Environmentally Friendly Drilling Program (EFD) have been identifying technology and sponsoring research in reducing surface impact. A specific “Disappearing Roads” program was underway in West Texas specifically addressing such technology. The site is located at the Texas A&M University Desert Test Center near Pecos Texas on the edge of the Chihuahua desert. The Texas Transportation Institute Pavement and Materials (TTI) managed this site and assisted with the project.

(http://tti.tamu.edu/research_areas/topic.htm?p_tid=5)

The Pecos site was used to test three new types of low impact roads plus one comparison standard gravel lease road, all road test sections constructed at the Desert Test Center. For the first two years, the roads were monitored and evaluated for the ability to withstand both normal and heavy truck traffic over intermittent periods through complete yearly seasonal changes. Two of the low impact roads (“disappearing roads”) were incorporated into the test site as part of a nationwide competition conducted by the Texas A&M Petroleum Engineering Department. The new concept for a "laydown road" was the 2008 competition award winner --developed by the University of Wyoming and Heartland Biocomposites Inc, http://www.heartlandbio.com/

Key Deliverables:

1. Numerous briefings and presentation were given to promote technology transfer.
2. Workshops were held to promote technology transfer to regional stakeholders.
3. Monthly reports documenting the development of the prototype lay down road system and documentation of field tests were provided for sponsors.
4. Conducted field testing of prototype systems in desert ecosystems to determine long term stability and effectiveness during the duration of the RPSEA EFD program.
5. An SPE paper[10] summarized the needs and barriers for the region including a discussion of the application of EFD technologies to the region.
6. A patent was issued to one of our sponsors Scott Environmental for a process to recycle drill cuttings into a road base material.[11]
7. Worked with EFD alliance members to identify opportunities for future work.

Summary & Accomplishments:

- The collaborative project within the Environmentally Friendly Drilling Program has been testing new types of “disappearing roads” in a desert like environment to measure their effectiveness and ability to lower the surface footprint of surface operations. The field demonstration was created to:
- Provide a realistic field trial in representative desert ecosystems so that results could be evaluated efficiently so as to benefit both the industry, the organizations with the technology, and the public sector.

- Document and provide the results of technology field trials so that promising processes, systems and products could be utilized in a wider range of gas shale plays.
- Speed the commercial development of technology developed to reduce the environmental footprint of drilling activities.

The RPSEA EFD program focused specifically on the “laydown road” concept developed by the University of Wyoming for the Texas A&M University Disappearing Roads contest in 2009. Three types of advanced low impact roads were installed at the Pecos Research Test Center in west Texas. One road was constructed with materials made with recycled drilling waste, a second road incorporated reusable composite mats, and the third represented a new type of “roll out road” developed in by a student engineering team from the University of Wyoming as a class project. Figure 1 is a composite graphic showing installation of a mat road segment, a base road made of recycled drill cuttings, and a basic design of a roll out mat invented by students at the U. of Wyoming.

Since starting on this project, the development of composite modular road and drill pad technologies have progressed substantially and have been proven to alleviate environmental impacts normally associated with oil and gas exploration and drilling. Texas A&M University, University of Wyoming, HARC, EFD, WyoComp and private industry have all worked together to make all this a reality. With the help of Texas A&M and HARC, the composite matting systems were able to take the next step from trial tests being conducted in the lab and at the Pecos Research site in Texas to real field applications and testing in the Eagle Ford Shale play in southern Texas starting in early 2011.

Composite matting systems perform well and are believed to provide expanded environmental benefits compared to using wood mats or no mats at all. The composite matting technologies previously tested appear to be ready for market. Additional design changes are needed for specialized installations where the soil structures are soft such as sand, otherwise the single layer mats may sink into the soil. WyoComp has developed several design improvements to composite matting systems that address the need for taller or elevated matting systems. The matting systems are ideal for energy exploration and drilling on public lands like BLM and Forestry since they potentially offer the highest level of environmental protection and quickest remediation timing compared to other existing technologies being used.

A life-cycle assessment (LCA) is being performed by WyoComp in 2012 to assist universities, energy companies, government and others understand the true costs and benefits of using composite matting systems versus wood and other available technologies. LCA’s, also known as life-cycle analysis or cradle-to-the-grave analysis, is a scientific technique used to assess environmental impacts associated with all stages of a products life including raw materials extraction, processing, manufacture, distribution, use, repair/maintenance and disposal/recycling. The goal of LCA is to compare the full range of environmental effects assignable to products/services in order to improve processes, support policy and provide a sound basis for informed decisions by government and industry. Anticipated results include a better understanding of the true costs of composite matting systems compared to wood systems and a determination made if they provide preferred environmental benefits.

One of the standard requirements of a road base of recycled oil field waste is that there are no hazardous materials leaching from the stabilized rock bed. To affirm that the material was stable, a set of samples was taken at the outset of the year-long test, then again after approximately 13 months.

The plan was to direct Pecos Test Center traffic through the road test sections. However in March, 2010, Texas A&M University removed the roadway overpass to the test segment we had constructed and since that time road traffic has been intermittent at best.

New installation

While the Pecos Desert Test Center location of the site allowed testing of how the roads stand up to environmental conditions, the EFD team wanted to relocate the removable mats to South Texas to the Eagle Ford Shale play. Lease roads and well pads are a highly visible and often less than welcome aspect of O&G drilling and producing operations. In South Texas this is occurring as the Cretaceous Eagle Ford shale is being developed from near the Mexican border outward to the east/northeast across several counties stretching more than 150 miles. The “Brush Country” as it is often referred to, is a semi-arid landscape where measures to lessen the impact of developing the shale are fostering a host of new technologies.

The team relocated the mats to Webb County Texas where they are awaiting installation at a fracturing brine pond to serve as a ramp for trucks unloading produced fluids. Texas A&M is collaborating with the Cerrito Prieto Ranch and with Land steward Consultants Inc. to implement low impact environmental practices on the ranch property.

Papers and/or Presentations and other Technology Transfer Efforts:

Burnett, D. B., Yu, O.K. and Schubert, J. A., "Well Design for Environmentally Friendly Drilling Systems: Using a Graduate Student Drilling Class Team Challenge to Identify Options for Reducing Impacts. SPE/IADC 119297 – MS Drilling Conference and Exhibition, 17-19 March 2009, Amsterdam, The Netherlands

Scott, J.B., Scott, B.R., Scott, J. H., Incorporation of Drilling Cuttings into Stable, Load Bearing Structures U.S. patent 2010/0127429 (May, 2010)

[1]Burnett, D. B., Texas A&M University, McDowell, J., Newpark Resources, Scott, J. B., Scott Environmental, and Dolan C. University of Wyoming, SPE -142139-PP Field Site Testing of Low Impact Oil Field Access Roads: Reducing the Environmental Footprint in Desert Ecosystems, SPE Americas E&P Health, Safety, Security and Environmental Conference held in Houston, Texas, USA, 21–23 March 2011.

Burnett, D. B., Haut, R. E., Williams, T.E., Theodori, G.L. – Sam Houston State University, Reducing Impacts of Oil & Gas Development on Rangelands, presented at the EFD Workshop March 2011. San Antonio, TX.

Burnett, D. B., " Team Challenge: Environmentally Friendly Using Low Impact Access Practices for Desert Ecosystems., Crisman Institute Workshop, August, 2010, College station TX.

RPSEA EFD Project 08122-35

Program Area: 4.5 Public Perception
Lead: Utah State University/Sam Houston State University

Prepared for the
Environmentally Friendly Drilling Systems Program
Houston Advanced Research Center

July, 2012

7/6/12

Date Signed

Program Area: 4.5 Public Perception

Lead: Utah State University/Sam Houston State University

Description o f Task/Milestone(s):

- The work scope includes:
  - Establish rapport with members of the general public, community leaders, representatives of oil and gas associations, regulatory agency personnel, non-governmental organization representatives, and other interested individuals who are expected to be affected by energy development in the Uinta Basin through face-to-face meetings and teleconferencing.
  - Empirically examine stakeholders' level of familiarity with environmentally friendly energy exploration and production practices.
  - Empirically examine stakeholders' level of agreement that environmentally friendly energy exploration and productions practices can be used in environmentally sensitive areas that are currently off-limits or highly restricted should such areas be opened up for development.
  - Hold a workshop to establish dialogue among members of the general public, community leaders, representatives of oil and gas associations, regulatory agency personnel, non-governmental organization representatives, and other interested individuals in the Uinta Basin of Utah with respect to the acceptance and assimilation of environmentally friendly energy exploration and production practices drawing upon the empirical data collected in steps 2 and 3.

Key Deliverables:

1. A white paper (8 – 12 pages) that summarizes the needs and barriers for the region.
2. A series of factsheets, 2 pages in length, (at least two) that discuss the application of EFD technologies to the region.
3. A series of workshops (at least two) that will transfer EFD technologies to regional stakeholders.
4. A paper and presentation at a conference concerning the Public Perception study.
5. Working with the other alliance members, identify various research projects and funding sources for future work.
6. Work with EFD team to facilitate promulgation of new entrepreneurial opportunities in the commercialization of new technology emanating from National Laboratories and University partnerships.

Summary & Accomplishments:

With support from the EFD project, our team conducted a study of the familiarity with and use of a range of environmentally-friendly natural gas exploration and production practices in the Uintah Basin (UB) of northeastern Utah. Our primary goals were to (1) document the use of EFD practices in the UB; (2) understand the drivers that have led to increased use of EFD practices, (3) identify remaining barriers to EFD use in this region. We also sought to raise awareness of EFD practices among key actors in this area, and to better understand public concerns and priorities related to natural gas exploration and development. Our key outcomes included publishing a detailed white paper summarizing our research findings, organizing a workshop in the UB that brought together local stakeholders and outside experts (from our EFD national team) to talk about opportunities to reducing the environmental footprint of local natural gas exploration and development, and presentations at national meetings and conferences.

We began by introducing our project to representatives from the natural gas industry, local community, and public land management agencies at regularly scheduled quarterly meetings of the UB oil and gas working group in the spring of 2010. We then identified a set of key informants to represent a diverse array of topical and organizational experience and perspectives. A total of 26 key informant interviews, each lasting about 75 minutes, were conducted in summer and fall 2010. Results of the interviews were summarized in written narrative reports and analyzed using standard qualitative analysis techniques and software. Interviews were combined with secondary data to write a white paper on the "Opportunities and Barriers to Reducing the Environmental Footprint of Natural Gas Development in Utah's Uintah Basin" (published in April 2011). The results were also presented at our UB workshop in October, 2010, and at several professional meetings (see details below).

The core findings from our study included:

- Several energy **companies working in the UB have already taken some steps to reduce their environmental impacts**, though most of these have yet to become 'standard practice' in the industry. The most common practices currently in use include:
    - Reducing the footprint of drilling activities through growing use of directional drilling that enables the placement of multiple wells on single pads, and reduces the number of pads.
    - Increased use of enhanced post-drilling reclamation practices to recover native vegetation and landscaping.
    - Development of strict rules to protect endangered plants and other wildlife from drilling activities.
    - The growing use of centralized water piping facilities, and the reuse and recycling of drilling water to reduce the use of water, minimize trucking, and protect water quality.

- There are seven distinct drivers of environmental innovations in the UB. These include:
    - **Increasing regulatory requirements** from state and federal agencies.
    - **Advances in engineering & technology** (that make it feasible to reduce impacts in an economically viable manner).
    - **Higher energy commodity prices** (that provide an economic cushion which makes it easier to develop and implement environmental practices without risk of losses).
    - **Concerns about public relations** and a desire to improve the public image of the industry by several companies.
    - **Changes in corporate culture** and leadership in particular companies – in particular a perceived shift toward a more environmentally-oriented ethic among younger company managers.
    - **A desire to avoid future legal battles** and challenges from environmental groups (particularly in regard to the federal NEPA review process required when developing resources on federal land or where federal mineral rights prevail).

- While there is a general trend toward greater use of EFD practices, our respondents identified many barriers to change that need to be addressed to improve adoption.
    - **Economic barriers** when the cost of implementing EFD practices is not compensated by improved efficiencies or reduces profit margins below a critical threshold.
    - **Inadequate technology for local geology** – many informants felt that EFD practices used elsewhere may not be easily transferable to the UB due to complexities in local geology and the nature of the resource.
    - **The complex mix of state, federal, and tribal regulatory agencies** who oversee energy development in the UB provides a uniquely difficult environment for energy companies because the rules, regulations, and practices associated with environmental footprint can differ based on small changes in location, and multiple agencies may be involved in reviewing proposals for exploration and drilling projects.

Interestingly, unlike areas in other parts of the United States, there is virtually no local community opposition to expanded natural gas development (and much less local pressure for stricter environmental oversight). The main environmental interest groups who monitor and engage in energy development decisions are state-wide or national groups with members and headquarters located far away from the Uintah Basin.

Taken as a whole, there is a high level of interest by nearly all parties to accelerate and facilitate efforts to both increase development and also reduce the environmental footprint of fossil fuel production in the Uintah Basin. Our research suggests that **future investments in new technical and engineering innovations are important** to help reduce logistical and economic barriers to adoption. **However, new technology alone is unlikely to generate widespread adoption of EFD practices** that are not already of interest to (and demanded by) industry and agency actors. **Market factors** (including natural gas prices and pipeline capacity) will influence the extent to which industry actors are able to experiment with and invest in new technology and practices. **Regulations and agency oversight** also play a key role – though in a more complicated way that is often appreciated. Interestingly, the initial adoption of EFD innovations in the UB have almost all preceded the formal adoption of state or federal regulatory requirements. However, **perceptions that stricter regulatory standards will be coming** appear to be required to motivate agency staff and industry actors to **engage in conversations and experimentation** to develop viable practices that can improve environmental performance while sustaining the economic viability of the industry. It is likely that a handful of larger industry actors will provide a leadership role in generating and adopting environmental innovations, with smaller firms and local service contractors following their lead (perhaps only when such changes become mandatory).

The link between regulation and behavior is made more complex because of uncertainties about regulatory jurisdiction and authority in the Basin, and perceptions of variability in federal agency practices across political administrations in Washington. If they continue, these uncertainties will make it more difficult for industry actors to make informed judgments about which kinds of environmentally-oriented change are most likely to be required. A number of industry informants suggested that they would be happy to live with stricter environmental rules if (a) all relevant agencies would agree to follow the same rules, (b) they know they could get decisions on applications for leases and permits more quickly and in a predictable manner, and (c) they could be assured that these rules would be stable for the foreseeable future.

Papers and/or Presentations and other Technology Transfer Efforts:

ORGANIZED WORKSHOP: Opportunities and Obstacles to Reducing the Environmental Footprint of Natural Gas Development in the Uintah Basin. October 14, 2010, Vernal, Utah.

Growing interest in the environmental footprint of natural gas exploration and development has generated innovations in management and technical practices. This public workshop reviewed results of a recent study of energy-environment issues in the Uintah Basin of Northeastern Utah, and highlighted examples of environmental innovation taking place in the region. Presenters included industry representatives, state and federal government leaders, and university scientists. For more information, including copies of the full agenda, participant list, and PowerPoint presentations from speakers, go to the Vernal Workshop webpage at http://www.oilandgasbmps.org/workshops/vernal2010/index.php.

Gentry, B., D. Jackson-Smith, L. Belton, and G. Theodori. 2011. **Assessing Opportunities and Barriers to Reducing the Environmental Footprint of Natural Gas Development in Utah's Uintah Basin.** April. USU-ISSRNR Research Report. Full report and executive summary available online at: http://www.efdsystems.org/Portals/25/EFD%20Uintah%20Basin%20Tech%20Report%20Final.pdf

Theodori, G., D. Jackson-Smith, L. Belton, and J. Allen. 2010. "Opportunities and Barriers to Environmentally Friendly Energy Exploration and Production Practices in the Uinta Basin." Paper presented at the 2010 International Symposium on Society and Resource Management, Corpus Christi, TX, June 6-10, 2010.

Jackson-Smith, D. and G. Theodori. 2010. "Assessing opportunities and barriers to improving the environmental footprint of oil and gas development in Utah." Invited presentation to Utah Energy Forum, Salt Lake City, Utah, July 7, 2010.

Theodori, G.L. and D. Jackson-Smith. 2010. "Public Perception of the Oil and Gas Industry: The Good, the Bad, and the Ugly." Paper selected for presentation and included in Proceedings of the Society of Petroleum Engineers Annual Technical Conference and Exhibition, Florence, Italy, September 19-22, 2010.

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Public Perception of the Oil and Gas Industry: The Good, the Bad, and the Ugly

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Abstract

Data collected in a general population survey from a random sample of individuals in Tarrant County, Texas, were used to empirically explore issues associated with public perception of the natural gas industry. In addition, the association of public perception of the energy industry with dependent measures such as individual-level actions that (a) may or may not have been taken and/or (b) may or may not be taken in response to the exploration and production of natural gas was investigated. Echoing findings from research in two neighboring Barnett Shale counties (Theodori 2009), it appears that members of the general public in Tarrant County distrust the intrusion of the gas industry and dislike certain potentially problematic social and/or environmental issues perceived to accompany development. Conversely, these same Tarrant County residents appreciate and view less negatively the economic and/or service-related benefits that tend to result from such development. Furthermore, the results of this study suggest that the social/environmental perceptual variable is a key factor to explaining past behaviors and predicting future behaviors taken in response to the exploration and production of natural gas. Possible implications of these findings for the energy industry are proposed.

Introduction

For the past nine years, the Gallup Organization has polled Americans on their views of more than 20 business and industry sectors in the country. The survey asks respondents to rate each business and industry sector in the United States on a five-point scale ranging from “very positive” to “very negative.” Between 2001 and 2009, the industries ranking near the top and bottom of the list remained fairly consistent. Either the computer industry or the restaurant industry topped the list as the most positively viewed industry sector each year (computer industry rated most favorably in 2001, 2002, 2003, 2004, 2008, and 2009; restaurant industry rated most favorably in 2005, 2006, and 2007) (Jones 2008, 2009; Newport 2007). Concurrently, with the exception of 2002, the oil and gas industry unfailingly ranked as the least positively viewed industry.

In 2001, the year of Gallup’s initial poll on the images of various business and industry sectors, roughly 24% of respondents viewed the oil and gas industry in a positive manner (either “somewhat positive” or “very positive”). That percentage increased by one percentage point in 2002. In 2003, the oil and gas industry had its highest rating, with 35% of respondents viewing it in a positive manner. One year later, that percentage dropped to 21, and in 2005 it dropped to 20. The percentage of respondents who rated the oil and gas industry positively in 2006, 2007, and 2008 were 15, 19, and 15, respectively. According to the most recent Gallup data (as of August 2009), approximately one in every five respondents (21%) regarded the oil and gas industry in a positive light (Jones 2009).

Over a span of numerous years now, the Gallup Organization and other national/international polling entities have produced extensive macro-level survey results on perceptual issues surrounding the oil and gas industry for the mass media (Bolsen and Cook 2008; Polling Report, Inc. 2009). Despite this vast knowledge on the perceptual issues surrounding the oil and gas industry, surprising little theoretical and/or empirical work has examined the effects of varying levels of public perception of the oil and gas industry on a dependent variable by incorporating public perception as the primary independent variable of interest. With the present research, we add to the scientific literature on public opinion of the energy industry. Specifically, public perception of the natural gas industry is investigated. Moreover, the association of public perception of the energy industry with dependent measures such as individual-level actions that (a) may or may not have been taken and/or (b) may or may not be taken in response to the exploration and production of natural gas is investigated.

Data

The data used for this paper were drawn from a 2009 study that focused on quality of life and energy production in Tarrant County, Texas. Tarrant County is a metropolitan county located in the core production zone of the gas shale basin known as the Barnett Shale. As of September 2001, there were 19 regular producing gas wells in Tarrant County (Railroad Commission of Texas 2001). Four years later, in September 2005, the number of regular producing gas wells in Tarrant County increased to 573 (Railroad Commission of Texas 2005). Between September of 2005 and February 2009, regular producing gas wells in Tarrant County increased by roughly 200% (n = 1,708) (Railroad Commission of Texas 2009).

Gas and oil well production data in Tarrant County from January 2001 through December 2009, as well as between January 2010 and April 2010, are reported in Table 1. Included in the table are figures for the amount of gas well natural gas (i.e., wells without completions for the production of oil), condensate (i.e., natural gas liquid recovered from gas wells from lease separators or field facilities), casinghead gas (i.e., natural gas produced along with crude oil from oil wells), and oil. As shown in Table 1, production of natural gas from gas wells in Tarrant County between 2001 and 2009 increased by approximately 16,652% (from 3,271,732 mcf to 548,090,638 mcf) (Railroad Commission of Texas 2010). Between January 1, 2010 and April 30, 2010, gas wells in Tarrant County produced 196,995,500 mcf of natural gas (Railroad Commission of Texas 2010).

Table 1—Production data from oil and gas wells in Tarrant County: 2001 through 2009 and January 2010 through April 2010

County	Time period	Gas well gas (mcf)	Condensate (bbl)	Casinghead (mcf)	Oil (bbl)
Tarrant	2001	3,271,732	58	0	0
	2002	17,884,104	465	0	0
	2003	40,529,629	2,115	0	0
	2004	75,283,248	3,124	0	0
	2005	123,642,479	5,278	0	0
	2006	183,672,082	14,967	0	0
	2007	281,023,780	43,219	0	0
	2008	464,399,110	56,659	0	0
	2009	548,090,638	42,685	0	0
	Total 2001 through 2009	1,737,796,802	168,570	0	0
	January 2010 through April 2010	196,995,500	14,320	0	0

Following a modified total design method (Dillman 1978), a survey questionnaire was delivered via the United States Postal Service to 450 randomly selected households in the county. In order to obtain a representative sample of individuals within residences, a response was requested from the adult in the household who most recently celebrated his/her birthday. The survey instrument, organized as a self-completion booklet, contained 42 questions and required approximately 60 minutes to complete. After the initial survey mail out, a post card reminder, and two follow-up survey mailings, a 34 percent response rate was achieved.[1]

[1] Eighteen of the 450 questionnaires were returned as undeliverable. None of the undeliverable household addresses were replaced with new ones. Hence, the final sample size was reduced to 432.

Perception of the Oil and Gas Industry

Measuring Perception of the Oil and Gas Industry. Perception of the oil and gas industry was assessed using a list of ten statements. Respondents were asked to indicate whether they "strongly agree," "agree," "disagree," or "strongly disagree" with each of the following items:

a. The natural gas industry is important to the local economy;
b. Natural gas industry operators in Texas are too politically powerful;
c. Not enough information concerning the development of natural gas is being made available to the general public;
d. Even when carefully controlled, natural gas development is likely to upset the quality of life in a local area;
e. Too little attention is being paid to the social costs of natural gas development;
f. The natural gas companies have no compassion for our natural environment;
g. Natural gas operators MUST adopt and use more environmentally friendly drilling practices;
h. Natural gas companies will do only what's required by law;
i. Natural gas operators are drilling and producing too close to homes and businesses; and,
j. In the long run, I'm sure that people in this area will be better off if our natural gas resources are developed.

Response categories were coded so that higher values reflected more negative views of the oil and gas industry. Items "b" through "i," which reflected less positive views of the oil and gas industry were coded as 1 = strongly disagree, 2 = disagree, 3 = agree, and 4 = strongly agree. Items "a" and "j," which reflected more positive views of the oil and gas industry were reverse coded (1 = strongly agree; 4 = strongly disagree).

Maximum likelihood factor analysis using oblique rotation was conducted on these perceptual items to determine what, if any, underlying structures existed among them (Costello and Osborne 2005). The analysis produced a two-factor solution. After rotation, two of the ten items loaded on factor 1 (see Table 2). These items addressed the perceived economic aspects of natural gas development. Eight of the ten items loaded on factor 2. These measures addressed the perceived social/environmental aspects of the oil and gas industry in Texas. Factor 1 accounted for 28.43% of the total variance; factor 2 accounted for 22.12% of the total variance.

Table 2—Factor loadings for perception of the natural gas industry items

	Loading
Factor 1: Economic aspects of the natural gas industry	
The natural gas industry is important to the local economy.	0.52
In the long run, I'm sure that people in this area will be better off if our natural gas resources are developed.	0.99
Factor 2: Social and environmental aspects of the natural gas industry	
Natural gas industry operators in Texas are too politically powerful.	0.61
Not enough information concerning the development of natural gas is being made available to the general public.	0.63
Even when carefully controlled, natural gas development is likely to upset the quality of life in a local area.	0.63
Too little attention is being paid to the social costs of natural gas development.	0.67
The natural gas companies have no compassion for our natural environment.	0.67
Natural gas operators MUST adopt and use more environmentally friendly drilling practices.	0.51
Natural gas companies will do only what's required by law.	0.64
Natural gas operators are drilling and producing too close to homes and businesses.	0.80

The two economic items and the eight social/environmental perceptual items were ranked in decreasing order according to mean score (see Table 3). As noted, each of the mean scores for the items comprising the social/environmental factor, as well as the overall mean score for that factor, was higher than the mean score for the two economic items and the overall mean economic score. This indicated that, overall, members of the general public in Tarrant County, Texas, viewed the items on social/environmental factor less positively than the items on the economic factor.

Table 3—Mean scores for perception of the natural gas industry items

	Mean Score
Factor 1: Economic aspects of the natural gas industry	
In the long run, I'm sure that people in this area will be better off if our natural gas resources are developed.	1.98
The natural gas industry is important to the local economy.	1.72
Overall mean – factor 1	***1.84***
Factor 2: Social and environmental aspects of the natural gas industry	
Natural gas operators MUST adopt and use more environmentally friendly drilling practices.	3.16
Natural gas companies will do only what's required by law.	2.94
Not enough information concerning the development of natural gas is being made available to the general public.	2.81
Natural gas industry operators in Texas are too politically powerful.	2.75
Natural gas operators are drilling and producing too close to homes and businesses.	2.74
Too little attention is being paid to the social costs of natural gas development.	2.64
The natural gas companies have no compassion for our natural environment.	2.44
Even when carefully controlled, natural gas development is likely to upset the quality of life in a local area.	2.43
Overall mean – factor 2	***2.75***

Association of the Oil and Gas Industry and Individual-Level Actions. In the study, respondents were asked to indicate (1) whether or not they engaged in certain individual-level actions as a response to the exploration and production of natural gas and (2) their likelihood of engaging in such actions in the future. First, respondents were asked whether or not they had ever: (a) attended a public meeting to get information and learn more about the drilling and production of natural gas; (b) contacted a local elected official or governmental agency to complain about a natural gas drilling and/or production issue; (c) voted FOR a political candidate because of his/her favorable position on the drilling and/or production of natural gas; and (d) voted AGAINST a political candidate because of his/her favorable position on the drilling and/or production of natural gas. Each individual-level action was dummy coded (1 = yes; 0 = no). Next, respondents were asked to indicate their likelihood of engaging in these same four actions in the future. The likelihood of engagement for each item was dummy coded (1 = likely; 0 = not likely).

The association of public perception of the energy industry with individual-level actions that (1) may or may not have been taken in response to the exploration and production of natural gas and (2) may or may not be taken in response to the exploration and production of natural gas was assessed using multivariate logistic regression techniques. Net odds ratios for the effects of public perception on individual-level actions that may or may not have been taken in response to the exploration and production of natural gas are reported in Table 4.[2,3] Net odds ratios for

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[2] An odds ratio (θ) is *e* (natural logarithm) raised to the power of "b" (the metric logit coefficient); θ refers to the effect of a one-unit change in X on the odds of Y. It has a "times as likely" interpretation and θ can equal any nonnegative number. When X and Y are independent, θ equals 1. A value of 1 generally serves as a baseline for comparison. Odds ratios on either side of 1 reflect certain types of associations. An odds ratio greater than 1 ($1 < \theta < \infty$) indicates a positive association, while an odds ratio less than 1 ($0 < \theta < 1$) denotes a negative association. Values of θ farther from 1 in either direction designate stronger levels of association (Agresti 1996; Liao 1994).

[3] Following Theodori (2008), three variables – mineral rights ownership, personal/familial ties to the natural gas industry, and length of residence in the county – were included in this research as control factors. Mineral rights ownership (0 = does not own mineral rights; 1 = owns mineral rights) and personal/familial ties to the natural gas industry (0 = respondent and/or family members not employed either part-time or full-time in an occupation related to the natural gas industry; 1 = respondent and/or family members employed either part-time or full-time

the effects of public perception on individual-level actions that may or may not be taken in response to the exploration and production of natural gas are reported in Table 5.

As shown in Table 4, individuals with more positive views on the economic factor and those with more negative views on the social/environmental factor were more likely than their respective counterparts to have attended a public meeting to get information and learn more about the drilling and production of natural gas. Individuals with more negative views on the social/environmental factor were more likely than their counterparts to have contacted a local elected official or governmental agency to complain about a natural gas drilling and/or production issue. Moreover, such individuals were more likely to have voted against a political candidate because of his/her favorable position on the drilling and/or production of natural gas. Individuals with more positive views on the social/environmental factor were more likely to have voted for a political candidate because of his/her favorable position on the drilling and/or production of natural gas.

Table 4—Net odds ratios for the effects of public perception on individual-level actions that may or may not have been taken in response to the exploration and production of natural gas

	Multivariate Odds Ratios[a]
Attended a public meeting to get information and learn more about the drilling and production of natural gas.	
Economic factor	0.31*
Social/environmental factor	2.71*
Contacted a local elected official or governmental agency to complain about a natural gas drilling and/or production issue.	
Economic factor	0.71
Social/environmental factor	35.16**
Voted FOR a political candidate because of his/her favorable position on the drilling and/or production of natural gas.	
Economic factor	0.46
Social/environmental factor	0.12*
Voted AGAINST a political candidate because of his/her favorable position on the drilling and/or production of natural gas.	
Economic factor	5.29
Social/environmental factor	17.53*

[a] Odds ratios computed controlling for mineral rights ownership, personal/familial ties to the natural gas industry, and length of residence in the county.
* $p \leq 0.05$; ** $p \leq 0.01$.

As shown in Table 5, individuals with increasingly negative views on the social/environmental factor indicated that they would be more likely than their counterparts to contact a local elected official or governmental agency to complain about a natural gas drilling and/or production issue in the future. Such respondents also indicated that they would be more likely to vote against a political candidate because of his/her favorable position on the drilling and/or production of natural gas.

in an occupation related to the natural gas industry) were both dummy coded. Length of residence in the county was measured in years.

Table 5—Net odds ratios for the effects of public perception on individual-level actions that may or may not be taken in response to the exploration and production of natural gas

	Multivariate Odds Ratios[a]
Attend a public meeting to get information and learn more about the drilling and production of natural gas.	
Economic factor	1.08
Social/environmental factor	2.39
Contact a local elected official or governmental agency to complain about a natural gas drilling and/or production issue.	
Economic factor	0.97
Social/environmental factor	6.68***
Vote FOR a political candidate because of his/her favorable position on the drilling and/or production of natural gas.	
Economic factor	0.65
Social/environmental factor	0.82
Vote AGAINST a political candidate because of his/her favorable position on the drilling and/or production of natural gas.	
Economic factor	1.88
Social/environmental factor	3.28*

[a] Odds ratios computed controlling for mineral rights ownership, personal/familial ties to the natural gas industry, and length of residence in the county.
* $p \leq 0.05$; *** $p \leq 0.001$.

Concluding Comments

Two primary conclusions can be drawn from this research. First, it appears that in Tarrant County, Texas, as well as in other Barnett Shale counties (Theodori 2009), members of the general public distrust the intrusion of the gas industry and dislike certain potentially problematic social and/or environmental issues perceived to accompany development. Conversely, the majority of citizens appreciates and views less negatively the economic and/or service-related benefits that tend to result from such development (Theodori 2009). Second, it appears that the social/environmental perceptual variable is a key factor to explaining past behaviors and predicting future behaviors taken in response to the exploration and production of natural gas.

Based upon the results of this study, certain recommendations can be posed to the energy industry. With respect to the first finding, the energy industry must do a better job of recognizing and addressing earnestly the perceived negative social and environmental consequences associated with development. Concomitantly, the energy industry must do a better job of educating the general public about its low-impact technologies and other environmentally friendly drilling systems which substantially reduce adverse impacts in the social and environmental arenas (Haut et al. 2009). Funding and promoting informational and educational programs at the local level on the advances in environmentally friendly drilling practices may be an effective strategy for operators to address some of the public (mis)perceptions about the energy industry.

With respect to the second finding, transparent communication between the energy industry and all pertinent stakeholders is paramount. The energy industry must inform local residents about the potentially negative social and environmental consequences of energy development in and around their communities. At the same time, community leaders, government and regulatory agencies, environmental organizations, and other stakeholders must effectively communicate their perceived social and environmental fears and/or anxieties associated with unconventional gas development to each other and, in turn, to industry. Open and honest communication will reduce the spread of rumors and inaccuracies about perceived negative social and environmental consequences of current activities and proposed developments at the local level. Furthermore, county and municipal leaders must communicate the social and environmental concerns of their constituents to industry and work with them to minimize the negative "objective" social and environmental aspects of the unconventional gas recovery process. As research and practice can attest, attitudes and behaviors often change.

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Challenges Facing Developers of the Marcellus Shale Play

Introduction

The Appalachian basin Marcellus Shale (Middle Devonian) gas play is one of the hottest, if not the hottest, shale plays in the United States. The potential of the play is so big – resource estimates have exceeded 500 TCF – the play is becoming the land of the giants. ExxonMobil entered the play with its purchase of XTO Energy and their portfolio of shale gas properties; Royal Dutch Shell followed with its own purchase of East Resources and their 650,000 acres of prime Marcellus acreage, mostly in Pennsylvania; and Chevron purchased Atlas Energy, one of the main players in southwestern Pennsylvania. International companies, such as Statoil, Mitsui E&P, Mumbai's Reliance Industries, and UK's BG Group also entered the play through joint ventures with US independents who already were involved.

All of this began when a deep test to the Lockport Dolomite (Upper Silurian) in Washington County, Pennsylvania was killed with 13 # mud and failed to come back, causing the operator to move up hole to take a look at shallower potential, including the Marcellus. Although the logs indicated few natural fractures in the Marcellus, they were similar to logs from a Floyd Shale well, which gave William Zagorski, who has been referred to as "The Father of the Marcellus Play," the idea to apply the biggest frac job ever east of the Mississippi River. The result was the discovery well for the Marcellus play – the Renz #1 Unit – which was completed in late 2004.

Range, Equitable, CNX, Atlas and others quickly got involved in the southwest Pennsylvania play, and Chief, Cabot, Fortuna, Chesapeake and others moved into northeast Pennsylvania adjacent to the New York border.

Although shale gas production had been established in the Appalachian basin more than 80 years prior to the #1 Renz discovery, the Marcellus Shale never had attracted much interest as a reservoir. Most of the gas in the established Devonian shale play areas has been and continues to be from the Upper Devonian Huron Shale, which is present only on the western side of the basin, mainly in Kentucky, West Virginia and Ohio. During the late 1970's, when the Morgantown Energy Research Center funded the Eastern Gas Shales Project (EGSP), the US Geological Survey and the state geological surveys from New York to Kentucky mapped the structure, thickness and extent of all black Devonian shales from the Huron Shale to the Marcellus Shale, using data from thousands of Oriskany Sandstone (Lower Devonian) wells that had been drilled in the 1930's, 40's, 50's and 60's.

Many of these Oriskany Sandstone well records indicated the presence of gas in the Marcellus Shale, as well as in the underlying Huntersville Chert and Oriskany Sandstone, which continued to be the prime target of drillers. Unfortunately, most of these Oriskany wells were drilled in the western half of the basin, so maps of the Marcellus Shale produced by the EGSP contained question marks in a large blank area between the easternmost Oriskany wells and Marcellus outcrops further east.

But, it is this eastern area, especially in northeast Pennsylvania and southeastern New York, which is of interest to many of those who are developing the Marcellus play. Because this area had never been drilled, no drilling rigs or large trucks hauling water, sand or chemicals had been observed in the area; no oil and gas infrastructure had been established; no oil and gas inspectors had been assigned to work there; and no one had ever knocked on the door of a local resident asking if they would like to lease their mineral rights – for a typical fee per acre plus a one-eighth royalty on production.

What followed was a race among eager producers to acquire acreage in the play. As the available pool of acreage dwindled, the law of supply and demand resulted in ever increasing prices for both acreage and royalties. The end result was predictable – those who signed early for a lower price felt they deserved more, and those who had yet to sign organized to demand more than ever had been paid.

This eastward push in play development also extended into the drainage basins of the Susquehanna and Delaware Rivers, areas that provide essential water to eastern cities, such as New York, Philadelphia, Baltimore and Washington, DC. Consequently, the Delaware and Susquehanna River Basin Commissions became additional, first-time but highly-interested, stakeholders in the play, and numerous environmental groups began to express their serious concerns that the play could not be developed in a manner that would protect those public water supplies.

The state regulatory agencies in New York, Pennsylvania and West Virginia reacted to the concerns of environmental groups, local officials and the general public with draft copies of new rules and regulations, a moratorium on drilling in certain areas, public calls for a moratorium in other states, and a restriction on the volume of water that can be used to fracture a well that essentially eliminated horizontal drilling in New York.

Meanwhile, industry was facing serious technical problems that had to be solved to extract gas economically from the shale. The existing gas infrastructure had to be upgraded and expanded, and by invoking horizontal drilling and large slickwater frac jobs, commercial production was established. But, high volumes of water, chemicals and sand were required, so industry needed to develop better water management practices to treat flow back water prior to disposal or reuse. And, even as industry developed best practices to resolve their technical problems, they had to deal with an ever-increasing, negative public outcry, which suggested the need for new public outreach and education programs, and with increased environmental awareness and challenges.

The following report will attempt to briefly summarize the various problems and issues facing operators involved in the Marcellus play, including technical, environmental and regulatory roadblocks to development. From reading this summary, one may correctly conclude that industry has been successful in overcoming technical barriers that challenged the economic development of the Marcellus play, i.e., by incorporating horizontal drilling and large hydraulic fracture stimulation into their plans. However, industry initially failed to alleviate the negative perception of the public regarding this play and the implementation of those technologies. This led to increasingly negative public outcry, which in turn led to increased social protests and political activity, and ultimately to an increase in regulations and to a deceleration in play development, especially in New York.

Technical Challenges to Overcome

Although still in its infancy, the vast economic potential of a fully-developed Marcellus play has been established, along with a summary of technical problems facing those attempting to develop it. Engelder and Lash (2008), while pointing out the importance of natural fractures and modern stimulation techniques to economic production, estimated total gas in place in the play area to be at least 500 trillion cubic feet (Tcf), of which 50 Tcf was technically recoverable. An early report by Tristone Capital (2008) summarized the main problems facing producers, mainly upgrading or creating an adequate infrastructure and developing water management plans that meet regulatory approval, and outlined their methodology for the valuation of unbooked, upside resources and per share value for the main players. Moss and others (2008) produced a report on the potential of the natural gas resource in the Marcellus for the National Park Service, which has approximately 33 units of their system within, or in the vicinity of, the Marcellus play. In their report, the authors cited an estimate by unnamed experts of 31 Tcf of recoverable gas from the Marcellus.

As drilling continued and more production data became public, estimates of the gas resource in the Marcellus began to increase. The Ground Water Protection Council and All Consulting (2009), in a report prepared for the Department of Energy, increased the estimated gas-in-place to 1,500 Tcf, of which 262 Tcf was considered technically recoverable. The United States Geological Survey (USGS), which at one time (2002) had assumed that the Marcellus contained only 1.9 Tcf (based on production from a limited number of wells), not only increased their estimate to 84 Tcf of undiscovered gas reserves, but in another report (Soeder and Kappel, 2009) the USGS appeared to endorse an estimate of 363 Tcf of recoverable gas reported by Esch (2008). This estimated volume was based on production data provided by Chesapeake Energy Corporation, and is sufficient to supply the needs of the nation for 15 years, at 2009 rates of production. These early production numbers also caused Engelder (2009) to reconsider, resulting in a much higher recoverable gas estimate of 489 Tcf.

As estimates from various sources continued to be released to the public, confusion resulted, and charges of industry over estimating the resource to gain public support and move forward were made, especially after the USGS value of 84 Tcf and the EIA value of 410 Tcf were both released in 2011. In 2012 EIA attempted to reconcile their number with the USGS number and came up with 141 Tcf by using a higher EUR/well (1.56 vs 0.93 Bcf/well).

In March 2012, Terry Engelder assembled a panel of experts to discuss the divergent estimates for the gas resource in the Marcellus Shale play. His objective was to assure that the federal arbitrators (USGS and EIA) were using the best possible methodology to derive the correct estimates of resource size. At the March 2012 PSU meeting, Harry Vidas (ICF International) presented a methodology that resulted in an estimate of 461 Tcf on 80 acre spacing and 698 Tcf if the Marcellus is developed on 40 acre spacing.

Thus, when fully developed, the Marcellus Shale has the potential to be the second largest gas field in the world, with cumulative gas production equivalent to the energy content of 87 billion barrels of oil (Considine et al, 2009), enough to meet the energy needs of the entire world for nearly three years.

However, the economic development of this play would not have been possible without the advent of new technologies, mainly horizontal drilling from multi-well pads and large hydraulic fracturing jobs. Unfortunately, these technologies bring with them other technical and logistical problems to be solved, along with environmental challenges that led to a slowdown in the permitting process by regulatory agencies. Furthermore, because much of the play area is over pressured, the existing infrastructure had to be upgraded before it could handle the expected large volumes of high pressured gas from Marcellus wells.

Other technologies also have been implemented, and continue to evolve, to drill and complete wells and to deal with flowback water with high concentrations of dissolved and suspended solids. Closed loop systems are being used to eliminate drill pits in which cuttings and flow back water formerly accumulated, and larger well pads were created from which multiple horizontal wells could be drilled and treated with large hydraulic fracture jobs. Because these pads reduce the need to excavate and create five or six other sites (per lateral) from which individual vertical wells would be drilled, the overall effect has been to reduce the environmental footprint in the area. Unfortunately, however, the public does not see these green areas that will not be disturbed. Instead, they only see an increase in activity at this one site, which can last for many months as the additional wells are drilled and completed.

Industry also had to create new gas infrastructure, including a network of gathering and collection lines, especially in northeastern Pennsylvania and adjacent southeastern New York, an area with little or no previous oil and gas activity, and to upgrade older gas infrastructure in the over pressured area of the play. In addition, other public infrastructure, such as local roads and bridges, has been impaired by the high volume of heavy truck traffic, and has to be upgraded, repaired and eventually replaced.

In areas of lower thermal maturity, mainly southwestern Pennsylvania and northern West Virginia, wet gas, condensate and natural gas liquids are produced. Although economically attractive, this liquid production has created the necessity of further infrastructure development, including gas processing plants and "crackers," ethylene cracker plants designed to crack wet gases, such as ethane, propane, and butane, to make ethylene, propylene, and other hydrocarbons that are used to make plastics. Shell Chemical has announced plans to build such a plant on a site 30 miles west of Pittsburgh. EPA followed that announcement with a warning that this type of plant emits a wide range of pollutants, and Shell will need to use the best-available control technologies to meet air emissions laws.

Industry also is faced with developing technology, or implementing technology developed by others, to treat flowback water prior to reuse or disposal. This return water typically contains high concentrations of suspended solids that would reduce permeability if injected into another well, and high concentrations of total dissolved solids, that could reduce the effectiveness of chemical additives in frac water, and could cause precipitation of minerals in induced and natural fractures in the reservoir. The concentration of TDS increases each day that water flows back following a frac job, typically reaching greater than 200,000 ppm after 30 days.

Water management technologies used by operators in the Marcellus play have been summarized by Veil (2010). Several commercial technologies have been applied in the field, and DOE currently is funding nearly a dozen research efforts designed to treat flow back water to the point where it can be mixed with makeup water and injected into the next well. The good news seems to be that of the approximately 5 million gallons used in a large frac job only 20% may return and need to be treated; the bad news is that of the 5 million gallons taken from streams and public water supplies only 20% returns. The remainder is lost forever from the water cycle, which is an additional concern for environmentalists and the general public.

As these technologies are being developed, the following areas of concern will be addressed:

- Life cycle planning and management of produced water (water withdrawal, transportation, storage, drilling, fracturing, treatment, reuse/recycle, disposal)
- Make up water sources: access to public supplies, streams and rivers, POTWs, mines; compliance and reporting
- Make up water blend; mix acid mine drainage (AMD) with flow back water (FBW)
- Flowback/well cleanup; chemical reactions that may occur in the reservoir
- Consumptive use: most (80%) of the water is lost in the reservoir, if flow back water is injected in a disposal well, total loss equals 100%
- Wide range of chemicals in flow back water; Ca, Ba, Fe, Mg, Mn, Sr, $CaCO_3$; TDS, NORMS
- Must deal with NORMs; Ur, Radon in solids and flow back water

Industry also is faced with the need to expand the local pool of well-trained, drug-free personnel to work in the gas field. Public opposition already has been directed at the number of trucks with out-of-area license plates being driven by gas field workers. To create a more general acceptance of the play, it may be advisable to develop a workforce training program for local workers.

Other interesting technical issues to be resolved may lead to funding for future research:

- Over pressured versus normal pressured areas
    - Mapping over pressured areas
    - Determining/predicting causes/locations of over pressured areas
    - Determining ranges and distributions of critical physical properties of shale

- Mapping & geologic modeling programs
    - Mapping TOC, thermal maturity thickness
    - Determining key criteria for well placement
    - Determining key criteria for lateral location/direction/length

  - Geologic modeling to predict low flow back areas

- Reservoir & water chemistry, interaction; stray gas
  - Chemistry of rock-water interaction that controls composition of FBW
  - Produced water carrying trace element contaminants (Hg, As, Ba)
  - Produced water carrying radiogenic materials
  - Potential formation damage with reused FBW
  - Sulfate-reducing bacteria; precipitation of minerals in the reservoir
  - Precipitation of $CaCO_3$, $FeCO_3$, in reservoir
  - Need to deal with high variability of FBW over time
  - Technology to treat FBW lags behind frac technology
  - Isotope fingerprinting to identify the source of stray gas

- Improved treatment technology
  - Alternative (greener) frac fluids
  - Smart proppants (reduce use of sand resources)
  - Low percent of FBW; rest may "plug" portions of the reservoir
  - Making frac chemistry work in high salinity FBW in the next well
  - Improved efficiency to reduce trucks, water use, land disturbance

- Inadequate infrastructure, especially in the northeast & east
  - Roads – upgrade and repair public roads; build location roads
  - Drill sites – wooded, hilly; cross many streams; pits versus tanks, cover
  - Rigs – begin to use smaller, lighter?
  - gathering network – gathering & collection lines

Finally, it should be noted that the fracing process itself and the combination of additives used in the process are continuing to evolve and improve to more effectively stimulate the reservoir, enhance production, and improve environmental and safety concerns.

Expanding Environmental and Social Issues

The Marcellus Shale, and the two main technologies that have enabled industry to begin to extract natural gas from it, i.e., horizontal drilling and hydraulic fracturing, have become the targets of a variety of groups, including environmental organizations, the media, local and state politicians – even "film" makers (including semi-professional and student amateurs).

Shortly after the play began to be developed, in 2010, American Rivers included West Virginia's Monongahela River in their list of America's most endangered rivers due to what they referred to as toxic pollution created by natural gas extraction in the river basin. "We must put the brakes on the rampant gas drilling that is already threatening the drinking water for hundreds of thousands of people," stated Rebecca Wodder, President of American Rivers. "We simply can't let energy companies rake in the profits while putting our precious clean water at risk."

Leaders of other regional environmental groups were quick to respond with warnings of their own. "The scale of this gas drilling has caught regulators by surprise, and the environmental problems associated with it are affecting millions of people" added Shandra Minney, who is with the West Virginia Rivers Coalition. "State and federal governments must move quickly to put regulatory safeguards in place that protect our resources for the benefit of all."

"Just as mountaintop removal coal mining is rightfully known as 'strip mining on steroids', horizontal drilling and hydrofracing deep in the Marcellus Shale is surely 'gas drilling on steroids'" according to Cindy Rank with the West Virginia Highlands Conservancy. "Enforceable standards are needed to control fresh water withdrawal, the use and disposal of chemically-laced frac and flowback water, and the treatment and disposal of the brine and naturally occurring radioactive material in the produced water."

Politicians were less than reluctant to express their opinions on "the Marcellus problem." Protection of New York City's pristine water supply was an issue in a mayoral election in the city; city councilmen and state legislators were quite outspoken with demands for increased regulation; former New York Governor David Patterson instructed the NY DEC to update their environmental impact statement in regard to the Marcellus; even Secretary of State Hillary Clinton, in a letter to the New York State Environmental Conservation Commissioner, said she was concerned about the environmental impact of drilling in the Marcellus Shale and further stated that current federal protections are fairly weak.

Articles and editorials in newspapers from New York to West Virginia warned of the dangers associated with drilling and fracing in general, and in exploiting the Marcellus Shale in particular. Headlines such as "Natural gas rush stirs environmental concerns" (Morgantown Dominion Post, 11/16/08), "Drilling in shale is a shell game" (Morgantown Dominion Post, 12/7/08), "Gas drilling in Appalachia yields a foul byproduct," (Associated Press, 2/2010), "Time to repeal 'Halliburton exemptions,'" (Binghamton Press & Sun Bulletin, 4/4/10), and "Drilling companies won't take no for an answer" (Syracuse Post Standard, 7/11/10) helped to create a negative environment for those involved in the early development of this play, and for the state regulatory agencies charged with regulating the industry and protecting the environment.

Magazines also became involved, warning of "The hidden danger of gas drilling" (Business Week, 11/24/08) and implying that hydraulic fracturing is an expletive to be deleted ("A colossal fracking mess"; Vanity Fair, 6/21/10).

But neither the newspapers nor the magazines could keep pace with the explosion of websites dedicated to revealing the dangers of horizontal drilling and applying massive hydrofracs in the Marcellus play. Propublica's website (www.propublica.org) featured seemingly daily articles on the dangers of developing the Marcellus with horizontal wells and large frac jobs, and pushed for increased government control, and the Shaleshock Action Alliance (www.shaleshock.org) defined their role as "a movement that works toward protecting our communities and environment from exploitative gas drilling in the Marcellus Shale region."

Some of these websites contained short film clips produced by concerned environmentalists, would-be film makers, and university amateurs. The most notable of these probably is the film "Gasland," which was shown at the Sundance Film Festival and found its way to HBO, resulting in an Oscar nomination. Lesser known, and actually quite humorous, is "Frac attack: dawn of the watershed," available in both PG-13 and R-rated versions, which was released on the internet (www.fracattackthemovie.com) and shown on public television in the central New York area and at local film festivals.

Conversely, more positive articles on the Marcellus play, especially on the huge economic potential, have appeared in the New York Times, the Oil & Gas Journal, Technology Review, and other media. In addition, websites have been created by groups such as Energy in Depth that are attempts to conduct public outreach and education while addressing some of the more serious environmental concerns.

Universities in upstate New York also began to conduct due diligence. Cornell University established an ad-hoc advisory committee on "leasing of land for exploration and drilling of natural gas in the Marcellus Shale" and charged it with producing a set of guidelines for their President when he was attempting to decide whether or not to lease university-owned land for natural gas drilling. And, several professors in the Department of Earth Sciences at Syracuse University attempted to present unbiased, scientific information to prove that drilling for natural gas in New York would benefit the state far more than it might hurt, and that the risk to water supplies posed by chemical additives in the fracing process has been highly exaggerated. They also acknowledged that hydrofracing needs to be regulated and suggested that the New York DEC needs more staff to do this effectively.

Industry support groups, like the Marcellus Shale Committee, a joint initiative between IOGA-PA and POGAM, and the Marcellus Shale Coalition, were formed to address public concerns and enhance outreach and education efforts. The Marcellus Shale Coalition, now the largest of these groups, produces weekly, if not daily news releases, and has become well organized, funded and respected, with a large membership of Marcellus stakeholders.

The Pennsylvania Council of Professional Geologists (PCPG), a group that advocates "the use of sound science to formulate public policy, protect human health and the environment, establish and evaluate regulatory programs and disseminate accurate information," also released a position statement on the Marcellus.

According to the PCPG, Marcellus Shale gas exploration and production are worthwhile and necessary, and will have a positive effect on Pennsylvania's economy. PCPG also stated that information on the Marcellus, as reported in print, broadcast media and the Internet, often conveys erroneous information that can lead to "unnecessary confusion and exaggerated concerns." However, natural gas drilling and production "can and must be done in an environmentally responsible and scientifically sound manner" to minimize adverse impact on the environment. PCPG believes that horizontal drilling and hydraulic fracturing technologies have had a "low incidence of proven adverse impacts to potable water quality," but gas drilling and production "can and must be conducted in accordance with best industry practices and well-established state oil and gas, and environmental regulations."

WPSU-TV, the PBS affiliate for central Pennsylvania produced two programs on the Marcellus, "Gas exploration in Pennsylvania," and "PA gold rush." Both were posted on YouTube. And, Branded News, located in Oklahoma City, produced two DVDs on the Marcellus play, one that focused on Pennsylvania, the other on West Virginia.

With all of the attention, both pro and con, that the Marcellus Shale has and is still receiving in the media, on websites, and through numerous public meetings, it is easy to lose sight of exactly what are the legitimate environmental concerns that should and must be addressed. As the debate became increasingly more emotional, it became increasingly more difficult to focus on what were substantive environmental issues and not concerns based on fear rather than fact.

Initially, concerns expressed during public settings focused on the perceived dangers inherent in hydraulic fracturing, specifically, fear of unknown chemicals in the frac fluid, potential danger to water supplies, and health hazards to people, pets and farm animals that came in contact with contaminated water. Additional concerns were focused on the high volumes of water that was used, and the impact of reduced stream flow on other users and the aquatic environment in streams and rivers, and dangers associated with dealing with large volumes of flow back water, including potential contamination of public supplies of drinking water.

Specific comments expressed in public meetings included:

- High consumptive use, high water withdrawal volumes
- Adverse impact of high water use on water resources
- Adverse impact on fish and wildlife
- Ensuring water supplies to meet public needs
- Fear for New York City's unfiltered water supply
- Negative impact on streams and stream flow
- Competing use for water
- Storm water runoff near wellsites and roads; damage to streams
- Carcinogens and radioactivity in flow back water
- Surface spills contaminating water supplies
- Water management, size of locations, treatment & disposal of FBW
- Safety procedures
- Health effects of operations
- Composition of frac fluids
- Protecting fresh water zones from frac fluid & flowback water
- Water treatment and discharge plan
- Radioactive water and solids in FBW (NY Times article 3/11)
- Water left in reservoir – future migration upward to fresh water zones
- Waste treatment & disposal; storage and hauling
- Municipal plants and POTW inadequate to treat FBW

- Intentional (illegal) dumping of FBW
- Subsurface pathways for methane migration into shallow water zones
- Inadequate set back from water supplies, dwellings and farm buildings
- Recent studies that dispute the claim that fracing has never polluted a water well

Later, once drilling began and truck traffic increased – along with noise, dust and degradation of local roadways and bridges – residents began complaining that their quiet rural environment had been turned into what they termed "an industrial zone." Concerns voiced by local residents included:

- Increase in truck traffic; road & bridge destruction
- Dust control
- Noise
- Night time "light pollution" due to rig lighting in formerly dark, rural areas
- Air quality and emissions near wells, pipelines and compressors
- Increased duration of local activity due to multi-well pad drilling & fracing
- Over drilling in an area
- Potential problems with pits and liners; spill potential
- Well location, roads, pipelines, pit construction - all involve land disturbance
- Land disturbance results in habitat fragmentation, riparian degradation, increased sediment in streams
- Inadequate casing and cementing programs; shallow gas migration into aquifers
- Material Safety Data Sheets (MSDS) inadequate for chemical disclosure
- Re-fracing of wells within a few months re-introduces these problems
- Fracing multiple wells from a single site requires hauling high volumes of water & chemicals on the same roads and bridges
- Injection into disposal wells may have triggered small earthquakes in Ohio
- Cumulative, long-term impacts are not being addressed

Eventually, as protests became more organized, protection of property rights, especially for non- mineral owners, and the threat of declining property values, along with increased costs for local communities, became more important, and residents expressed these concerns:

- Protection of property rights & the environment; receive fair royalties
- Increasing opposition among an increasing number of groups
- Need for groups to became more organized, more vocal, better funded
- Websites with or without videos became numerous; movies (documentaries) produced
- Decreasing property values
- Increase in crime, drug use, prostitution; leads to a higher cost for police force
- Compensation for property owners who do not own mineral rights
- Encroachment into buffer zones around cities and towns
- No public notice and comment period prior to issuing well permits
- Will the Marcellus play be a short-term boom followed by an economic bust?
- Decreasing property values

- Overnight millionaires versus property owners without mineral rights
- Displace low-income people
- Short term increase in rentals, vacancy rates, housing prices, etc
- Boom-bust cycles as industry moves on
- Public services break down significantly when population growth reaches 15%
- New hires come from other industries
- Jobs are filled by experienced out of state workers
- By the time locals are trained for hire, industry has moved on
- Local inflation increases more than wages
- Farming decreases as local farmers "cash out" and move away
- Evidence of a decrease in new subdivisions
- Decrease in tourism

It is important to note that industry responded by testing well water to develop baseline data prior to drilling, and by developing new best practices, including better casing and cementing programs, closed-loop drilling systems, replacing lined pits with steel tanks, using impervious well pads, and bringing "disappearing roads" into the basin from the southwest. In addition, microseismic detectors are being installed and left in place to serve more than one well, providing a better regional picture of induced fractures. Most of these changes were made even before new laws, rules and regulations were passed.

The Changing Regulatory Landscape

The increase in public opposition to drilling and fracturing Marcellus Shale horizontal wells did not go unnoticed by local and state governments. Consequently, operators involved in developing the play have had to deal with a constantly changing regulatory landscape that varied state-by-state.

Much of this was predictable and was due, at least in the early years of development, to industry moving into eastern areas of the basin with no prior history of drilling and completing gas wells, areas in which no oil and gas inspectors had ever been assigned, and areas in which no gas company had ever attempted to lease mineral rights. These areas also were in the river basins that supplied drinking water to major eastern cities, especially New York City with its unfiltered water supply. Thus, the various river basin authorities became reluctant but necessary stakeholders in the regulatory process, which added additional layers to the permitting and approval process.

Opponents of play development made the case that current state laws, rules and regulations were written for shallow, vertical wells, not for deep, horizontal wells which required large pads, and consequently large surface disturbance, high volumes of frac water, sand and chemicals, and more equipment to be moved on local roads and bridges. Thus, groups from New York to West Virginia began to call for new, Marcellus-specific regulations, which would require a complete overhaul in the regulatory framework for drilling and completing these wells. Consequently, New York imposed a drilling moratorium while the regulatory agency wrote a draft supplemental generic environmental impact statement (dSGEIS) and permitting slowed in Pennsylvania and West Virginia while the legislatures of both states considered new, Marcellus-specific rules and regulations.

The movement toward increased regulations and control was not restricted to the states alone. Numerous towns and cities in New York, Pennsylvania and West Virginia – 115 in Pennsylvania alone – insisted on more local control and imposed their own restrictions on land use, road use, noise limits, gas well setback requirements, and even moratoria on the drilling of Marcellus Shale wells within their boundaries and within a buffer zone around their municipalities. Others suggested using the river basin model to include local involvement in the regulatory process. This lack of a consistent set of statewide operating rules has made it very difficult for gas companies to remain in compliance and still operate efficiently.

Other groups insisted that this was not enough, and believing that no state had a totally comprehensive oil and gas regulatory framework, and thus could not adequately protect the environment, called for more federal control, including a federal bill to remove the water injection exemption from the Safe Drinking Water Act.

EPA responded with a 2-year study of the possible impact of hydraulic fracturing on drinking water, the US House of Representatives issued a report on the chemicals used in hydraulic fracturing, and DOE Secretary Steven Chu appointed a panel of experts – the Energy Advisory Board Shale Gas Production Subcommittee – to produce a report on the immediate steps that could be taken to improve the safety and environmental performance of shale gas developers. After three months of deliberations and public hearings, the subcommittee issued a series of recommendations in four key areas: making information about shale gas operations more accessible to the public; immediate and longer-term actions to reduce environmental and safety risks of shale gas operations, especially to protect air and water quality; creation of a shale gas industry operation organization committed to continuous improvement of best practices; and research and development to improve safety and environmental performance.

Eventually, new laws, rules and regulations were drafted in all three states in which the play is being developed. While developing these new laws, rules and regulations, the states were conscious of the fact that the play is providing a huge economic boost to the area, and is impacting a large, diverse group of individuals with conflicting points of view, and thus is presenting a big challenge to legislators to balance economic benefits with safety and environmental preservation.

In New York, a State DEC report (June 2011) concluded that controversial hydrofracing could be done safely, and the draft supplemental generic environmental impact statement (dSGEIS) was released for public comment.

The draft SGEIS contains 9 chapters, one of which is a geologic summary of the Marcellus and Utica shales. A second chapter deals with natural gas development and high-volume hydraulic fracturing. Twenty six appendices were attached, of which Appendix 10 focused on high volume hydraulic fracturing permit conditions for among other things, site preparation, site maintenance, drilling, stimulation and flowback, and reclamation.

- Closed loop system for floodplains; no reserve pits
- Biocides to be registered with NYS
- All frac chemicals must be identified & submitted to NYS
- Flowback fluids must be contained in steel tanks, no lined pits
- NORM testing of flowback and production fluids prior to removal

In Pennsylvania, a revised set of stray gas regulations was issued in June 2011; the Marcellus Shale Advisory Commission assembled by Governor Tom Corbett issued a sweeping set of 96 recommendations to address environmental, health and safety policies on how best to responsibly develop the play; and the legislature passed new laws that dealt with better casing and cementing programs, that included the following:

- Increases the minimum setback from 200 to 500 feet from a Marcellus gas well to a private water well and 1000 feet from a public water supply
- Gives the PA DEP authority to require water management plans designed to protect the ecological health of water resources
- Provides local communities with additional resources to address local, short-term impacts
- Provides regulatory certainty across municipalities, thus providing a framework to enable the most environmentally and economically responsible means for gas production
- Provides for sharing of best management practices between state regulators and industry to ensure natural gas development in an environmentally responsible manner

In West Virginia, the initial changes were issued in December 2008 (WV Pit Inspection Directive), and March 2009 (WV DEP Guidance Policy on water issues, site construction and fluid disposal that was finalized in January 2010), and continued with the WV Governor's Executive Order (July 2011), that required disclosure of fracturing additives, certification of plans for sites greater than 3 acres, a water management plan for water use greater than 210,000 gal/month, a well site safety plan, adequate public notice for permits within municipalities, and review by DEP of overall regulatory authority over horizontal drilling and hydraulic fracturing. Eventually, a special session called by the Governor reached agreement on a new law regulating the drilling and fracturing of horizontal wells other than coal bed methane (CBM) wells.

The new West Virginia Horizontal Well law applies to any proposed natural gas well (other than CBM) that would employ a horizontal drilling method that:

- will disturb three or more acres of surface land or use more than 210,000 gallons of water in a 30-day period; and
- was not permitted or the subject of an order relating to a permit application filed

The Act requires further study and authorizes potential rulemaking by the West Virginia Department of Environmental Protection (DEP), including:

- a report to the Legislature due by December 31, 2012 on the noise, light, dust, and volatile organic compounds generated by horizontal drilling operations;
- a report due by January 1, 2013 on the safety of pits and impoundments, and need for new regulatory requirements for such structures;
- a study due by July 1, 2013 on the need for rulemaking establishing additional requirements for the control of air pollution from horizontal well sites;
- rules regarding drilling in karst terrain; and
- regulations establishing casing and cementing standards

Some of the major provisions of the new legislation are as follows:

- $10,000 permit application fee for the first horizontal well at a particular location, and $5,000 application fee for each additional well drilled from the same pad;
- a proposed erosion and sediment control plan; well site safety plan; site construction plan; and a detailed water management plan (to include a listing of anticipated and actual additives used in fracturing or stimulating the well);
- detailed surface owner compensation requirements, including a proposed surface use and compensation agreement containing an offer of compensation to be included as a part of the pre-filing notice given to surface owners;
- performance standards applicable to: disposal of drilling cuttings and associated drilling mud; protection of quantity and quality of surface and groundwater systems; advance designation of water withdrawal locations to the DEP; and recordkeeping and reporting for all flowback and produced water;
- prohibiting any well from being drilled within 100' of a perennial stream or other water body (including wetland), or within 300' of a "naturally reproducing trout stream," and prohibiting any well pad within 1000' of a surface or groundwater intake for a public drinking water supply;
- restricting location of wells (prohibited within 250' from any existing drinking water well or developed spring) and well pads (prohibited within 625' of an occupied dwelling or farm building of a size of 2500 square feet or greater), subject to waiver and/or DEP approval of specific plans allowing for closer locations that are sufficiently protective; and
- rebuttable presumption of causation for contamination or loss of a drinking water source located within 1500' of a well pad, subject to certain delineated defenses (including pre-drilling water quality analyses performed by an independent certified laboratory showing that the problem existed prior to drilling), and upon DEP order, mandatory temporary and permanent replacement of water supplies to persons whose use of water for domestic, agricultural, industrial or "other legitimate use" was adversely affected by the gas well operation (unless waived in writing by the owner).

Final statement

Industry has done an adequate job of solving the technical problems that had prevented the Marcellus from becoming an economic play, i.e., by employing horizontal drilling and large hydraulic fracture programs. However, industry has been much less successful in dealing with the fallout from the use of these technologies. A failure to reach out and educate local communities and concerned environmental groups that horizontal drilling and fracturing are not inherently dangerous has led to local protest meetings and cries for more regulatory control. This in turn has led to revised rules and regulations from oil and gas regulatory agencies and bills being passed in New York and Pennsylvania to establish a drilling moratorium and lower the amount of acceptable TDS in treated flow back water.

Thus, the biggest challenge facing those who wish to develop the Marcellus play cannot be solved with geology or engineering – it is a sociological issue. Better public outreach and education programs targeting concerned citizens and lawmakers, coupled with strict adherence to all rules and implementation of best practices at well sites, are necessary to meet this challenge.

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RPSEA EFD Project 08122-35

Program Area: 4.7 National Laboratories Advisors
Lead Institute: Los Alamos Laboratory – Argonne National Laboratory

Prepared for the
Environmentally Friendly Drilling Systems Program
Houston Advanced Research Center

July, 2012

Christopher Harto, Argonne National Laboratory

7/13/12
Date Signed

4.7 Summary & Accomplishments:

Argonne has provided technical, analytical, and outreach support to the Environmentally Friendly Drilling Systems Program. Through participation in monthly conference calls and quarterly workshops Argonne has contributed to the development of the program. Argonne has also supported the EFD Program's mission by increasing public awareness of the role that environmentally friendly technologies and practices can play in reducing the environmental footprint of unconventional gas exploration and development through participation in a number of conferences and webinars. An additional role that Argonne has played has been to provide timely analytical support to EFD as new issues surrounding hydraulic fracturing emerged. An example of this type of support included collaborating with other EFD participants to review and draft an official response to Robert Howarth's controversial paper on fugitive methane emissions from shale gas development.

As a major component of this support effort, Argonne conducted a survey to identify a wide range of technologies, best practices, and active research areas that have the potential to significantly reduce the environmental footprint of oil and gas development. The survey identified a range of commercial or near commercial technologies in the areas of produced water management, well pad construction and drilling operations, and waste reduction and pollution monitoring. It also identified a number of emerging best practices in the areas of life cycle water management and air emissions reductions. Finally it summarized ongoing research efforts likely to result in either new technologies or improved processes that will reduce the environmental footprint of future unconventional natural gas exploration and development activities. This effort has resulted in a final summary report which is currently under review and is expected to be published by Argonne and available on the EFD website soon.

Papers and/or Presentations and other Technology Transfer Efforts:

Robert Horner, "The Evolving Regulatory Landscape of Shale Gas Development," paper to be presented at the Western Energy Policy Research Conference, Boise, ID, August 30-31 2012.

David Murphy and Christopher Harto, "Survey of Existing Environmentally-Friendly Drilling Technologies, Best Practices and Research," Argonne technical report, under review.

Christopher Harto, "Shale Gas- The Energy-Water Nexus," presented as part of the "Hydraulic Fracturing: Fresh Facts & Critical Choices" webinar series organized by the Clean Waters America Alliance and the American Water Resources Association, November 1, 2012

Susan Stuver and Christopher Harto, "Environmentally Friendly Drilling scientific review of Climatic Change Letter: 'Methane and the Greenhouse-Gas Footprint of Natural Gas from Shale Formations,'" http://www.efdsystems.org/Portals/25/EnvironmentallyFriendly%20Drilling%20scientific%20review%20of%20Climatic%20Change%20Letter.pdf

Christopher Harto, "Shale Gas – The Energy-Water Nexus," presented at the 2011 AWRA Spring Specialty Conference, Baltimore, MD, April 18-20 2011.

RPSEA EFD Project 08122-35

Program Area: 5.1 Application for Semi-Arid Ecosystem
Lead: Houston Advanced Research Center

Prepared for the
Environmentally Friendly Drilling Systems Program
Houston Advanced Research Center

July, 2012

7/27/2012
Date Signed

5.1 Application for Semi-Arid Ecosystem

The EFD team met with operators concerning the application of EFD technologies in semi-arid ecosystems. A workshop was held with appropriate representation from the project team and various environmental organizations to develop the environmental cost/benefit methodology. The project team also held workshops to show how Systems Engineering Design Methodology and the EFD Scorecard can be used to identify low impact systems.

The Nature Conservancy invited the EFD System program to perform noise surveys and performance measurement of various drilling and production equipment that is in use at the Texas City Prairie Reserve. The noise survey involved using a hand held GPS, a sound level monitor and a simple measuring device. The EFD team performed the measurements and compared the results to the prairie chicken distribution maps provided by the Nature Conservancy.

RPSEA EFD Project 08122-35

5.2 Texas A&M University

Prepared for the
Environmentally Friendly Drilling Systems Program
Houston Advanced Research Center

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5.2 Abstract

Lease roads and well pads are a highly visible and often less than welcome aspect of O&G drilling and producing operations. In South Texas this is occurring as the Cretaceous Eagle Ford shale is being developed from near the Mexican border outward to the east/northeast across several counties stretching more than 150 miles. The "Brush Country" as it is often referred to, is a semi-arid landscape where measures to lessen the impact of developing the shale are fostering a host of new technologies.

To address environmental concerns about the development of the resource, Texas A&M University is adapting "Disappearing Roads" technology to the particular needs of the Eagle Ford. A collaborative project within the Environmentally Friendly Drilling Program has been testing new types of "disappearing roads" in a desert like environment to measure their effectiveness and ability to lower the surface footprint of surface operations. One road was constructed with materials made with recycled drilling waste, another incorporated reusable composite mats, and a third represented a new type of "roll out road" developed in by a student engineering team from the University of Wyoming as a class project. The field demonstration is expected to:

1) Provide a realistic field trial in representative desert ecosystems so that results could be evaluated efficiently so as to benefit both the industry, the organizations with the technology, and the public sector.

2) Document and provide the results of technology field trials so that promising processes, systems and products could be utilized in a wider range of gas shale plays.

3) Speed the commercial development of technology developed to reduce the environmental footprint of drilling activities,

The removable mat concepts may also be used to lessen the impact of constructing water ponds and to provide temporary enlargement of well pads that can accommodate service equipment used in fracturing operations. This paper will describe the technology behind the roads and document their performance in semi-arid rangeland landscapes.

Introduction Background

While the energy industry is developing better practices to manage its environmental impact1,2,3 its drilling activity faces restrictions, and in some cases complete prohibitions of operations in sensitive areas. Environmental constraints, including laws, regulations, and implementation procedures, can limit natural gas development and production on both federal and private lands. More than 30 environmental policy and regulatory impediments to domestic natural gas production have been identified and documented.4 Surface footprint is one of the more vexing problems that energy developers must face.

Public concerns about the footprint of human activity (ORV tracks and oil and gas operation lease roads) in ecologically sensitive desert locations have resulted in regulatory impediments to E&P activities. At the same time, significant amounts of oil and gas resources remain to be discovered and developed in arid regions of the U.S. This is particularly true of natural gas resources in the Rocky Mountains.

Lease roads are a significant component of the impact of drilling and producing operations. If technologies can be developed to reduce the ecological impact of these roads it may become possible to lessen regulatory impediments to development as well as impact to sensitive arid landscapes. Constructing roads with materials that can be readily removed or using recycled drilling waste as native road construction material could serve both environmental and economic objectives. Actions that eliminate or reduce the impacts can help the nation meet its natural gas demands.

1. Environmentally Friendly Exploration and Production

The Houston Advanced Research Center (HARC), Texas A&M University and TerraPlatforms, L.L.C. along with industry sponsors and stakeholders (NGO's, government agencies, others) operate a program integrating advanced technologies into systems that significantly reduce the impact of petroleum drilling and production in environmentally sensitive areas5,6. The team focuses on technologies for developing unconventional energy sources that can be used in environmentally sensitive areas to maintain our standard of living and preserve our quality of life. The objective is to identify, develop and transfer critical, cost effective, new technologies that can provide policy makers and industry with the ability to develop U.S. domestic reserves in a safe and environmentally acceptable manner.

There are two potential impacts that could result from this research. First, if the research shows that low impact roads can provide the same degree of safety and performance as conventional roads, use of these roads could lead to reduced environmental impact, which in turn could lead to increased resource development. Studies have demonstrated that removing environmental concerns (and thus restrictions) to E&P operations can boost recoverable gas resources (perhaps by trillions of cubic feet). A second impact could result if the low impact roads are also less expensive to construct and maintain. Reduced operating costs could also lead to increased production. Any technology or practice that reduces the cost of operations will increase reserves and increase production. A $1/BOE ($170/MMcf) decrease in operating cost for a producing field can add 1% to its reserves 7.

1. Low Impact Access in Sensitive Ecosystems: How Access Roads Change the Environment

Access roads constructed for E&P operations can have immediate and long-term effects on the surrounding terrain and the life it supports. Pollutants can originate from construction or maintenance activities, vehicle traffic, seasonal road treatments, and spills and leaks related to vehicle operation and chemical transport. Elevated concentrations of heavy metals can extend up to 330 ft. from the highway, and toxic levels may exist only a few feet from the highway (Ministry of Transport, Public Works and Water Management 1994). Erosion can be a significant in some areas and the displacement of soil during road construction can contribute to significant or severe changes in run-off and flow patterns. The simple roads typically associated with oil and gas operations can have both beneficial and detrimental effects on wildlife. Benefits include food, water and shelter provided by roadside ditches, while disadvantages include the removal of vegetation for construction purposes, dangers from traffic and run-off pollution containing minerals, heavy metals, organic compounds, sediments and agricultural chemicals. In relatively arid lands, such as Otero Mesa in New Mexico, the forage and water accumulating by the roadside may have a positive impact on local wildlife populations.

A negative consequence of creating oil and gas lease roads in the desert is the segmentation of the ecosystem8. This "ecological effect of linear development" has been addressed by several environmental organizations. Early studies of O&G development8 indicated that the linear development itself typically does not cause a disturbance response; it‟s the human presence on it that causes problems, therefore the level of use must be assessed and evaluated. Some linear features could be positive and some negative in terms of wildlife impacts: they can provide habitat, serve as conduits for travel or seriously impact wildlife by becoming barriers or sinks that negatively affect wildlife travel and mortality.
These effects are not always negative, but the existence of an access road can invite unwarranted traffic into sensitive areas. The O&G industry‟s ability to remediate its lease roads offer a way to reduce its impact on the environment9. Reducing the environmental footprint imposed by drilling operations will help enlarge support for these operations, given the current attention being paid to energy shortages that can be resolved by encouraging domestic exploration and production. Low impact roads are an important feature of the overall effort to persuade environmentalists, our own O&G industry, and the general public that sensitive lands and waters will not be spoiled in the process.
The Research Partnership to Secure Energy of America (RPSEA) http://www.rpsea.org Unconventional Oil & Gas Development (Environmental Issues) funded a project by Texas A&M University to construct and then perform demonstrations of low impact O&G lease roads designed to reduce the environmental impact of field development in sensitive new desert ecosystems10. A project site in Jeff Davis County TX was chosen for demonstrating how certain types of "removable" or "disappearing" roads could be employed as temporary access to well site locations. Detailed information on the site is at: Low Impact Access Roads Demonstration (Pecos Research Test Center).

The Pecos Desert Test center is located on the edge of the Chihuahua desert, chosen because of it is representative of soils found in the desert southwest. The surface of the desert floor is classified as a Cryptobiotic soil crust, consisting of soil cyanobacteria, lichens and mosses11. These soils play an important ecological role in the arid Southwest where the crusts increase the stability of otherwise easily eroded soils, increase water infiltration in regions that receive little precipitation, and increase fertility in soils often limited in essential nutrients. Cryptobiotic soil crusts are highly susceptible to soil-surface disturbance such as trampling by hooves or feet, or driving of off-road vehicles, especially in soils with low aggregate stability such as areas of sand dunes and sheets in the Southwest, in particular over much of the Colorado Plateau.12 When crusts in sandy areas are broken in dry periods, previously stable areas can become moving sand dunes in a matter of only a few years.

The research project called for three types of lease road systems to be deployed at the site followed by an entire season of weathering and road traffic.

2. Using Recycled Well Site Waste as Base Roads

The O&G industry has had several programs focusing on recycling of tank bottoms and drill cuttings. Sand and heavy hydrocarbon materials removed from tanks and other production facilities are typically nonhazardous.13 Tank bottom hydrocarbons exhibit cohesive properties that support the beneficial reuse of these materials as binders in road paving materials. Tank bottoms mixed with local aggregate yields a product that has minimal environmental impact.

Road mix variability can be high due to the nature of the materials used, but does not severely impact the overall quality of the final product. Process and issues that directly or indirectly impact road mix variability include: free liquid removal, aggregate mining, produced sand characteristics, oil/binder viscosity and mixing operations. Despite the variability of road mix materials and processes, test results show that heavy oil road mix products meet most of the minimum standards for commercial cold mix paving products.

Potential environmental concerns with oilfield road mix are offset when net air and waste management benefits of this process are considered. Air emissions are a potential concern and are related to the level of volatile organic constituents (VOC) in the oil. Offsetting this concern would be:

-Low VOC content in most SJV heavy crude.
-Particulate reduction from paving onsite roads.
-In addition, offsite disposal of tank bottoms yields higher emissions from transport and disposal and fills up valuable landfill space with nonhazardous materials.

The effort to recycle drill cuttings in the U.K. has been well documented by Page et al.14 That work estimated that the UKCS produces between 50,000 to 80,000 tons wet weight of oily drill cuttings annually. With the implementation of new environmental rules, and given current offshore technology, it is no longer possible to discharge cleaned oily cuttings to sea. Increasingly stringent legislation makes it likely that cuttings derived using water-based muds would not be discharged to sea in the future. Although several commercially available treatment processes can remove oil from oil based mud (OBM) cuttings, there are few satisfactory outlets for the residual solid material most of which currently goes to landfill. In light of the legislative changes, increased focus on duty of care, and commercial considerations, viable alternatives were sought for the recycling and reuse of large volumes of material from future drilling programs. This paper described possible options for converting drill cuttings into reusable secondary products and discusses the advantages and disadvantages of each option when considered against the criteria of environmental impact, technical risk, logistics, liability and cost.

In Texas, the Texas Railroad Commission issued the Guidelines for Processing Minor Permits Associated with Statewide Rule 8, or *Guidelines Developed by Environmental Surface Waste Management in Coordination with Field Operations*. That document outlines the specifications for drilling waste materials intended for use in road construction, including limits on total petroleum hydrocarbons (TPH), total organic halides (TOX), and electrical conductivity (EC), as well as analytical standards for the Toxicity Characteristic Leaching Procedure (TCLP) Test for organics, metals and pH. These requirements would govern the development and testing of the proposed low impact roads.

New waste treatment and disposal practices that meet these requirments have been developed to convert drilling muds and associated cuttings to beneficial and environmentally friendly road base material to help minimize E&P operator liability. A variety of techniques and methods are used to treat and dispose these wastes with the materials either land applied, injected or landfilled. Often at a landfill facility, the waste treatment process includes removing the water which decreases the soluble salt content and reducing the oil concentration by recovery or degradation.

Scott Environmental Services Inc. (SESI) (http://www.scottenv.com/aboutus.html) has developed proprietary processes designed to allow the reuse of fresh water, saltwater, and oil based drill cuttings and heavy mud in a variety of applications including road and drill pad construction. SESI also provides environmental advisory services to the oil & gas industry. This roadway portion was built from water-base mud and cuttings taken from a reserve pit in a field in onshore coastal south Texas.

3. Using Composite Mats as Temporary Road and Pad Materials

The Alberta Energy, British Columbia Ministry of Energy and Mines, CAGC, CAODC, CAPP and PSAC support various programs to promote environmental stewardship.15 As early as 2003, the association was citing were citing new technology using suitable access matting to facilitate an extended drilling season and allowing easier access to remote locations, thus allowing companies to move in earlier and stay longer. Canadian companies currently provide replaceable mat technology to facilitate an extended drilling season. Temporary matted roads can be quickly installed and removed as a project dictates. Roadways of this kind are very functional in zones with closely-spaced wells and unstable ground soil conditions yet until recently desert lands have not been seen as a place where removable mats were of utility.

One of the industry sponsors of the A&M Desert Test Site is Newpark Mats & Integrated Services16. This company has deployed 40 rigid composite mats and supporting locking pins for a single-lane road in the desert of West Texas. The mats are eight feet wide, by fourteen feet long, nominally weighting 1040 lbs. This technology replaces hardwood board mats because the plastic composite mat do not rot, and the materials can be reused a number of times.

Mat installations can comprise of a variety of matting layouts, from single-lane access roads to large rectangular drill site arrays, to small pads for equipment staging. The mats are connected together by overlapping lip system and locking pins. The overlapping lips afford effective load transfer from mat to mat. The 16 pin holes around the perimeter of overlapping lips of each mat, provides a variety of joining possibilities, enabling a balance of surface coverage and site stiffness. This provides a load spreading product and by virtue of its structural design can effectively and efficiently dissipate vehicle loads, protecting the underlying sub grade from disturbance and rutting.

The level of site preparation is situation specific. There have been occasions in sensitive areas where the mats has been laid directly on the existing low lying vegetation in the construction of an access road. At the end of the project, they were removed and the vegetation was able to grow back because the existing root structures of the vegetation were not disturbed. This keeps a valuable material resource in productive roles and out of landfills. Research is ongoing to tap postindustrial sources of regrind plastic as a possible raw material.

4. Designing a "Disappearing Road": A Test Program at West Texas Demonstration Facility

In 2008, a student team from the University of Wyoming won Texas A&M‟s Disappearing Roads" competition for scholastic teams across the United States.17 The disappearing road competition is part of the Environmentally Friendly Drilling Program with the objective to develop innovative concepts for reducing the footprint of transporting equipment and materials to drill sites in environmentally sensitive areas. The "Disappearing Road" concept is not limited to a physical road and it encompasses any transportation method that can be used to move the equipment and materials to the drill site with the least disturbance to the environment.

The contest is open to all University Departments with interests in the utilization of natural resources in a sustainable manner.

The winning award from the University of Wyoming was for a test program that requires manufacture of two components, a mat element and the rollout road components. Mats are used for turning areas and for drilling platforms. The rollout road component is used in normal traffic rights of way. The rollout mats are delivered in a compact form, then unrolled directly onto the soil substrate. Each segment consists of 2 - 12 ft. wide by 25 ft. long rolls. The 12 ft. wide section consists of two 6 ft. long 2 x 8 in planks joined at the center with a hinge. For the test program, the hinge consists of two ½ in diameter by 6 in long eyebolts screwed into the end of the plank at 4 in. on center. The eyebolts are placed on both ends of the plank and offset by ¾ in. from the plank centerline. The placement has an opposite on each end of the plank to assure that each plank fits with its counterpart without the eyebolts interfering with each other.

Description of Project – Installation in the West Texas Desert

The three types of low impact O&G lease roads were tested in the field at the Texas A&M University Desert Test Center http://www.pecosrtc.org/ near Pecos Texas on the edge of the Chihuahua desert. The Texas Transportation Institute Pavement and Materials (TTI) manage this site and their personnel assist with the project. (http://tti.tamu.edu/research_areas/topic.htm?p_tid=5). **FIGURE 1 AND 1A** shows an aerial view of the site and the site where road placement was planned.

1. Construction of Spine Road using Recycled Material

This roadway portion was built by Scott Environmental Services, Inc. (SESI) with a starting material taken from a reserve pit and mixed with a plasticity reducing agent (PRA), using a large excavator bucket. The amount of PRA used had been previously determined by laboratory test to be (i) sufficient to make the mixture, unlike the starting material, easily transportable by truck without loss from sloshing; and (ii) not sufficient to cause the mixture to harden into a monolithic structure.

The material was trucked to the site and used as road base for construction of the model lease road. A cross section of the road design is shown in **FIGURE 2**. The design is planned for a multi-season "spine road" that would serve as access to the field and serve as a high use local or rural road. A test section of *in situ* soil approximately 170 feet long x 14 feet wide (**FIGURE 3 AND 3A)** was readied as the test site. Work began by watering, scarifying, and compacting the *in situ* soil using a water truck, grader, compactor, and roller, to form the road subgrade. Then a single lift of PRM and some water was placed on top of the prepared subgrade in sufficient quantity to have 10 inches of thickness after compaction, and the lift of material was smoothed, shaped, and compacted using the water truck, loader, grader, compactor and roller. Next, a pre-determined amount of Portland cement was spread over the prepared PRM by the cement truck, and then the cement and the PRM were mixed with the reclaimer and grader to a depth of 12 inches, then compacted.

Water was then sprayed from the water truck over the mixture in an amount to achieve optimum moisture content, as determined by previous laboratory testing, and the wet mixture was again mixed using the reclaimer. After that, all of the emplaced materials were compacted, then bladed and shaped to get a uniform mixture again, with additional water added as needed.

Construction, as described above, was successfully accomplished in one day, although strength gain in the material continued for several days. **FIGURE 4** shows the strength gain of the material in place. A photograph of the completed road is shown in **FIGURE 5**. The PRM was sampled at several instances during the placement, and a composite sample was formed from these samples and sent for evaluation to a geotechnical testing laboratory, where it was mixed with the percentage of cement used and with an amount of water determined to yield a maximum density mold, then aged for seven days while being maintained moist. After completion of aging, the compressive strength and dielectric properties were obtained by standard tests.

5. Placement of Composite Mats

The composite mats were placed in a mowed area of the new roadway abutting the previously constructed SESI road. A total of 40 mats were delivered to the site, unloaded by a forklift and placed in a sequenced order in the road. **FIGURE 6** shows the mats being installed.**.** A guide line was used to keep the mats in a straight line as they were placed, and then connected with the locking devices **FIGURE 6A**. Once the mats were installed, the guide line was removed and the road was ready for use. Total time to install the mats (not counting unloading from an 18-wheeler) was less than 3 hours for a 250 foot road on an unprepared soil.

6. Placement of Rollout Road Element

Construction of the rollout roads and mats requires the use of synthetic 2x8 in. (full 2 in. by 8 in. not modified to current lumber standards) boards. The original tests used 2x8 in. boards fabricated by Heartland Biocomposites Inc., in Torrington, WY. The boards were recycled plastic with straw and sand filler. The boards displayed excellent “cross grain” strength, suitable for the heavy loads of the “mountain mover” trucks hauling the fracing sand. The flexural strength of the boards were less than oak, therefore a hinge was placed midspan to relieve the flexural stress caused by truck tires.

The units to be installed were delivered in September of 2010 to the test facility near Pecos Texas. The storage of the units was approximately 800 yds from the final installation point at the access road. Installation was accomplished using a three man roustabout crew and forklift and operator. Each unit was moved from storage to final installation point by forklift.

The initial installation was to match the fixed rigid mats to the Newpark road section. Crews moved the first section to the road and cleared the dirt from the edge of the Newpark mat to match the sections. Shown in **FIGURE 7** is the installation against the composite mat section. A second section of rigid road was installed against the first utilizing a tongue and groove type of junction connection. A third section was installed before crews began the flexible section.

Several notes on this installation before beginning lay-down of rigid mats a fixed line of installation needs to be set by survey and line. Without it the potential for drift right or left is significant. An incorrect set of the first mat can cause the road to exit the right of way quickly which will cause problem with the landowner and create the need to tear out and reinstall sections of the road.

At this point the crew began the installation of the flexible mats on the roadbed. The mat were installed and located using both the forklift and the winch truck for proper placing as shown in **FIGURE 8.** The final two rigid mats were installed behind this flexible mat with the tongue and groove connections on the opposite side from the flexible mat. (The rigid section against the flexible section is designed to fit the groove section against the tongue portion.)

Description of Project – Monitoring Performance

1. Durability of Roads

The hybrid lease roads were used for traffic going to and coming from the field office at the Pecos facility. During the latter part of 2009 and the beginning of 2010, traffic levels ranged from 5 to 25 vehicle passages per day. During the summer of 2010, the site operator removed an overpass being used for inbound traffic and for a short time diverted truck and automobiles across the road. In the Fall of 2010, most traffic ceased across the road as a new entrance road was constructed.

FIGURE 9 shows the roads in the Fall of 2010. Use of the road beds did not appear to affect either the recycled cuttings road base or the composite rigid mats. However the roll out road made of composite beams linked by stainless cable had several failed beams in the structure. Failure occurred where the composite planks were placed over undulations in the desert floor. The plank's strength was not enough to withstand truck traffic across the road. The rigid composite cross tie material was stable however as shown in the Figure.

The entire season of Fall, Winter Spring, and Summer caused the composite rigid mats to curl slightly along the edge of the road. No impact was seen at the connector point and it is probably that, had a two mat herringbone pattern had been installed, no curling would have been observed. The composite mats are composed primarily of High Density Polyethylene (HDPE). To provide toughness and durability, a specific high-end grade of HDPE raw material is used to manufacture the mat. To further the life of the plastic, a package of custom additives is compounded with the high-end polymer to guard against process and environmental degradation.

2. Strength of Roads

Road strength was measured by a number of standard tests used in civil engineering. The drilling waste material used for road base material is similar in nature to other types of granular stabilized materials used for highway construction so the materials were measured in the laboratory using (1) Sieve Analysis, (2) Atterberg Limits, (3) Optimum Moisture Curve, and (4) Unconfined Compressive Strength. These are tests commonly used in Texas to characterize roadway base materials and for the latter two tests, completed roads; these tests provide an indication of the expected performance characteristics of the recycled materials. Figure 4 (UCS) shows strength values of the material where the compacted samples were subjected to a 10-day soak in the laboratory.

Tested before and after 1 year in the desert, the road base performed well. A photo of the road base after one year in the desert can be compared with the original photo (**FIGURE 5**) the only difference is the growth of the greasewood.

3. Environmental Impact on Soils

One of the standard requirements of a road base of recycled oil field waste is that there are no hazardous materials leaching from the stabilized rock bed. To affirm that the material was stable, a set of samples was taken at the outset of the year-long test, then again after approximately 13 months. **FIGURE 10** shows the location of the samples taken.

TABLE 1 contains the early and late time data. Very little difference in the concentration of metals was observed – slight differences were judged to be within experimental error.

Conclusions and Recommendations

The road base material made from recycled well material performed well, exceeding expectations in every category. The rigid mats linked by the ½ turn locks also performed well, with no apparent change in structural properties after an extended time in the desert. The roll out road, though novel in concept, will require modifications to its design.

A second phase to this project will be to evaluate the remediation of the road surface beneath the removable mats. Because the road was constructed in the desert, the gradual regrowth of native plants is expected to take an extended time, depending upon weather and rainfall patterns. In climates with higher rainfall and with denser grass cover, remediation should proceed more rapidly.

Now that the "disappearing roads" have proven themselves capable of withstanding a harsh semi-arid climate it is recommended that further field testing be arranged. Work is underway to arrange that the removable mats and the road made from recycled materials be established in an active oil and gas drilling area to evaluate under more rigorous conditions. Remediation of the road bed after removal will be dependent upon appropriate technology being adapted to the desert environment.

Acknowledgements

This project could not have been performed without the support of its sponsors. Thanks is given to the Research Partnership to Secure Energy for America (RPSEA). Sponsor Scott Environmental Services, Inc. Longview Texas supplied and installed the recycled road made from drilling waste. Sponsor Newpark Composite Mats generously provided the rigid mats for the project and supervised their installation. Heartland Biocomposites manufactured the laydown road to the design of the U of Wyoming‟s “Disappearing Roads” contest winning team.
Special thanks are given to Halliburton for their sponsorship of the Disappearing Road competition.
This project is dedicated to our late friend David Moore of the Rio Vista Bluff Ranches in McFaddin Texas, one of our generous sponsors. His imagination and humor have been greatly missed.

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FIGURES AND TABLES

Figure 1 is an aerial view of Pecos Desert Test Center, located approximately 80 miles SW of the Midland Odessa TX airport.

Figure 1a shows the location of the planned test roads. Yuccas and agaves, growing with grasses and often Creosote Bushes, give this desert its characteristic appearance.

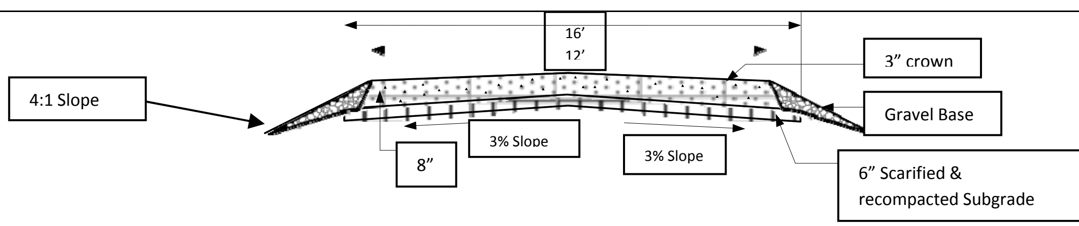

Figure 2 represents a cross section plan for the road, designed to accommodate routine and rural traffic typical of a county road.

Figure 3 represents a site view ready for road construction. The area was cleared with a brush hog, but not graded. The entrance ramp to the test facility is shown in the background.

Figure 3a shows the road material being placed on the prepared base. The entire construction of the road required less than 8 hours.

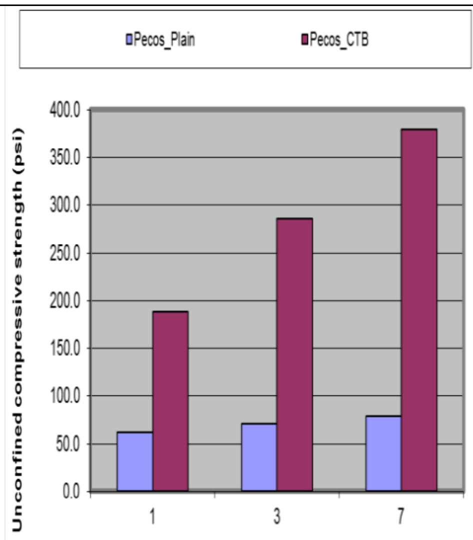

Figure 4 represents a chart of the unconfined compressive strength of the Pecos road material as measured using the standard Tex-120-E Test Method "Soil-Cement Testing" protocol.

Figure 5 shows the completed SESI road. The segment of the road was laid out in such manner as to join the two other types of road and offer an alternate route to the offices to the staff at the test center.

Figure 6 Installing the rigid composite mats requires a forklift and two roustabouts. The rigid mats, because of their flexibility, can be laid directly on unprepared ground.

Figure 6a locking pins attach the composite mats together at the tongue and groove link.

Figure 7 shows the fork lift bringing a hinged mat to place against the composite mats already in place. All mats were placed on unprepared soils.

Figure 8 Placing flexible rollup mats at the intersection of the road test section. The most effective method of installation was found to be lifting the entire section then placing it at the desired location. The section is hinged at the center to allow the section to fit the grounds uneven surface.

Figure 9 The final view of the road route looking East toward the entrance of the Pecos test facility. During the Fall of 2010, traffic was rerouted across the road segment.

Table 1 sampling

Metal concentration, ppb								
Date Samples Taken: July 15, 2009								
Sample ID	**Ba**	**Ag**	**Se**	**As**	**Pb**	**Hg**	**Cr**	**Cd**
Pecos Soil Sample #1	316.1	96.88	34.44	4.283	2.343	-0.344	-47.12	-29.29
Pecos Soil Sample #2	61.63	129.6	31.39	6.085	8.968	-0.285	-58.2	-31.01
Pecos Soil Sample #3	106.1	40	31.61	1.014	7.974	-0.47	-62.93	-31.84
Pecos Soil Sample #4	125.9	61.19	24.22	5.098	11.29	0.178	-65.57	-28.45
Pecos Soil Sample #5	107	11.67	32.18	4.434	5.764	-0.325	-66.87	-40.94
Pecos Soil Sample #6	45.1	31.44	32.98	6.538	8.672	-0.042	-69.63	-32.08
Sample average	126.97	61.80	31.14	4.58	7.50	-0.21	-61.72	-32.27
Date Samples Taken: October 7, 2010								
Sample ID	**Ba**	**Ag**	**Se**	**As**	**Pb**	**Hg**	**Cr**	**Cd**
Pecos Soil Sample #1	310.1	88.88	30.23	4.673	2.711	NDA	NDA	NDA
Pecos Soil Sample #2	60	133	23.99	5.085	8.678	NDA	NDA	NDA
Pecos Soil Sample #3	106.5	44.4	41.22	2.104	8.33	NDA	NDA	NDA
Pecos Soil Sample #4	120.9	53.99	55.68	6.66	9.98	NDA	NDA	NDA
Pecos Soil Sample #5	103.3	13.11	31.11	4.333	5.778	NDA	NDA	NDA
Pecos Soil Sample #6	50.7	55.6	31.88	5.8	8.090.	0.01	NDA	NDA
Sample average	125.25	64.83	35.69	4.78	7.10	0.01		

RPSEA EFD Project 08122-35

Program Area: 5.3 Prototype Small Footprint Drilling Rig
Lead: Tom Williams, Sr. Advisor to EFD Program

Prepared for the
Environmentally Friendly Drilling Systems Program
Houston Advanced Research Center

July, 2012

7-31-12
Date Signed

5.3 Project Objective

Facilitate prototype test of low impact rig

Results

Report "Documenting Advanced Drilling Technology – Low Impact Rigs"
Report and update of a EFD DOE report: Field Testing of Environmentally Friendly Drilling Systems
Presented paper with Huisman on test results at 2011 AADE conference (AADE-11-NTCE-61) *The Impact of Rig Design and Drilling Methods on the Environmental Impact of Drilling Operations*
Facilitated sponsor tours of eco-friendly drilling rigs:

- Huisman LOC 400
- NOV Rapid Rig
- AMC Green Rig

Each EFD presentation or article normally uses an element from this task.

In 2008 EFD issued a report in order to take a snapshot of the current practices, so we could document an evolution of the modern land rig taking place. At that time 36 hour rig up time was considered acceptable with 40 + loads. The rig market was evolving to modular rigs where mid 20's loads and one day moves were being introduced. Rig innovations in rig manufacturing like the H&P Flex Rig became a trend setter; NOV acquired IRI Int. (IDEA Rigs = Rapid Rig); Nabors AC Pace Rigs; while niche players like Huisman and modified CT Drilling rigs like Xtreme were building more of the newer generation rigs where the impact of technology were utilized. Innovations were cost effective because of enabling technologies including Rig Automation, Rotary Steerable tools and Casing While Drilling. These innovations were having a major impact on drilling and environmental performance.

The drivers for innovation included safety, EPA driven regulations impacting rig power and emissions, unique needs associated with unconventional gas plays where drilling in urban areas, the requirements for pad drilling, the need to "get in-get-out" approach was becoming a factor, as were new computer tools to help operators track drilling performance. The need to reduce cost in a low gas market environment, and ROC demands that required companies to get gas to market faster were also (financial) drivers.

The rig manufacturing companies were also influenced by offshore technology being applied on-shore, causing design changes for building efficient modular rigs. Offshore drilling innovations which allow companies to drill and produce multiple wells on a single pad have profoundly influenced on-shore drilling and environmental improvements.

Arctic drilling challenges (particularly exploration and production) on the North Slope also impacted rig design. Environmental and logistical challenges have driven improvements to developing more efficient rigs, horizontal and extended reach drilling, smaller drilling pads, seismic acquisition on monitoring, drilling and completion fluids, coiled tubing drilling, and ways to improve access for faster and more efficient drilling and well testing.

The features for modular rigs common today include minimized rig-up/down time, closed loop drilling systems, compact wellsite footprint, smaller crew size all allowing the drilling operation to become safer and more efficient. The modular designs also include lower transport cost, fast, efficient pipe handling, fewer loads, and AC driven to minimize hydraulics. Innovative skid design improvements have been made for pad drilling and faster turnaround times. Added benefits include the reduced size of work crew, improved safety performance, reduced environmental performance in emissions, roads, discharges, and land impacts. Statistics show that pipe and material handling cause almost 50% of the recorded accidents during well drilling.

The fully automated pipe handling, with its automated drill floor, eliminates the need for personnel on the drill floor and thus eliminates the potential for accidents. In addition, the simple modular rig-assembly process – with smaller loads, less rig crew involvement and improved overview and visibility – effectively mitigates the risk for the crew and the potential for accidents and damage during rig moves.

Another innovation is the use of multi task rigs; simultaneous operations are common place offshore and while they have been around for several years and there are a number of patents to improve the drilling process one of the more novel concepts is a recent new rig design by National Oilwell Varco. The NOV SPRED rig changes the traditional rig design and uses a modular platform similar to their Rapid Rig but will allow the drilling and completion process to be carried out in a continued process. This rig is designed for small footprint pad or batch drilling and incorporates the innovations in the smaller modular rigs combined to carry out the process in parallel operations.

The EFD research has shown us the public demands reduced traffic, dust, noise, emissions, excessive lights that disturb nearby residences. These demands are impacting operator decisions on rigs and drilling contractors are starting to fill that demand.

As design has changed – so have fuel options. The North American natural gas industry is in search of an environmental and economic solution to address significant fuel use. Because natural gas has potential for widespread applications, it is critical that early adopters within the industry help trigger greater use. EFD reported on these innovations in promoting distributing relevant articles (American Oil and Gas Reporter 2011, David Hill, Encana).

The AADE Paper: **The Impact of Rig Design and Drilling Methods on the Environmental Impact of Drilling Operations, by** Eric Quinlan, Robert van Kuilenburg (Huisman) Tom Williams, Gerhard Thonhauser (EFD systems) highlighted the changing drilling landscape brought on by the requirement to drill an enormous amount of wells and are often located in urban or environmentally sensitive locations. The findings of that study are included in the remainder of this report.

The Environmentally Drilling Systems (EFD) has been promoting environmentally friendly drilling for years and has developed the EFD Low Impact Drilling Scorecard which can be used to measure the trade-offs associated with implementing low impact drilling technology in environmentally sensitive areas.

This study and AADE paper documented the analysis in which the impact that an individual drilling rig can make through its design and operations. The importance of the environmental performance of drilling rigs will grow to be an important decision factor for choosing rigs or even allowing a well program to be executed. EFD is helping to promote what some operators are doing by making rig contract decisions based on overall performance and value vs. day rates. Safety performance, smaller footprint, drilling and transport (rig-up rig down) times are becoming factors in rig awards. Traditionally drilling contractors have not concerned with the amount or type of fuel used, or with of other consumables used, since it was paid for by the operator; but this is changing.

This task shows how, with careful design, the impact of a drilling rig can be minimized. And that a rig designed to minimize the environmental impact can be very efficient even outpacing conventional rigs.

The EFD project has reported on a number of new rig designs, including:

Huisman, which started the design of the LOC 250 drilling rig in 2003. After two years of drilling in South Texas the lessons learned were incorporated in the next generation, the LOC400. The LOC series of rigs are characterised by being fully containerised, and by being highly automated and built to include modern drilling techniques. The LOC 400 series are also completely electrically driven, electronically controlled, fully integrated and can be scaled in size by adding more containers. It is designed for fast rig moves, and is able to compete globally with local rigs.

Figure 1, LOC 400 Drilling on location in the Netherlands 2010

Environmental impact can be measured in different ways including air, water, soil, social, and sight pollutions. Various studies have been performed on the LOC 250 & 400 to assess noise, emissions to air, and the effects of the rig design on these forms of pollution.

Emissions

For the LOC series of rigs, air pollution through emissions was investigated by assessing three different activities:

- Construction of the drilling rig;
- Transportation of the drilling rig, and;
- Operation of the drilling rig in different cases
    - Drilling normally
    - Drilling with casing
    - Using the power grid as opposed to diesel driven gen-sets.

The environmental performance of the drilling rigs is assessed in terms of emissions to air (CO2, NOx, CO, PM and SO2).

Emissions of operations while drilling traditionally with drill pipe (DP mode) and operations while drilling with casing (CWD mode) mode are assessed. For other drilling rigs on the market, for basis of comparison, we only included DP mode as the LOC was designed specifically for Casing While Drilling and does not require extra tools for this form of drilling. (Note: while CWD is a feature, it is also designed to drill efficiently with drill pipe as well.)

The standard drilling installation is represented by a 'standard low' and 'standard high' case. Emissions were defined related to construction, transportation and drilling for a typical one year drilling program consisting of drilling fifteen wells at various locations and the transport of the rig between these locations.

Construction

The type of steel used in a drilling rig is low-alloyed steel. Based on the expert information on standard drilling rigs it is estimated that these rigs to be 1.5 – 1.75 times heavier than the LOC 400. Table 1 presents the resulting emission values.

Emissions	Unit	LOC 400	Standard (low)	Standard (high)
CO_2	t/rig	1,027	1,540	1,797
NO_x	t/rig	3.0	4.5	5.2
CO	t/rig	17.3	25.9	30.2
PM	t/rig	2.0	3.0	3.5
SO_2	t/rig	2.7	4.0	4.6

Table 1 – Emissions (in t/rig) for the LOC400 and standard drilling rigs.

It is evident that due to the smaller weight of the LOC design the construction emissions are considerably lower.

Transport

During its lifetime, a drilling rig is transported frequently. Drilling rigs can be used anywhere around the world, but in practice they are mostly used regionally. Besides the regional transportation between the drilling locations, the drilling rig is first transported from the factory where it is manufactured to the continent or region where it is going to be used. This can include intercontinental transport. For a standard basis of comparison, the manufacturing of the LOC 400 and the other drilling rigs documented in the study reported in the AADE paper were located in Europe.

The modular design has several advantages:

- small individual units, enabling transport in limited areas (cities, back roads)
- lower weight per unit, less damage to environment, less cost for transport
- containerised design, enabling efficient transport modes (container ship and train), less cost for transport

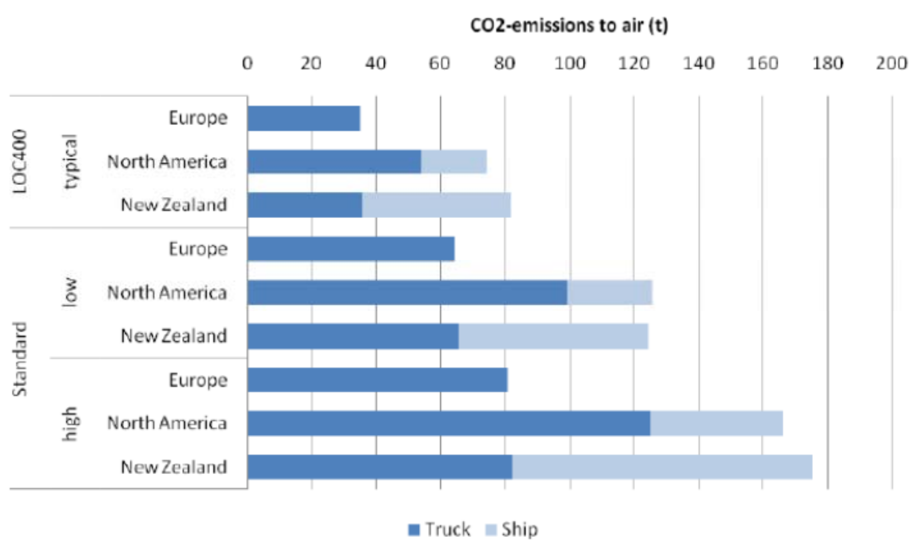

Figure 2. CO2 emissions (in kg) from initial transport from Europe & North America.

The distances for transportation over land are based on the typical transportation cycles that have been constructed for two different continents based on practical experience. When needed the cycles are extended to represent the drilling of fifteen wells at fifteen different locations. For calculation of the emissions the average (unweighted) distance was used.

The results for transportation over land show that emissions from truck transport of the LOC 400 was significantly less compared to emissions of standard drilling rigs. For basis of comparison, the LOC 400 was compared with other 350t – 400t drilling rigs operating in the USA and Europe and based on expert advice of people who have worked with these rigs. The results do not reflect a comparison with each individual rig on the market.

Transporting the standard rig 'high' case causes the emissions of more than two times as much CO2 as the LOC 400. Compared to a diesel passenger car travelling 25,000 miles per year, the CO2 emissions from transporting the LOC 400 by truck is the same as about 8.9 diesel passenger cars. Train transport might be considered for the LOC 400 as an interesting option. In principle one train would be sufficient to transport the entire rig. Transporting the rig with a train has a significant beneficial effect on the CO2 emissions (figure 4).

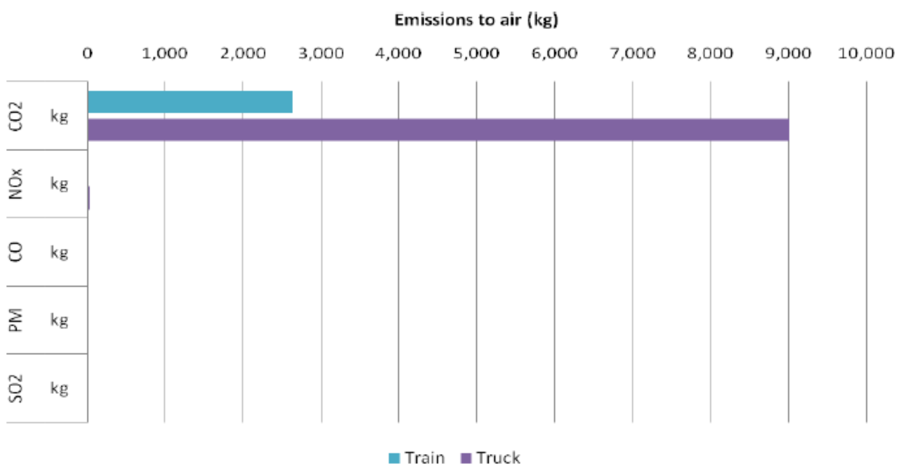

Figure 4. Emissions of transporting the LOC400 by truck and train (in kg)

Drilling Emissions

The third source of emissions results from drilling operations. Power is used for the various activities that make up the drilling cycle. A standard drilling cycle consists of many activities, including:

- Standby
- Drilling
- Tripping
- (Back)reaming
- Casing running
- Cementing

Drilling and (back) reaming are the most power intensive activities of the drilling phase, followed by tripping and casing running. In this analysis the drilling time for standard drilling mode (DP) is set to three weeks (500 hours) for both LOC 400 rigs and standard rigs.

The LOC 400 is built with an Autodriller function that does lead to improved drilling performance. However, due to lack of offset data for the wells drilled and due to lack of data from other similar rigs, it was decided to treat drilling performance as the same between all rigs for this study. It is obvious though, that the reducing the time spent on the well will also reduce the emissions released while drilling.

Operating in CWD drilling mode involves a number of changes compared to DP drilling mode:

1. total drilling time is reduced by an assumed 30%;
2. the relative importance of activities in total drilling time changes (tripping time reduces from 26% to 10%), and;
3. the mud pumps can run at 50% of their capacity instead of 80%.

The time required on the well is 350 hours in CWD mode compared to 500 hours for drilling in DP. For this study, we have assumed the mud pumps are operated at 50% of their load instead of 80% in DP mode. The power demand and time for each drilling activity is presented in table 2.

Activity	Power demand DP drilling (in kW)	Time needed on DP drilling (%)	Power demand CWD (in kW)	Time needed on CWD (%)
Drilling	1839	32%	1359	35%
Tripping	948	26%	948	10%
(Back)reaming	2187	1%	1707	4%
Cementing	173	5%	173	8%
Casing running	904	8%	904	11%
Stand-by	173	28%	173	32%
Total		**100% (500 hrs)**		**100% (350 hrs)**

Table 2. Power demand (in % of maximum power demand) and time per activity

If we look at a period of a year a significant beneficial effect can be seen (figure 5) if CWD technology is used.

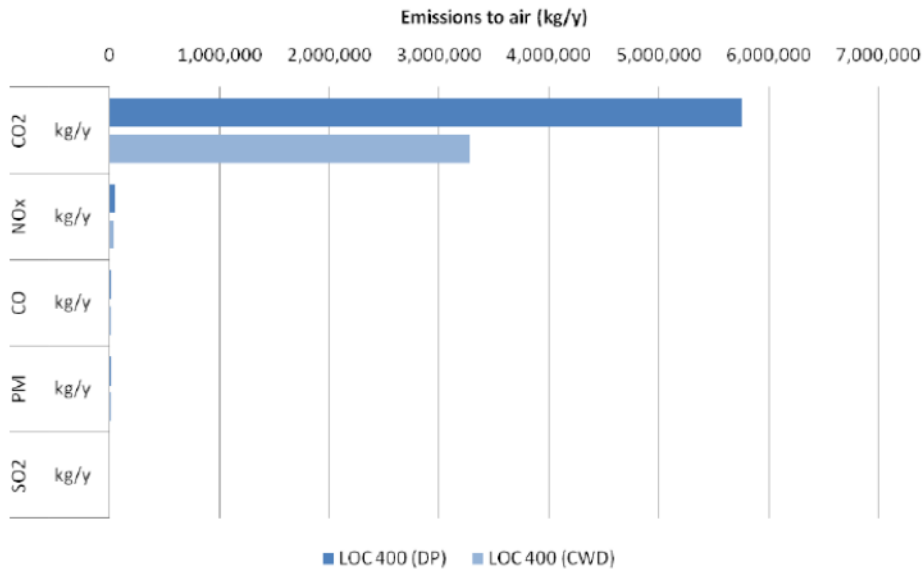

Figure 5. Emissions from drilling operations (in kg/y)

Figure 6 shows that the LOC 400 operating in CWD represents lowest CO2 emissions of 3.4 kt CO2 per year, followed by the LOC 400 DP drilling mode (5.8 kt CO2. The CO2 emissions for standard drilling rigs 'high' are almost twice the emissions of the LOC 400 in CWD mode. The figure shows that drilling operations have the highest contribution to CO2 emissions, typically about 96 to 98 per cent. CO2 emissions resulting from the construction process contribute typically between 1 and 2 per cent. The contribution of transport to total CO2 emissions is between 1 and 2 per cent as well.

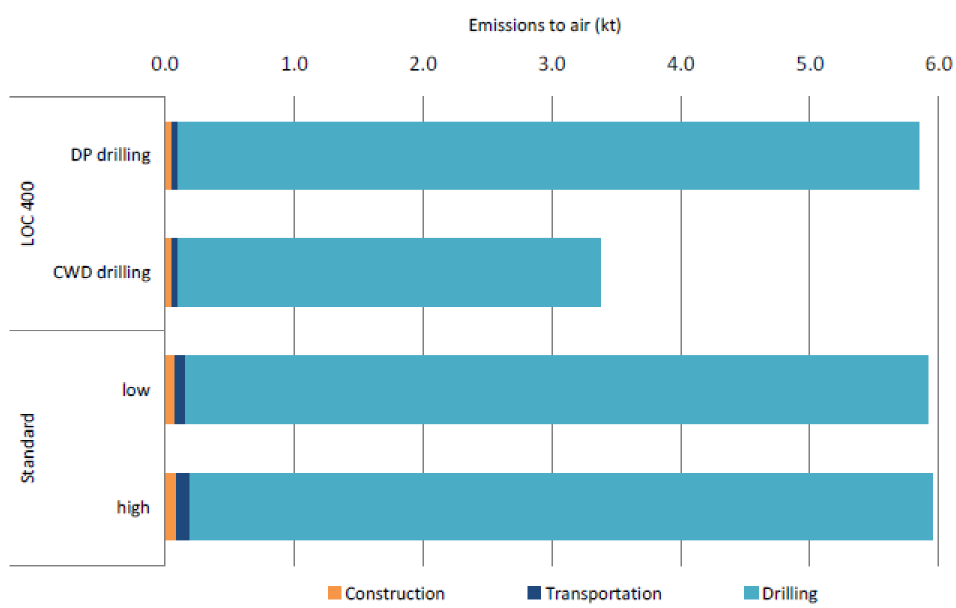

Figure 6. CO2 emissions of a one year drilling program, generator powered (in kt/y)

Energy from the existing power grid

As alternative for diesel generators the electricity grid can be used to power the drilling rigs. This will not always be possible as grid connections are not available on all locations. It should also be noted that drilling rigs require high power capacities, which should be arranged beforehand with power suppliers and local utilities. To connect the drilling rig to the grid, a transformer is needed. The advantage of connecting the drilling rig to the grid is that the emission factor of the electricity mix is mostly lower than of dedicated diesel generators. This is especially the case for countries that have a significant part of renewable energy in their energy mix. Based on the information on drilling activities, the electricity demand for drilling one well is about 500 MWh in the DP mode and about 285 MWh in the CWD mode. Note that this varies for each individual well and drilling rig type. The LOC 400 is designed for easy conversion to work from the grid, and it can be powered by both 480V 60Hz and 400V 50Hz sources. In order to further benefit working from the power grid, it is important to keep the Total Harmonic Distortion to a minimum in order to minimize potential problems to the grid.

Using electricity from the grid results in around 39% less CO2 emissions compared to using diesel generators in the Netherlands. CO2 emissions decrease from 5,751 tonnes to 3,521 tonnes of CO2 for DP drilling and from 3,275 tons to 2,018 tons of CO2 for CWD drilling in the Netherlands. Should the grid be powered by renewable energy sources (wind, geothermal, solar), the emissions would be reduce to next to zero.

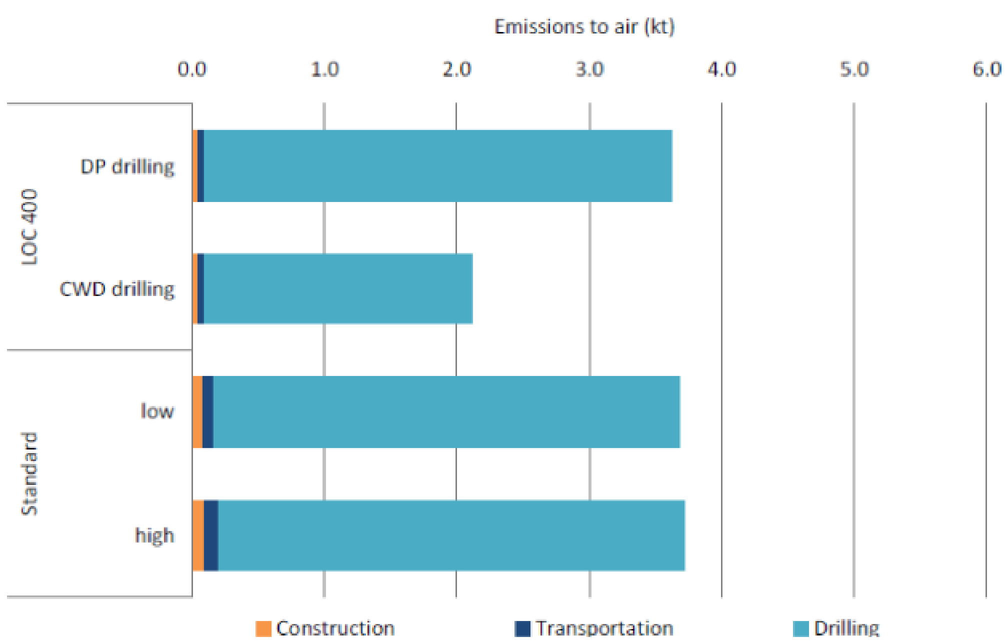

Figure 7. CO2 emissions of a one year drilling programme, grid powered (in kt/y)

Connecting the rig to the power grid also has a significant cost benefit for a typical well.

Cost savings for a typical well can go up to 50% or more on fuel cost with the current energy price mix (table 3).

	DP			CWD			Fuel	DP	CWD
	[-]	[hrs]	[kWh]	[-]	[hrs]	[kWh]	[gal/kWh]	[gal]	[gal]
75%	33%	165	82500				0.069	5731	0
50%				39%	137	55185	0.073	0	4017
25%	34%	170	85000	21%	0.74	29715	0.086	7344	2567
10%	33%	165	82500	40%	1.4	56600	0.095	7838	5377
		kWh	**250000**		kWH	**141500**			
This equates to a 10day drilling program							TOTAL	**20913**	**11962**

		[usd/gal]	[usd]	[usd]
DIESEL	**US**	3.6	75,285	43,063
	EU	7	146,388	83,733
		[cent/kWh]	[usd]	[usd]
ELECTRICITY	**US**	15	37,500	21,225
	EU	24	60,000	33,960
Delta - Diesel/Elec	**US**		50%	49%
	EU		41%	41%
Max Difference (CWD/ELECTRIC)	US			**28%**
	EU			**23%**

Table 3. Cost savings for a typical well (USD)

Noise Pollution

A result of the new shift to unconventional energy sources (Shale oil, Shale gas, Geothermal sources) has resulted in more wells being drilled in built up areas. A result of drilling close to houses is that the local populations do not allow for noisy drilling operations. This has resulted in some areas in rigs requiring to be completely built in (Los Angeles), or requiring temporary sound proofing.

For two geothermal wells drilled in the centre of the Hague (the Netherlands), intensive noise studies have been done to evaluate the potential impact of the drilling rig (figure 8). Due to the LOC 400's design, most major noise producers are at ground level, including the drawworks. A notable exception being the top drive. To further reduce noise levels, the rig drilled from the local power grid instead of gen-sets.

Figure 8. Well location in the Hague – Large building on the left is a hospital

Noise studies were completed; measurements were taken and extrapolated to the distance of housing from the worksite. Noise levels had to be kept under 50 dB within the houses 35m away. These noise studies were completed while working from the gen-sets on wells in the centre and in the north of the Netherlands (table 4). 50dBa is the noise equivalent to a quiet street, in comparison 60dB is a normal conversation.

The results have led to the rig requiring minimal sound proofing to deflect the noise caused by the top drive cooling fan. The slim design of the mast has enabled minimal sound proofing to be built and easily installed on the rig.

1	RIG UP AND TEAR DOWN	43,1	L Aeq, dB(A)
2	DRILL ACTUAL	46,2	L Aeq, dB(A)
3	REAMING	45,3	L Aeq, dB(A)
4	CORING	-	L Aeq, dB(A)
5	CONDITIONING MUD & CIRCULATE	44,7	L Aeq, dB(A)
6	TRIPS	44,9	L Aeq, dB(A)
7	LUBRICATE RIG	-	L Aeq, dB(A)
8	REPAIR RIG	43,6	L Aeq, dB(A)
9	CUT OFF DRILLING LINE	-	L Aeq, dB(A)
10	DEVIATION SURVEY	-	L Aeq, dB(A)
11	WIRE LINE LOGS	45,2	L Aeq, dB(A)
12	RUN CASING & CEMENT	46,0	L Aeq, dB(A)
13	WAIT ON CEMENT	44,3	L Aeq, dB(A)
14	NIPPLE UP B.O.P.	44,7	L Aeq, dB(A)
15	TEST B.O.P.	43,8	L Aeq, dB(A)
16	DRILL STEM TEST	-	L Aeq, dB(A)
17	PLUG BACK	-	L Aeq, dB(A)
18	SQEEZE TEST	-	L Aeq, dB(A)
19	FISHING	-	L Aeq, dB(A)
20	DIR. WORK	-	L Aeq, dB(A)
21		43,1	L Aeq, dB(A)
22		44,5	L Aeq, dB(A)
23		43,9	L Aeq, dB(A)

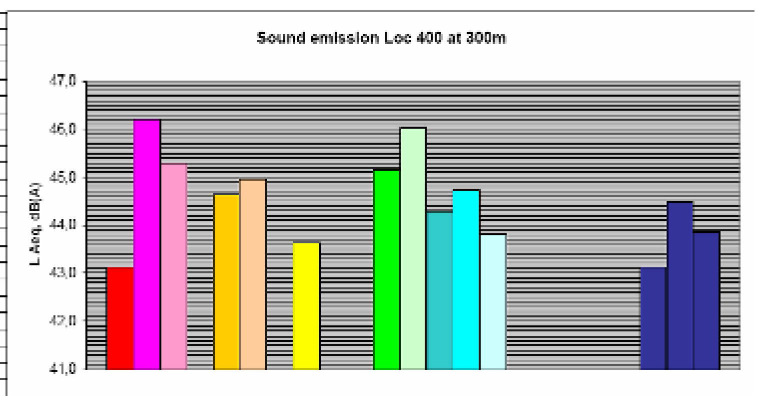

Table 4. Noise profile of the LOC 400 drilling rig at 300m

Site impact

The LOC 400 was designed for a minimal location size. Minimizing the location size also minimizes the impact to local ecologies around the drill site. The containerized design also allows for adapting the layout of the rig to its location, and for standard truck transportation. This leads to smaller access roads on top of minimizing the location size.

The LOC 400 footprint is approximately300 feet by 600 feet, but can be adapted to specific constraints caused by geography, housing, etc.

Conclusion

It can be expected that the importance of the environmental performance of drilling rigs will grow to be an important decision factor for choosing rigs or even allowing a well programme to be executed. Through careful design, the environmental impact of a drilling rig can be minimised while still maintaining high drilling performance.

Through the design of a drilling rig, the following environmental improvements can be achieved compared to the use of more traditional equipment:

- Lower carbon foot print through
  - Containerization
  - Quick rig moves
  - Less time on well (improved drilling performance)
  - Casing drilling
- Noise mitigated through:
  - Main noise producers at ground level
  - Ability to work from main power grid
  - Sound wall around site and on mast and top drive
  - Horizontal setback of drill pipe
- Rig built to work from grid, which can be run from renewable resources

RPSEA EFD Project 08122-35

5.4NOx Air Emissions Studies

Prepared for the
Environmentally Friendly Drilling Systems Program
Houston Advanced Research Center

July, 2012

7/27/2012

Date Signed

5.4 Guidelines Concerning the Application of Selective Catalytic Reduction (SCR) Technologies for Drilling and Production Applications - Guidelines to Reduce NOx Emissions

Nitrogen oxides (NO_x) are formed when nitrogen (N_2) and oxygen (O_2) are combined at high temperatures and pressure during the combustion of fuel. All fuels, such as gasoline, diesel, biodiesel, propane, coal, and ethanol, emit NO_x when burned. The EPA estimates that 49% of NO_x emissions come from on-road and off-road vehicles, 27% from power generation (electric utilities) and the remaining 24% from industrial, commercial and residential sources. Due to the many compounds that are a part of NO_x (predominantly nitrogen dioxide and nitric oxide), the pollutant contributes to a wide variety of health and environmental problems. NO_x is also a main component of ground-level ozone and contributes to global warming. Since the passage of the Clean Air Act in 1970, all primary air pollutants have decreased - except NO_x, which has increased by 10%. Due to its serious health and environmental impact, the reduction of NO_x in our atmosphere has now become a major focus in the fight against air pollution.

Exposure to diesel PM may result in both cancer and non-cancer health effects. Non-cancer health effects from one or more of these compounds may include irritation to the eyes and lungs, allergic reactions in the lungs, asthma exacerbation, blood toxicity, immune system dysfunction, and developmental disorders.

In 2004 the EPA introduced stringent air emission standards for on-road vehicles. Any pre-existing vehicle is not required to comply with these newer standards. Diesel vehicles from older model years will have higher non-methane hydrocarbon and particulate matter emissions.

Typically, diesel retrofit involves the addition of an emission control device to remove emissions from the engine exhaust. Retrofits can be very effective at reducing emissions, eliminating up to 90 percent of pollutants in some cases. Some examples of emission control devices used for diesel retrofit include diesel oxidation catalysts, diesel particulate filters, NO_x catalysts, selective catalytic reduction, and exhaust gas recirculation. Devices to control crankcase emissions also exist.

Significant improvement in diesel emission levels, in both light- and heavy-duty engines, was achieved in the 1970 - 2000 period. PM, NO_x, and HC emissions were cut by one order of magnitude. Most of that progress was achieved by emission-conscious engine design, such as through changes in the combustion chamber design, improved fuel systems, implementation of low temperature charge air cooling, and special attention to lube oil consumption.

However, more progress was still required, as the NO_x and PM emissions from diesels remained higher than those from Spark Ignited (SI) engines. A new series of diesel emission regulations was developed with implementation dates around 2005-2010, which require the introduction of exhaust gas aftertreatment technologies in diesel engines, as well as fuel quality changes and additional engine improvements.

Technology	Emission Impact	Significance
Engine Design Technologies		
Fuel Injection System	~90% PM reduction, ~75% NOx reduction, large reductions in HC/CO emissions achieved in the 1980-1990 timeframe	Combination of these engine design techniques was the major source of diesel emission reduction through the end of 1990s; Potential for further emission reductions in the future
Charge Air System		
Combustion Chamber		
Electronic Control		
Exhaust Gas Recirculation	30-50%+ NOx reduction	Light duty vehicles; Major heavy-duty engine applications from 2002 (USA)
Fuel, Oil & Additive Technologies		
Fuel & Lube Oil	Only limited direct emission impact in modern engines	Sulfur content remains the critical property due to its effect on catalytic aftertreatment technologies
Alternative Diesel Fuels	Variable, depending on fuel and emission	Short term: emission-driven niche markets; Long term: critical importance due to depletion of petroleum reserves
Fuel Additives	Small emission effect with modern engines and quality diesel fuels	Possible use to assist particulate filter regeneration
Water Addition	1% NOx reduction for every 1% added water	Niche markets: marine and stationary engines; centrally fueled fleets (emulsions)
Exhaust Gas Aftertreatment		

Technology	Emission Impact	Significance
Diesel Oxidation Catalyst	High reduction of HC/CO emissions; PM conversion depends on fuel sulfur, usually limited to maximum 20-30%	Widely used on Euro 2/3 cars and on 1994 and later heavy-duty urban bus engines in the U.S.; Will remain a component of future emission control systems
NOx Adsorber Catalysts	~90% NOx reduction potential	Potential future technology for light duty engines worldwide and for heavy-duty engines in the U.S. (2007/2010)
Urea SCR Catalysts	~90% NOx reduction	Future technology for Euro 5 heavy-duty diesel engines; Currently used in stationary engines and other niche markets
Diesel Particulate Filters	70-90%+ PM emission reduction	Expected widespread use for (heavier) Euro 4 cars and heavy duty US2007 engines; Currently used in retrofit programs and voluntary diesel car applications.
Lean NOx Catalysts	NOx reduction potential of ~10-20% in passive systems, up to 50% in active systems	Uncertain; NOx reduction potential insufficient for long-term regulatory objectives
Plasma Assisted Catalysts	NOx reduction potential up to ~50%	Uncertain; NOx reduction potential insufficient for long-term regulatory objectives.

Available Diesel Retrofit Technologies

Technology	Emissions Reductions			Fuel Requirements	Additional Information
	HC	PM	NOx		
Diesel Oxidation Catalyst (DOC)	50-90%	25-50%	--	500 ppm sulfur	DOC's have an established record in the highway sector and are gaining in nonroad applications. Sulfur in fuel can impede the effectiveness of DOCs; therefore, the devices require fuels with low sulfur levels. Can be combined with other technologies for additional PM and or NOx reductions.
Diesel Particulate Filter (DPF)	50-95%	>85%	--	CB-DPF – ULSD; active, non-CB-DPF – 500 ppm	DPF's use either passive or active regeneration systems to oxidize the PM in the filters. Passive filters require higher operating temperature to work properly. Filters require maintenance. Can be combined with NOx retrofit technologies.
Flow-through Filter (FTF)	50-95%	30->60%	--	500 ppm sulfur	Filtration efficiency is lower than DPF, but is much less likely to plug under unfavorable conditions, such as high engine-out PM emissions and low exhaust temperatures.

Technology	Emissions Reductions			Fuel Requirements	Additional Information
	HC	PM	NOx		
Lean NOx Catalyst (LNC) with a DPF	--	>85%	5-30%	ULSD	Verified LNCs are always paired with a DPF or a DOC.
Selective Catalytic Reduction (SCR)	80%	20-30%	80%	500 ppm sulfur	Common in stationary applications. Require periodic refilling of an ammonia or urea tank. Often used with a DOC or DPF to reduce PM emissions.
Exhaust Gas Recirculation (EGR) with a DPF	--	>85%	40-50%	ULSD	Both low-pressure and high-pressure EGR systems exist, but low-pressure EGR is used for retrofit applications because it does no require engine modifications. The feasibility of low-pressure EGR is more of an issue with nonroad equipment than on-road equipment.
Closed Crankcase Ventilation (CCV)	--	5-10%	--	500 ppm	Usually paired with a DOC or DPF.

The array of emission control methods provides the designer with building blocks which need to be chosen and combined into the emission control system, which in turn is integrated with the engine to achieve a given emission target. A system approach is necessary to develop the clean emission diesel engine. There is no miraculous “plug-in” device available which could be installed on a particular engine and effectively clean emissions. An effective emission control strategy has to combine elements of engine design with the use of appropriate fuels and exhaust aftertreatment methods.

Selective catalytic reduction (SCR) of NO_x by nitrogen compounds, such as *ammonia* or *urea*—commonly referred to as simply “SCR”—has been developed for and well proven in large-scale industrial stationary applications. The SCR technology was first applied in thermal power plants in Japan in the late 1970s, followed by widespread application in Europe since the mid-1980s. In the USA, SCR systems were introduced for gas turbines in the 1990s, with increasing potential for NO_x control from coal-fired power plants. In addition to coal-fired cogeneration plants and gas turbines, SCR applications also include plant and refinery heaters and boilers in the chemical processing industry, furnaces, coke ovens, as well as municipal waste plants and incinerators. The list of fuels used in these applications includes industrial gases, natural gas, crude oil, light or heavy oil, and pulverized coal.[1]

SCR is the only proven catalyst technology capable of reducing diesel NO_x emissions to levels required by a number of future emission standards. Urea-SCR has been selected by a number of manufacturers as the technology of choice for meeting the Euro V (2008) and the JP 2005 NO_x limits—both equal to 2 g/kWh—for heavy-duty truck and bus engines. First commercial diesel truck applications were launched in 2004 by Nissan Diesel in Japan and by DaimlerChrysler in Europe.

SCR systems are also being developed in the USA in the context of the 2010 NO_x limit of 0.2 g/bhp-hr for heavy-duty engines, as well as the Tier 2 NO_x standards for light-duty vehicles.

The technologies and strategies being developed for the 2007/2010 heavy-duty highway diesel engine and Tier 4 nonroad diesel engine standards may be applicable stationary diesel engines provided adequate lead-time is given. The issue is to match the right technologies to the right applications. Reduction of emissions is influenced by the duty cycle of the engine.

[1] Cobb, D., et al., 1991. "Application of Selective Catalytic Reduction (SCR) Technology for NOx Reduction From Refinery Combustion Sources", Environmental Progress, 10, pg. 49.

RPSEA EFD Project 08122-35

Program Area: 5.5 Reduced Fracturing Footprints
Lead: CSI – Tom Williams, Advisor

Prepared for the
Environmentally Friendly Drilling Systems Program
Houston Advanced Research Center

July, 2012

____________________________ 7-31-12

Date Signed

Thomas E Williams

5.5 Reduced Fracturing Footprints

One of the deliverables in this task was to identify technologies that will reduce the overall environmental impact of fracturing wells. EFD identified a number of novel technologies that accomplish this goal and has included these in reports, presentations, sponsor briefings; industry efforts to promote environmentally sound practices which can be found in the EFD website, a variety of industry publications, the EnergyInDepth and in the Best Management Practices website.

The industry is now more aware and is applying methods to reduce the environmental impact which includes area and site specific methods; this can include portable onsite treatment, the use of pad systems where the water transported by temporary pipelines to a central area reducing truck traffic, reduce the pad size and associated environmental impacts; and the use of novel fluids and procedures.

Summary & Accomplishments:

The EFD project team has become a resource for the industry, regulators and environmental organizations on water and fracturing issues. This wok has justified the planned related activities in the Technology Integration Program.

EFD identified a 2010 RPSEA project from the Small Producer Program entitled, "Creating Fractures Past Damage More Effectively with Less Environmental Damage." This project successfully demonstrated viability of a novel fracturing treatment (NFT) by synthesizing suitable polymers for a range of temperature applications, confirming their performance in the lab, and developing well selection criteria for NFT application. EFD worked with the contractors CSI Technologies, DaniMer Scientific and Texas A&M in this effort. This technology has a much broader application than the RPSEA small producers program. EFD has worked with CSI on this project and has transferred this concept to industry for application. In July 2012 RPSEA chose to fund an additional effort to demonstrate a well stimulation process to increase production and/or ultimate hydrocarbon recovery from a reservoir in an environmentally friendly manner. The novel fracture technology (NFT) concept identified uses degradable biopolymers loaded with proppant in place of traditional cross-linked fracture fluids. The NFT leaves a residue-free fluid of environmentally benign materials that eliminates permeability loss, delivers optimum proppant pack, and require significantly less energy and fluid volume than conventional treatments.

The environmental advantages of this process include the small footprint required in the completion process, reduced traffic, emissions, noise, and personnel. This will also have a positive impact to reduce the environment impacts for recompletions and remedial treatments.

Papers and/or Presentations and other Technology Transfer Efforts:

The EFD website and the Intermountain Oil and Gas BMP site provides stakeholders with information on successful methods to reduce the footprint of fracturing footprints. The PTTC has published numerous references to the EFD program and in particular to this task.

Specific references include:

SPE 152189 Ecofriendly Creation of Propped Hydraulic Fractures, Presented at the SPE Hydraulic Fracturing Technology Conference in the Woodlands 2/6-8/2012. BY CSI, Danimer and Cook.

The EFD program supported two TAMU Undergraduates Fernandez and Gunter who published a White paper that is on the EFD website: Hydraulic Fracturing: Environmentally Friendly Practices. The summary and recommendations from that report include:

Several potential environmental issues can be associated with hydraulic fracturing, including air emissions from truck traffic, high water usage, the use of dangerous chemicals in fracturing fluid, and the impact on nature from the size of pad sites. Several new technologies and good management practices that are considered environmentally friendly are also economically efficient and plausible.

Closed-loop drilling and fracturing should be used for decreasing water usage, truck traffic and mileage, and to decrease the probability of spills of chemical fluids into surface and/or groundwater.

With the hazardous chemicals used in hydraulic fracturing, it is imperative that the industry, environmental groups and regulators work together to find more environmentally friendly chemicals to use.

Pad drilling should be used to decrease the amount of surface area taken by pad sites, which would decrease the impact on the nature around it and the overall landscape of the region.

Centralized fracturing should be used to decrease the truck traffic that comes through locations by fracturing several wells from a single, remote pad location.

Successful environmentally friendly operations often use combinations of good management practices.

Later Rigzone published an article on 9/6/11 on this study. This paper documents some of the successful practices. This paper points out that a practice that is used in combination with pad drilling is centralized fracturing. The concept is very similar to pad drilling, in that a recurring process is completed several times from a central location. This practice reduces the amount of truck traffic that comes through sites because the entire process is completed from one location. It can also be used in combination with pad drilling and/or closed-loop fracturing systems to significantly reduce the use of fresh water and further decrease the volume of truck traffic.

Centralized fracturing uses frac pumps located on remote, central pads that can pump frac water to remote sites. Lines are run from the pumps at the central pad to each individual well site. The pumps allow for pumping the frac fluids thousands of feet away from the central pad (“Optimizing” 2011). In some locations, it has even been recorded as fracturing up to 140 wells, even wells up to 3 miles away from the central location. Similar to other good management practices, centralized fracturing also reduces the time spent per well preparing for production

Encana completed a centralized location for water used for fracturing and treatment, saving cost and lowering Environmental impact. The Environmental Assessment of this project to the Bureau of Land Management is an excellent paper on the system's plan.

The EFD team has identified GasFrac as a technology using LPG fracturing which has demonstrated significant benefit in well performance and a reduction in environmental impact relative to conventional well fracturing. Papers include JCPT, December 2007, Volume 47, No. 12, "Liquid Petroleum Gas Fracturing Fluids for Unconventional Gas Reservoirs; SPE 124480; SPE 144093; SPE 111063.

References:

We concur with a recent report on fracturing by David Pursell, Managing Director - Head of Macro Research, Tudor, Pickering, Holt & Co. Securities Inc.

1. *Hydraulic fracturing – or" fracing" - is unlikely to be banned.* Given the scientific evidence available today and the economic impact of shutting down shale gas drilling, we don't see an outright ban sticking federally, nor in New York or Pennsylvania, and certainly not in the energy patches of the Gulf Coast and the West.

2. *The threat of new federal oversight is more serious in the wake of the BP oil-spill* disaster. If you think no one will connect deepwater oil to onshore shale, think again. Both the oil spill and recent gas-drilling accidents spotlight the inherently difficult nature of the oil and gas business and tarnished industry credibility.

3. *Whether or not the feds take charge, compliance and environmental costs will increase.* The added tab per well, without federal regulation, could reach $200,000 to $500,000, on top of current costs per well between $2.5 million and $10 million. If Congress does mandate EPA oversight of fracing, the industry predicts further costs of $125,000 to $250,000 per well. We think costs could be less than that, given changes companies are making voluntarily.

4. *An EPA study on fracing is just getting underway and could slow down the legislative train.* The agency aims to finish the study in 2012. We think it could take longer, up to 2013. The EPA study may end up as a positive for producers, by buying time to achieve wider adoption of drilling best practices.

5. *The EPA study will most likely identify risks to public health from sloppy drilling practices.* We expect the agency to call for better well design and materials-handling. States are already stiffening their standards in an effort to head off federal action.

6. *While the EPA study continues, opposition to fracing and gas drilling will escalate, not die down.* Attacking natural gas has become a key strategic goal of many environmental organizations. Among a

variety of reasons wide scale adoption of newly abundant, cheap natural gas throws off a mass embrace of renewable energy for a generation.

7. *The national conversation about fracing will continue to be loaded with disingenuous arguments– from both sides*. Environmentalists use the term “fracing” for alleged sins not directly tied to the completion technique. They are claiming there is no oversight for drilling that states, in fact, do regulate. They claim there is no information about the content of frac fluids, when much of it is disclosed to regulators. The industry is guilty of lack of rigor too. It repeats the mantra that “not a single case” has tied hydraulic fracturing to drinking water contamination. Maybe true, but spills, well blowouts and inadequate treatment of flowback water--none of it fracing per se--have caused trouble for some communities and impacted some water supplies.

8. *Over time, the conversation will shift from a hard-to-prove allegation*—that fracing fluids can migrate from deep underground to contaminate shallow aquifers—to a broader, more addressable set of objections.

The EFD efforts are also referenced in a number of publications. An example is from Eli Gruber, Ecologix Company who published an article “Re-thinking technologies for safer fracing” in the Oil and Gas Financial Journal, Volume 9 article 6: where the article stated:

With water treatment predicted to increase nine-fold to $9 billion by 2020, the advancement of innovative and groundbreaking technologies will expand to meet the industry's need. Lux Research recently revealed a few key companies that are working to revolutionize fracing through innovative water treatment processes:

As companies set out to revolutionize the industry with new water treatment solutions, we've observed that the most cost-effective treatment systems must be based on a mobile platform.

Mobile wastewater treatment systems allow for drilling companies to operate off the grid, which is a valuable time- and money-saving strategy. Mobile just makes a lot of sense in an industry where jobsites are constantly moving.

Another solution is on the brink of revolutionizing the industry. The Houston Advanced Research Center (HARC) and Petris Technology of Houston will be teaming together to commercialize a geographic information system (GIS) that will help predict—and prevent—ecological harm from drilling operations.

The system will enable the formulation of land-use benchmarks to assist in the optimal placement of wells, roads, gathering lines, and other necessary infrastructure. OGFJ

Work being done by EFD is supported by a paper: Estimating Frac Risk and Improving Frac Performance in Unconventional Gas and Oil Wells. George E. King, Apache Corporation, 8 November 2011; Society of Petroleum Engineers SPE 152596 at the Hydraulic Fracturing Conference in The Woodlands, TX. 6-8 February 2012. The author stated that: Transparency requires cooperation from all sides in the debate. To enable more transparency on the oil and gas side, both to assist in the understanding of oil and gas activities and to set a foundation for rational discussion of fracturing risks, a detailed explanation of well development activities is offered in this paper, from well construction to production, written at a level of general public understanding, along with an initial estimation of frac risk and alternatives to reduce the risk, documented by literature and case histories. King referenced several of the EFD studies and papers by Burnett and others in this paper.

RPSEA EFD Project 08122-35

Program Area: 5.6 Measuring Effectiveness of EFD
Lead: Sam Houston State University – Houston Advanced Research Center

Prepared for the
Environmentally Friendly Drilling Systems Program
Houston Advanced Research Center

July, 2012

7-11-12
Date Signed

5.6 Collaborative Effort Between Sam Houston State University and Texas A&M University: Measuring Effectiveness

With support from the EFD project, our team conducted a series of studies aimed at measuring the effectiveness of an Environmentally Friendly Drilling program. Focus groups, interviews, and household surveys were used to collect data in multiple study sites around the United States where energy development is – or is quickly becoming – an integral part of the local society. These sites included communities within Texas, Utah, New York, and Pennsylvania. While the results from these studies pertaining to public perception and social impacts are detailed in the papers listed below (and were shared in the presentations), we will highlight two of the more pertinent findings/recommendations:

First, in each study, the findings revealed that over 8 in 10 individuals believed that natural gas operators must adopt and use more environmentally friendly drilling practices. And, the data from one of the Texas studies revealed that an overwhelming majority of citizens are in favor of eliminating or relaxing governmental regulations that limit oil and natural gas development exploration and production in environmentally sensitive settings as the energy industry adopts and uses a more environmentally friendly approach to development. The reality is that an increasing number of industry operators are currently striving to satisfy energy demands while safeguarding the natural environment. Operators are producing hydrocarbons using an environmentally friendly approach to energy development, which includes advances in areas such as: rig technology, drilling technology, waste management, low-impact access and transport, and pollution control. However, the findings from our studies suggest that the environmentally friendly drilling practices used by operators are not fully recognized or understood by the public. In short, the energy industry must do a better job of educating the public about its low-impact technologies. Concomitantly, though, industry must recognize that it alone will not change public (mis)perceptions. Oil and natural gas producers and service companies must partner and work with government and regulatory agencies if they are to correct misconceptions and gain the public’s trust. The Environmentally Friendly Drilling Systems Program is a prime example of this effort.

Second, based on our studies, we propose that energy operators must make a more concerted effort to communicate openly with the public and enhance involvement at the community level. Local residents need to be informed about local energy developments. Open communication, including full disclosure about the potentially positive aspects and negative consequences of energy development, is likely to reduce the chances of rumors and inaccuracies about current activities and proposed developments. Moreover, finding ways to work with and give back to communities will contribute to the connection between local residents and the energy industry and, in turn, may decrease community dissatisfaction and increase support of industry operations. Such efforts will surely mean investments in time and money. Failure to do so, however, may prove to be even more time-consuming and costly.

Papers and/or Presentations and other Technology Transfer Efforts:

Peer-Reviewed Articles

Theodori, Gene L. 2012. “Public Perception of the Natural Gas Industry: Data from Two Barnett Shale Counties.” *Energy Sources, Part B: Economics, Planning and Policy* 7:275-281.

Theodori, Gene L., Mona E. Avalos, David B. Burnett, and John A. Veil. 2011. "Public Perception of Desalinated Water from Oil and Gas Field Operations: A Replication" *Journal of Rural Social Sciences* 26(1):92-106.

Theodori, Gene L. 2009. "Paradoxical Perceptions of Problems Associated with Unconventional Natural Gas Development." *Southern Rural Sociology* 24(3):97-117.

Theodori, Gene L., Brooklynn J. Wynveen, William E. Fox, and David B. Burnett. 2009. "Public Perception of Desalinated Water from Oil and Gas Field Operations: Data from Texas." *Society and Natural Resources* 22(7):674-685.

Anderson, Brooklynn J. and Gene L. Theodori. 2009. "Local Leaders' Perceptions of Energy Development in the Barnett Shale." *Southern Rural Sociology* 24(1):113-129.

Proceedings

Haut, Richard C., David Burnett, Tom Williams, Gene Theodori. 2010. "Balancing Environmental Tradeoffs Associated with Low Impact Drilling Systems to Produce Unconventional Natural Gas Resources," CSUG/SPE 137430. *Proceedings of the Canadian Unconventional Resources & International Petroleum Conference*. Richardson, TX: SPE.

Theodori, Gene L. and Douglas Jackson-Smith. 2010. "Public Perception of the Oil and Gas Industry: The Good, the Bad, and the Ugly," SPE 134253. *Proceedings of the 2010 Society of Petroleum Engineers Annual Technical Conference and Exhibition*. Richardson, TX: SPE.

Other Research Publications

Theodori, Gene L. 2011. "Introduction: Special Issue on Social Issues Associated with Unconventional Natural Gas Development." *Journal of Rural Social Sciences* 26(1):1-7.

Gentry, Brian, Douglas Jackson-Smith, Lorien Belton, and Gene Theodori. 2011. *Assessing Opportunities and Barriers to Reducing the Environmental Footprint of Natural Gas Development in Utah's Uintah Basin*. Logan, UT: Institute for Social Science Research on Natural Resources, Utah State University.

Gentry, Brian, Douglas Jackson-Smith, Lorien Belton, and Gene Theodori. 2011. *Assessing Opportunities and Barriers to Reducing the Environmental Footprint of Natural Gas Development in Utah's Uintah Basin: Executive Summary*. Logan, UT: Institute for Social Science Research on Natural Resources, Utah State University.

Theodori, Gene L. 2009. "The Paradox of Public Opinion on the Energy Industry." *Energy Report* (June 18):20-21.

Haut, Richard C., David Burnett, Tom Williams, and Gene Theodori. 2009. "By Adopting Low-Impact Technologies, Industry Can Change Perceptions, Open Off-Limits Acreage." *Drilling Contractor* (March/April):90, 92-93.

Paper Presentations at Professional Meetings

Theodori, Gene L., Cheryl L. Hudec, and Colter Ellis. 2012 (June 18). "Assessing Opposition and Support for Energy Development in Environmentally Sensitive Areas." Paper presented at the 18th International Symposium on Society and Resource Management. Edmonton, Alberta, Canada.

McGuckin, Michelle L., Robinson Schariah, Gene L. Theodori, and Cheryl L. Hudec. 2012 (February 5). "A Big Fracing Mess: An Examination of Public Perception of Hydraulic Fracturing." Paper presented at the annual meeting of the Southern Rural Sociological Association. Birmingham, AL.

Theodori, Gene L., David B. Burnett, Cheryl L. Hudec, B.R. Brocato, and William E. Fox. 2011 (June 6). "Produced Water Management and Disposal: Toward Beneficial Reuse Practices." Paper presented at the 17th International Symposium on Society and Resource Management. Madison, WI.

Hudec, Cheryl L. and Gene L. Theodori. 2011 (June 6). "Examining the Effects of Unconventional Natural Gas Development on Community Attachment, Satisfaction, and Action: Data from the Barnett Shale." Paper presented at the 17th International Symposium on Society and Resource Management. Madison, WI.

Williams, Thomas E., Rich Haut, David Burnett, Greg Anderson, and Gene Theodori. 2011 (May 12). "Creating a Company's Environmental Culture to Improve Performance in the Energy Industry." Paper presented at the 2011 International Association of Drilling Contractors Environmental Conference and Exhibition. Port of Spain, Trinidad.

Kinchy, Abby, Gene Theodori, and Leanne Avery. 2011 (May 11). "Public Perceptions of Marcellus Shale Knowledge Gaps: Preliminary Findings and New Questions." Paper presented at the Marcellus Shale Multi-State Academic Research Conference. Altoona, PA.

Haut, Richard C., Tom Williams, Gene Theodori, and Jim Slutz. 2011 (April 11). "Balancing Environmental, Societal and Energy Production Issues." Paper presented at 2011 Australian Petroleum Production and Exploration Association Conference and Exhibition. Perth, Australia.

Theodori, Gene L., Abby J. Kinchy, and Leanne M. Avery. 2011 (February 6). "This is All New to Us: Rural Residents' Views on Gas Drilling and Water Resources in an Emerging Energy Hotspot." Paper presented at the annual meeting of the Southern Rural Sociological Association. Corpus Christi, TX.

Haut, Richard C., Tom Williams, David Burnett, and Gene Theodori. 2010 (October 21). "Balancing Environmental Tradeoffs Associated with Low Impact Drilling Systems to Produce Unconventional Natural Gas Resources." Paper presented at the Canadian Unconventional Resources & International Petroleum Conference. Calgary, Alberta, Canada.

Haut, Richard C., Tom Williams, David Burnett, and Gene Theodori. 2010 (October 11). "Balancing Environmental Tradeoffs, Societal Issues and Energy Production." Paper presented at 2010 Gulf Coast Association of Geological Societies meeting. San Antonio, TX.

Theodori, Gene L. and Douglas Jackson-Smith. 2010 (September 22). "Public Perception of the Oil and Gas Industry: The Good, the Bad, and the Ugly." Paper presented at the 2010 Society of Petroleum Engineers Annual Technical Conference and Exhibition. Florence, Italy.

Theodori, Gene L. 2010 (August 14). "Deep in the Heart of Texas' Barnett Shale: Perceived and Objective Community-Level Impacts of Unconventional Natural Gas Development." Paper presented at the 73rd Annual Meeting of the Rural Sociological Society. Atlanta, GA.

Theodori, Gene L., Douglas Jackson-Smith, Lorien Belton, and John Allen. 2010 (June 7). "Opportunities and Barriers to Environmentally-Friendly Energy Exploration and Production Practices in the Uinta Basin." Paper presented at the 16th International Symposium on Society and Resource Management. Corpus Christi, TX.

Smith, D. Clayton, Jessica Aldridge, Jin Young Choi, and Gene L. Theodori. 2010 (June 7). **"**Exploring Texans' Conceptualization and Adoption of Hard, Soft, and Conservation Energy Paths as Ways to End America's Dependence on Foreign Oil." Paper presented at the 16th International Symposium on Society and Resource Management. Corpus Christi, TX.

Theodori, Gene L., Jin Young Choi, Jessica Aldridge, and D. Clayton Smith. 2010 (February 7). "Energy Development, Natural Environments and Quality of Life: The Good, the Bad, and the Ugly as Perceived by Texans." Paper presented at the annual meeting of the Southern Rural Sociological Association. Orlando, FL.

Theodori, Gene L. 2009 (November). "Public Opinion on Exploration and Production of Oil and Natural Gas in Environmentally Sensitive Areas." Paper presented at the 16th International Petroleum & BioFuels Environmental Conference. Houston, TX.

Theodori, Gene L., Nicole Miller, Gerard T. Kyle, and William E. Fox. 2009 (July). "Exploration and Production of Oil and Natural Gas in Environmentally Sensitive Areas: Views from the Public." Paper presented at the 15th International Symposium on Society and Resource Management. Vienna, Austria.

Invited Research-Based Presentations

Theodori, Gene L. 2012 (April 27). "Public Reaction to Shale Gas Development." Presentation delivered at the Center for Research Excellence in Science and Technology—Research on Environmental Sustainability in Semi-Arid Coastal Areas (CREST-RESSACA) Environmental and Energy Sustainability Conference. Houston, TX.

Theodori, Gene L. 2012 (April 25). "Assessing Opposition and Support for Shale Gas Development." Presentation delivered at the Society of Petroleum Engineers' Reducing Environmental Impact of Unconventional Resource Development Applied Technology Workshop. San Antonio, TX.

Theodori, Gene L. 2012 (April 10). "Water Management in Oil & Gas Unconventional Developments: A Sociological Perspective." Plenary presentation delivered at the 2012 American Association of Drilling Engineers Fluids Technical Conference and Exhibition. Houston, TX.

Theodori, Gene L. 2011 (August 9). "Case Study: Findings for the Public's Willingness to Adopt Purification of Oil & Gas Wastewaters." Presentation delivered at the 7th Annual Practical Short Course on Water Desalination, Process and Wastewater Issues & Technologies. College Station, TX.

Theodori, Gene L. 2011 (May 18). "Public Perception of Oil & Gas Industry." Presentation delivered at the East Texas Energy Expo. Center, TX.

Theodori, Gene L. 2011 (January 27). "Sociology of Urban Drilling." Presentation delivered at the International Association of Drilling Contractors Oil and Gas Shale Drilling Technology Workshop. Houston, TX.

Theodori, Gene L. 2010 (October 22). "Natural Gas Development and Social Well-Being." Presentation delivered at the Pennsylvania State University, Department of Agricultural Economics and Rural Sociology, M.E. John Lecture Series. University Park, PA.

Theodori, Gene L. 2010 (August 10). "Findings for the Publics' Willingness to Adopt Desalination (Purification) of Oilfield Brine." Presentation delivered at the 6th Annual Practical Short Course on Water Desalination, Process and Wastewater Issues & Technologies. College Station, TX.

Theodori, Gene L. 2010 (March 3). "Natural Resources, Energy Development and Policy: Technological and Sociological Considerations." Presentation delivered at Center for Environmental Research, Education, and Outreach, Washington State University. Pullman, WA.

Theodori, Gene L. 2009 (August). "Findings for the Publics' Willingness to Adopt Desalination (Purification) of Oilfield Brine." Presentation delivered at the 5th Annual Practical Short Course on Water Desalination, Process and Wastewater Issues & Technologies. College Station, TX.

Theodori, Gene L. 2009 (June). "Public Opinion Research on Urban Gas Drillers." Presentation delivered at the Shale Energy Symposium. Fort Worth, TX.

Theodori, Gene L. 2009 (April). "Public Perception of Shale Plays." Presentation delivered at the 4th Annual Developing Unconventional Gas Conference. Fort Worth, TX.

Environmentally Friendly Drilling Systems Program Research-Based Presentations

Theodori, Gene L. 2012 (June 12). "Public Perception Studies." Presentation delivered at the Environmentally Friendly Drilling Systems Program – Current Phase Milestone Review Conference. The Woodlands, TX.

Theodori, Gene L. 2012 (May 17). "Marcellus Development in New York and Social Well-Being." Presentation delivered at the Environmentally Friendly Drilling Systems Program – Best Management Practices for Utica and Marcellus Development Workshop. Morgantown, WV.

Theodori, Gene L. 2011 (November 10). "Public Reaction to Gas Shale Development." Presentation delivered at the Environmentally Friendly Drilling Systems Workshop – Managing the Eagle Ford Development. Kingsville, TX.

Theodori, Gene L. 2011 (July 26). "Public Perception and Reaction to Shale Gas Development: Data from the Barnett and Marcellus." Presentation delivered at Environmentally Friendly Drilling Systems – Lowering the Environmental Footprint of Marcellus Shale Development. Morgantown, WV.

Gentry, Brian, Douglas Jackson-Smith, Lorien Belton, and Gene Theodori. 2011 (May 26). "Opportunities and Barriers to Reducing the Environmental Footprint of Gas Development in the Uintah Basin." Presentation delivered at Environmentally Friendly Drilling Systems Program – Best Management Practices: What? How? And Why? Workshop. Boulder, CO.

Theodori, Gene L. 2011 (March 15). "Public Perception and Reaction to Shale Gas Development." Presentation delivered at the Environmentally Friendly Drilling Systems – Managing the Eagle Ford Development Workshop. San Antonio, TX.

Jackson-Smith, Douglas, Lorien Belton, Brian Gentry, and Gene Theodori. 2010 (October 14). "Assessing Opportunities and Barriers to Reducing the Environmental Footprint of Oil and Gas Development in Utah." Presentation delivered at the Environmentally Friendly Drilling Systems – Opportunities and Obstacles to Reducing the Environmental Footprint of Natural Gas Development in the Uintah Basin Workshop. Vernal, UT.

Theodori, Gene L. 2010 (August 24). "Natural Gas Development and Social Well-Being." Presentation delivered at the Environmentally Friendly Drilling Systems Program – Managing Marcellus Play Development in Sensitive Areas, PTTC-EFD Workshop. Pittsburgh, PA.

Jackson-Smith, Douglas, John Allen, and Gene Theodori. 2010 (January 6). "Opportunities and Constraints for Environmentally Friendly Drilling (EFD) Systems in the Uintah Basin." Presentation delivered at the Uintah Basin Oil and Gas Collaborative Group meeting. Vernal, UT.

Assessing Opportunities and Barriers to Reducing the Environmental Footprint of Natural Gas Development in Utah's Uintah Basin

Brian Gentry[1], Douglas Jackson-Smith[1], Lorien Belton[1], and Gene Theodori[2]

Utah State University
Institute for Social Science Research on Natural Resource (ISSRNR)
Research Report

April 2011

**Institute for Social Science Research on Natural Resources **
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EXECUTIVE SUMMARY

Introduction

Development of natural gas resources in the United States has increased dramatically over the past two decades, a boom driven by favorable prices, new technological developments, and growing interest in domestic sources of energy with a smaller carbon footprint than coal or oil. Most of the expansion in U.S. natural gas production has been from so-called 'unconventional' reserves in which extensive natural gas resources trapped in continuous sandstone and shale formations can now be extracted using modern directional drilling and hydraulic fracturing technologies. The Uintah Basin in northeastern Utah has been one of several areas in the U.S. where major tight sands and shale gas plays have been the focus of recent natural gas exploration and development.

While unconventional natural gas is likely to be a major contributor to America's energy future (NRC 2009), development of this new resource has not been without controversy. Local and national critics have expressed concerns about possible environmental impacts associated with the relatively dense surface disturbance footprint associated with unconventional natural gas development. Reports of ground and surface water contamination, air pollution, and wildlife impacts have attracted the attention of state and federal regulatory agencies. Access to many unconventional natural gas reserves that are located in/around environmentally sensitive areas likely will depend on the industry's ability to successfully lessen environmental impacts.

In response to local and national pressure, a growing number of industry and academic leaders have made efforts to develop technical options and managerial strategies designed to reduce the environmental footprint of unconventional gas exploration and production. The Environmentally Friendly Drilling (EFD) program, managed by the Houston Advanced Research Center (HARC), is one such example. The EFD program was initiated in 2005; its stated objective is to identify, develop and transfer critical, cost effective new technologies that can provide policy makers and industry with the ability to develop U.S. domestic reserves in a safe and environmentally friendly manner. Presently, the EFD partnership includes 11 universities, 5 national research laboratories, and numerous industry sponsors.

While new options exist, many U.S. producers face a number of challenges and barriers that may impede the adoption and diffusion of these new technologies. In 2009, the EFD program approached researchers at Utah State University and Sam Houston State University to conduct an exploratory study of the opportunities and barriers to the expanded use of EFD practices among natural gas industry actors in the Uintah Basin in Utah.

Our team worked in the Uintah Basin to accomplish four main research goals:

- Better understand local viewpoints on the main environmental issues, concerns, and challenges associated with natural gas development in the Uintah Basin,
- Discover what steps have been, or are being, taken by industry actors in the Basin to reduce their environmental footprint,
- Determine the drivers of and barriers to the expanded use of more environmentally-friendly practices by private industry, and
- Investigate the role, both positive and negative, played by various regulatory agencies at the local, state, and federal levels in shaping the use of these types of practices by private industry.

Methods

Our research relied on semi-structured interviews with key individuals from local, state, and federal government agencies, as well as key private sector actors in different sectors of the local energy industry. In addition, we gathered data from public records, previous studies, and other secondary sources to provide historical background on the evolution of the energy industry in this region and to provide context for the information we obtained from interviewees.

Our interviewees were purposefully selected from a master list of various stakeholders involved with energy development in the Uintah Basin. This list included county administrators, state and federal regulatory agency employees, and representatives from a diverse range of private and public groups and agencies. Key informants were selected to provide a diverse array of topical and organizational experience in the Basin. A total of 26 key informant interviews, each lasting about 75 minutes, were conducted during the spring and fall 2010.

Results of key informant interviews were summarized in written narrative reports and then analyzed using standard qualitative analysis techniques. The analysis focused on identifying related themes of response for each of the major research topics. These themes were used to organize the results presented in this report.

Our findings are not meant to reflect the views of a statistically representative sample of natural gas energy development stakeholders in Utah. However, they provide insight into of the common issues, priorities, and concerns of the diverse public and private parties working on natural gas energy development in this region. Moreover, the results paint a robust picture of the major drivers and barriers that have shaped the past and present use of technologies and management practices designed to minimize the environmental footprint of natural gas development.

Primary Findings

Our key informants identified a number of environmentally-oriented innovations currently being used by the energy industry in the Uintah Basin, helped explain the drivers behind decisions to use these innovations, and elaborated some of the barriers that impede the more widespread use of technologies and practices designed to reduce the environmental footprint of energy industry activities.

Examples of Current Environmental Innovation

- A number of companies working in the Basin have taken steps to **reduce their surface impact** by implementing interim and post-drilling reclamation and – when feasible – drilling multiple wells from a single pad. Other examples include adjusting pad locations or the timing of drilling activities to **protect endangered plants and other wildlife**.

- Similarly, our informants identified a number of **water quality** innovations used in the Basin, including the use of centralized piping facilities, reusing and recycling water, and protecting aquifers during drilling through the use of steel and cement casings.

- While less common, we heard reports of companies using innovations specifically designed to improve **air quality**. These include using higher tier engines, reducing release of hydrocarbon and volatile organic compounds (VOCs) from well pad machinery or pipelines, and taking steps to reduce dust particles in the air associated with surface disturbances or trucking.

Drivers of Change

Respondents identified several drivers associated with decisions by industry actors to utilize some innovative new technologies to reduce their environmental footprint. Examples of drivers of environmental innovation generally fell into 7 categories:

- The requirements of state and federal **regulatory agencies** are a major factor inducing the use of Best Management Practices (BMPs) and other innovations to reduce the environmental footprint of natural gas development in the Basin.

- Advancements in **engineering and technology** were mentioned as critical to enabling industry to address environmental concerns in a technically and economically viable manner.

- Although new environmentally-oriented practices were often perceived to add to the cost of exploration and production, respondents indicated that periods of **higher energy commodity prices** were important to facilitate the ability of industry to try new innovations. In addition, although adopting new practices may at first appear to be cost-prohibitive, upon implementation, many ended up saving money over traditional methods

- Energy companies appear to be sensitive to the importance of **marketing and public relations**, and were willing to use environmentally-oriented practices as a means to improve their public image.

- **A desire to avoid legal battles** (particularly related to the NEPA process for federal agency decisions) may prompt the industry to anticipate and adopt new and innovative techniques or technologies.

- Some industry actors appear to be motivated by a sincere **sense of responsibility to local communities**, and adopt environmental practices in part to limit negative impacts on local residents.

- Many respondents attributed the energy industry efforts to reduce their environmental footprint to **changes in corporate culture** toward a more environmentally-oriented ethic as younger managers enter the leadership ranks, a trend that reflects similar changes in American society at large.

Barriers to Change

In addition to highlighting the ‘drivers’ behind the adoption of new practices, our key informants were asked to identify barriers that prevented the expanded use of innovative technologies to reduce the environmental footprint of natural gas industry activities in the region. Responses were collapsed into three categories.

- **Economic barriers** were common reasons given for not implementing some new technologies or drilling practices.

- A number of respondents indicated that the current **state of technology** was inadequate due to the **geological formations** in the Basin.

- One challenge facing companies interested in using some new environmentally friendly technologies and practices in the Basin is the **complex mix of regulatory agencies** that oversee energy development in the region. Both industry and regulatory agency respondents indicated concern about the ability of current agency jurisdiction and regulatory rules to facilitate the use of new types of environmental innovations.

Implications and Conclusions

There appears to be a high level of interest by nearly all parties to accelerate and facilitate efforts to reduce the environmental footprint of fossil fuel production in the Uintah Basin. Our research suggests that investments in new technical and engineering innovations are important to help reduce logistical and economic barriers to adoption. However, new technology alone is unlikely to generate changes that are not already of interest to (and demanded by) industry and agency actors. Market factors appear to affect the pace of change: robust economic conditions in energy commodity markets make it easier for industry actors to experiment with and invest in new technology and practices, but are not likely to be a primary driver for change.

The role of regulation in driving future changes is likely to be mixed. On the one hand, if there were no possibility of stricter environmental rules and regulations in the future, the willingness of industry actors to incur costs to meet environmental objectives might be much lower. However, movement to reduce the environmental footprint of the industry will likely occur in ways that are not simply dictated by clear environmental laws and requirements. Conversations between regulators and industry are critical to clarify which kinds of environmental impacts are of most concern and to create the space for environmental innovation to occur. In addition, the perception that stricter regulatory standards will be coming down the pipe in the near future will likely serve as a major motivator for companies to proactively develop new strategies. It is likely that a handful of larger industry actors will provide a leadership role in generating and adopting environmental innovations, with smaller firms and local service contractors following their lead (perhaps only when such changes become mandatory).

The link between regulation and behavior is made more complex because of uncertainties about regulatory jurisdiction and authority in the Basin, and perceptions of variability in federal agency practices across political administrations in Washington. If they continue, these uncertainties will make it more difficult for industry actors to make informed judgments about which kinds of environmentally-oriented change are most likely to be required. A number of industry informants suggested that they would be happy to live with stricter environmental rules if (a) all relevant agencies would agree to follow the same rules, (b) they know they could get decisions on applications for leases and permits more quickly and in a predictable manner, and (c) they could be assured that these rules would be stable for the foreseeable future.

PART I

INTRODUCTION

Development of natural gas resources in the United States has increased dramatically over the past two decades, a boom driven by favorable prices, new technological developments, and growing interest in domestic sources of energy with a smaller carbon footprint than coal or oil. Most of the expansion in U.S. natural gas production has been from so-called 'unconventional' reserves in which extensive natural gas resources trapped in continuous sandstone and shale formations can now be extracted using modern directional drilling and hydraulic fracturing technologies. The Uintah Basin in northeastern Utah has been one of several areas in the U.S. where major tight sands and shale gas plays have been the focus of recent natural gas exploration and development.

While unconventional natural gas is likely to be a major contributor to America's energy future (NRC 2009), development of this new resource has not been without controversy. Local and national critics have expressed concerns about possible environmental impacts associated with the relatively dense surface disturbance footprint associated with unconventional natural gas development. Reports of ground and surface water contamination, air pollution, and wildlife impacts have attracted the attention of state and federal regulatory agencies. Access to many unconventional natural gas reserves that are located in/around environmentally sensitive areas likely will depend on the industry's ability to successfully lessen environmental impacts.

In response to local and national pressure, a growing number of industry and academic leaders have made efforts to develop technical options and managerial strategies designed to reduce the environmental footprint of unconventional gas exploration and production. The Environmentally Friendly Drilling (EFD) program, managed by the Houston Advanced Research Center (HARC), is one such example. The EFD program was initiated in 2005; its stated objective is to identify, develop and transfer critical, cost effective, new technologies that can provide policy makers and industry with the ability to develop U.S. domestic reserves in a safe and environmentally friendly manner. Presently, the EFD partnership includes 11 universities, 5 national research laboratories, and numerous industry sponsors.

While new options exist, many U.S. producers face a number of challenges and barriers that may impede the adoption and diffusion of these new technologies. In 2009, the EFD program approached researchers at Utah State University and Sam Houston State University to conduct an exploratory study of the opportunities and barriers to the expanded use of EFD practices among natural gas industry actors in Utah's Uintah Basin.

Our research Team worked to conduct research in the Uintah Basin to accomplish four main goals:

- Better understand local viewpoints on the main environmental issues, concerns,

and challenges associated with natural gas development in the Uintah Basin,
- Discover what steps have been, or are being, taken by industry actors in the Basin to reduce their environmental footprint,
- Determine the drivers of and barriers to the expanded use of more environmentally-friendly practices by private industry, and
- Investigate the role, both positive and negative, played by various regulatory agencies at the local, state, and federal levels in shaping the use of these types of practices by private industry.

PART II

METHODOLOGY

A mixed methods approach was used to address the four study objectives. Project scientists from Utah State University and Sam Houston State University reviewed previous literature on the social, institutional, and technical aspects of natural gas development, with particular focus on social and institutional dynamics of environmental behavior in the energy industry sector. We also collected secondary data from various government sources to better understand the spatial and temporal nature of natural gas development in this region. These secondary sources of information provided historical background on the evolution of the energy industry and provided a benchmark against which to compare information obtained from our key informants.

Our primary data collection methods involved key informant interviews with 26 purposively sampled individuals. The key informants were selected to provide different perspectives on the drivers, obstacles, and opportunities for using specific technologies and practices to reduce the environmental footprint of energy exploration and development activities in the Uintah Basin. Individuals were sampled from a master list that included over 100 possible respondents representing the following categories:

- Local farming and ranching interests
- Local and state environmental groups
- Energy industry actors, including both natural gas exploration and production
- companies, as well as representatives of the service and support industries that carry out much of the field operations in this sector
- Private consultants working with the energy industry to address environmental issues as part of their state and federal permitting requirements
- Federal agency representatives, including the Bureau of Land Management, Forest Service, Fish and Wildlife Service, Environmental Protection Agency, and Bureau of Indian Affairs
- State agency representatives, including the Division of Oil, Gas and Mining, Division of Air Quality, Division of Water Quality, Utah Geologic Survey, Division of Water Rights, and School and Institutional Trust Lands Administration
- Tribal government representatives Local government representatives Higher education representatives from Utah State University-Uintah Basin,
- Uintah Basin Applied Technical College, and the Utah Science Technology and Research (USTAR) system.

A total of 26 key informant interviews, each lasting around 75 minutes, were conducted between spring and fall 2010. Interviews were arranged by phone call and were mainly conducted in a face-to-face setting. Respondents were provided with full information about the study and given the option to voluntarily participate. When possible, interviews were digitally recorded. Written field notes and summarized recordings were used as the basis for our analysis below.

Results of key informant interviews were first summarized in written narrative reports and then analyzed through the use of standard qualitative analysis techniques. The analysis focused on identifying related themes or clusters of responses for each of the major research topics. These themes were then used to organize the results presented in this report. After drafting initial conclusions, we revisited the interview recordings to reacquaint ourselves with the rich detail in each interview and to validate the conclusions that we had developed. We are confident that the summary of results below is an accurate representation of the perspectives and information provided by the key informants. Where possible, we also note ways in which interview information is consistent with or diverges from patterns seen in the secondary data.

The results presented below represent our best effort to understand the drivers and constraints faced by key actors as they seek to reduce the environmental footprint of natural gas exploration and development activities in the Uintah Basin. The key informants were not selected to be a statistically representative sample of natural gas energy development stakeholders in Utah. However, the diverse perspectives of different respondents and the consistency of their answers suggest that our findings reflect a reasonably comprehensive inventory and assessment of the types of issues, priorities, and concerns that are most common among the interested public and private parties working on natural gas energy development in this region.

PART III

BACKGROUND AND CONTEXT

Natural Gas in the Utah and US Energy Economy

Natural gas currently provides roughly 25% of energy used in the United States and is considered the cleanest fossil fuel, with about half the CO2 emissions of coal when burned for electricity generation. Most natural gas used in the U.S. is produced from domestic supplies, with most of the remainder imported from Canada. While domestic production from ‘conventional’ natural gas reserves – defined as concentrated pockets of gas trapped in reservoirs in geologic formations -- has declined in recent decades, the development of new techniques to economically extract natural gas from ‘unconventional’ reserves has generated dramatic increases in production from these sources over the last decade (NRC 2009).

Gas shales, coalbed methane, and tight sands represent the largest untapped sources of unconventional natural gas (UNG) formations in the United States (NRC 2009). Over the past thirty years, research and development on these geologic formations has produced technologies to evaluate and develop gas reserves with the potential to significantly boost national natural gas production. New development of domestic natural gas reserves has been associated with advancements in geologic and engineering sciences and the creation of drilling techniques capable of extracting natural gas from previously unobtainable reservoirs. These technological advancements have combined with a national energy policy focused on improving domestic U.S. energy production to decrease dependence on foreign energy supplies. This, plus favorable market conditions, has increased development of natural gas reserves on both public and private lands across the U.S. in the past few decades.

The recent boom in unconventional natural gas exploration and development was also driven by historically high energy prices during the early part of this decade. Figure 1 illustrates trends in the annual natural gas wellhead prices in the U.S. and Utah from 1976 through 2010. It is clear that two large booms in production occurred in the years following sustained price spikes in the wellhead price of natural gas. The delay of a few years from the price spike to the production jump reflects the time lag associated with gaining permits, drilling wells, and initiating production. Utah’s natural gas wellhead prices have tended to be slightly below national averages, indicative of the fact that pipeline capacity constraints and lack of proximity to major metropolitan markets limit the ability of the market to utilize Utah’s reserves on a competitive basis.

In 1970, federal lands, such as those administered by the Bureau of Land Management (BLM), produced roughly 10 percent of U.S. fossil fuels. By 2009 federal lands produced 35 percent of U.S. fossil fuels, making up 32 percent of natural gas production and 29 percent of crude oil and lease condensate production (EIA 2009). While these statistics include both on- and off-shore resources, the importance of energy extraction on western public lands has continued to grow.

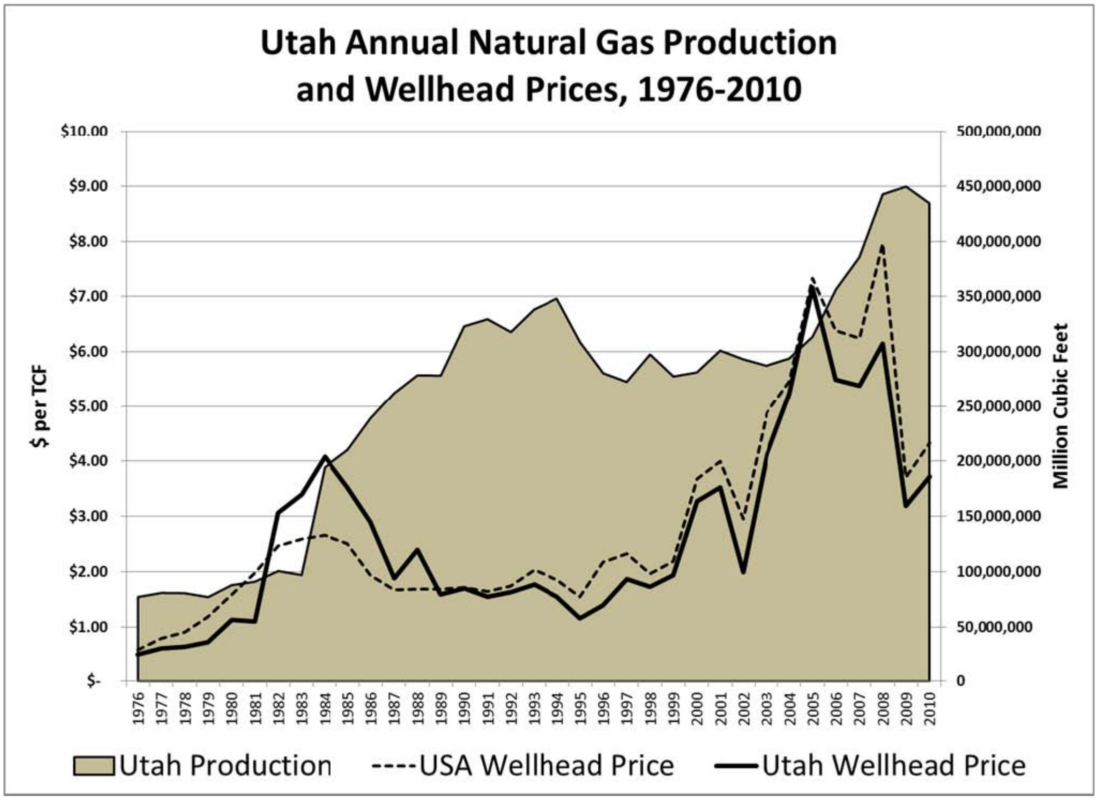
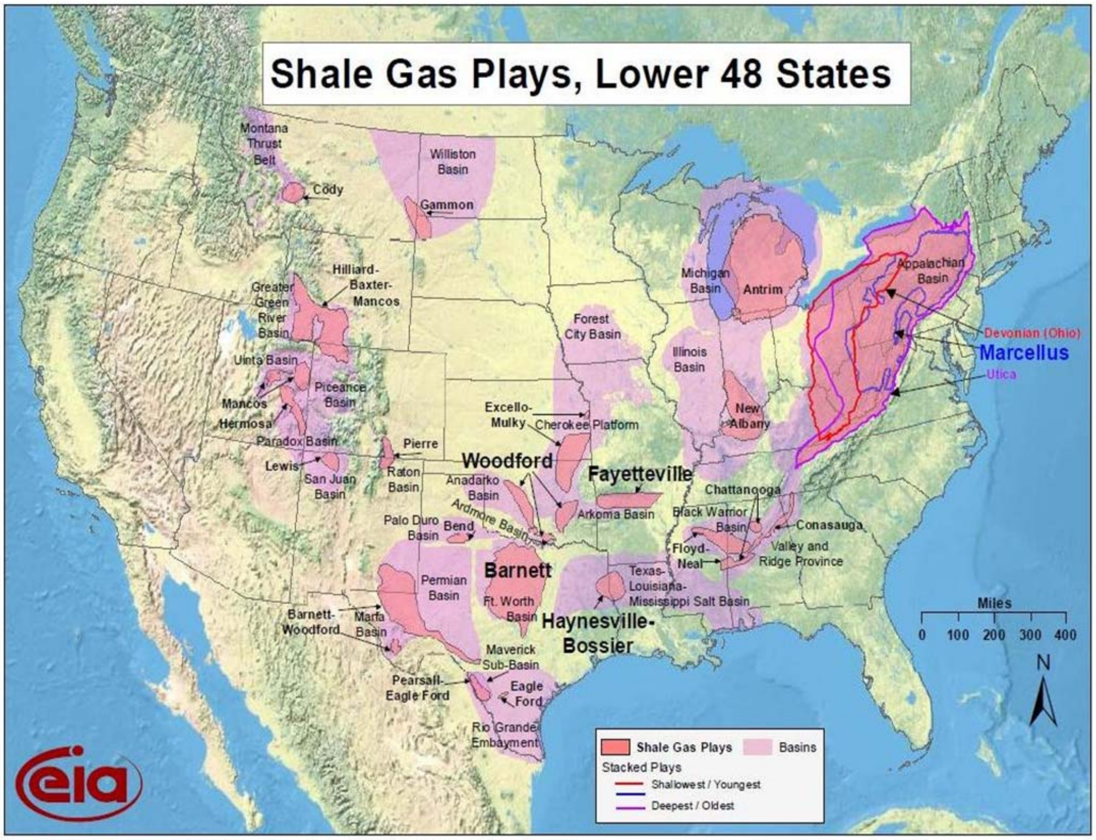


Figure 1: Trends in Utah Annual Natural Gas Prices and Production, 1976-2010.
Sources: Utah Division of Oil, Gas and Mining; USA Energy Information Agency.

The Role of the Intermountain West

The Energy Information Administration (EIA), the statistical agency of the U.S. Department of Energy, breaks down the continental United States into six major natural gas production regions. While natural reserves exist across the country, the Intermountain West represents a significant contributor to current and future natural gas production. The EIA estimates that onshore production of coalbed methane and shale gas will make up 34 percent of total U.S. natural gas production by 2035 (EIA 2010). Figure 2 shows the location of the major shale gas plays in the continental U.S. It also illustrates the importance of shale gas resources in the Intermountain West, Texas, and the Appalachian region along the east coast.



Source: Energy Information Administration based on data from various published studies.
Updated: March 10, 2010

Figure 2: Shale Gas Plays in the Continental United States.

These numbers come on the heels of The National Oil and Gas Assessment, a periodic examination of potential oil and natural gas resources in the United States conducted by the U.S. Geological Survey (USGS). In just the Eastern Great Basin Province, which includes Nevada, Utah, Idaho, and Arizona, there is an estimated mean of 1.8 trillion cubic feet of gas (TCFG), 1.6 million barrels of oil, and 85 million barrels of total natural gas liquids (USGS Eastern Great Basin Assessment Team 2007). Estimates of natural gas reserves are frequently revised upward based on changes in technology and economic conditions. For example, trends in the annual estimated volume of Utah's proven natural gas reserves are shown in Figure 3 below.

Between 2000 and 2008, the George W. Bush administration actively worked to speed up the approval process for oil and gas drilling permits on federally managed public lands. This is reflected in a dramatic increase in the number of Applications for Permits to Drill (APDs) reported on public lands during this time. From 1997 to 2007 the Intermountain West alone experienced an increase of 177 percent in the number of APDs approved (see Figure 4). These permits were approved for over 47.5 million acres of onshore federal lands, about 13 million of which have been actively engaged in energy development (U.S. House Committee on Natural Resources 2008).

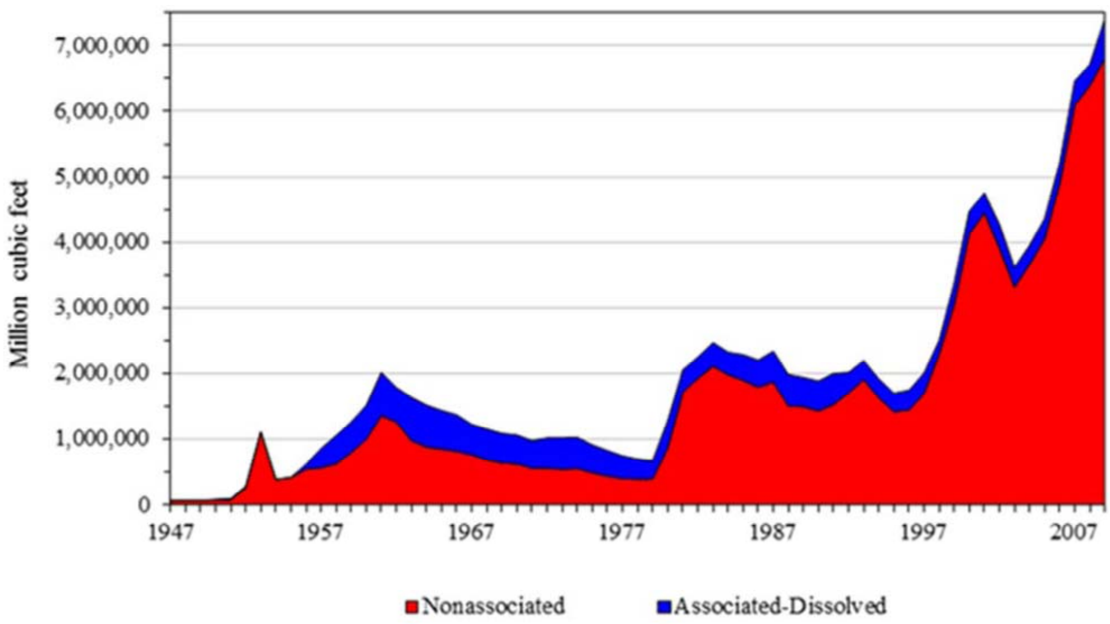


Figure 3: Proved Reserves of Natural Gas in Utah, 1947-2009.
Source: Utah Geological Survey Survey website (http://geology.utah.gov/emp/energydate/natgasdata.htm).

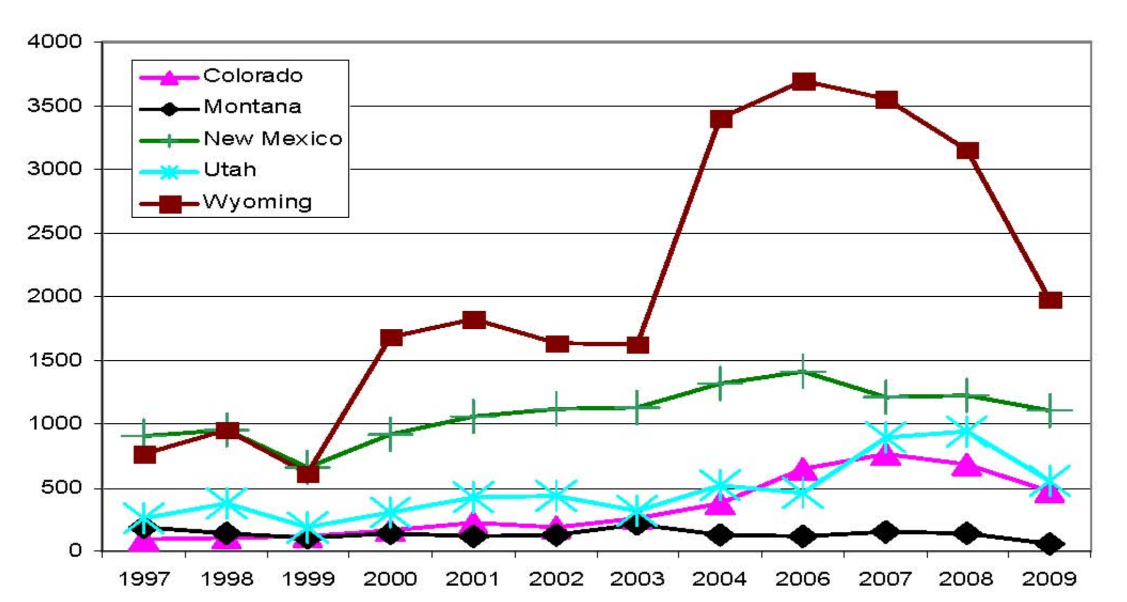


Figure 4: APD's Approved for Federal Lands, 1997-2009.
Source: "Public Lands Statistics," BLM

The Uintah Basin

Located in northeastern Utah, the Uintah Basin is the largest oil and natural gas producing area in the state. Almost all of the production activity associated with oil and natural gas is located in Duchesne and Uintah counties. At just shy of five million acres, 53 percent of which is controlled by the federal government, these counties provide a large area for natural gas and oil development. The Bureau of Land Management is responsible for managing around 32 percent of this land, with an additional 14 percent controlled by the U.S. Forest Service and lesser amounts in the hands of the U.S. Fish and Wildlife Service and National Park Service. The state of Utah controls additional lands predominately through the use of the Utah School and Institutional Trust Lands Administration (SITLA). SITLA administers 6 percent of the land in these counties with lesser amounts controlled by the Utah Division of Wildlife Resources and the Utah Division of State Parks and Recreation. Tribal holdings make up 16 percent of the Basin while the remaining 21 percent is private ownership. The resulting land tenure patterns produce a complex mosaic of different landowners and managers (see Figure 5).

Federal lands are also where most oil and gas extraction is taking place. In 2010, Uintah County had 7,349 oil and gas wells located on BLM lands, with an additional 2,438 located on Tribal property (Utah Division of Oil, Gas, and Mining 2010).

Oil and Gas Production in the Uintah Basin

Industry interest in oil and gas development in the Basin is reflected in trends in applications for permits from the State Department of Oil, Gas and Mining to drill exploratory wells and to develop completed producing wells. Figure 6 illustrates some of these trends between the years 2001 and 2010. It is apparent that interest in new drilling permits for natural gas rose quickly and peaked in 2006 (with almost 1,400 wells permitted), though the peak in well spudding activity and well completions came in 2007 and 2008, respectively. The lag between permitting and well completions reflects the time it takes for companies to mobilize drilling rigs and invest time and resources in developing permitted wells.

Natural gas production in the Basin more than tripled from 97.0 billion cubic feet (BCF) in 2000 to 308.3 BCF by 2010 (Figure 7). Uintah County experienced the majority of this growth and was responsible for approximately 65 percent of the natural gas produced in Utah in 2010, a production increase of 237 percent from 2000 to 2010. Over this same period the Basin's share of the state's total production more than doubled from 35 percent to 72 percent. Most new spudded wells are in the Basin (see details in Appendix 1 and 2).

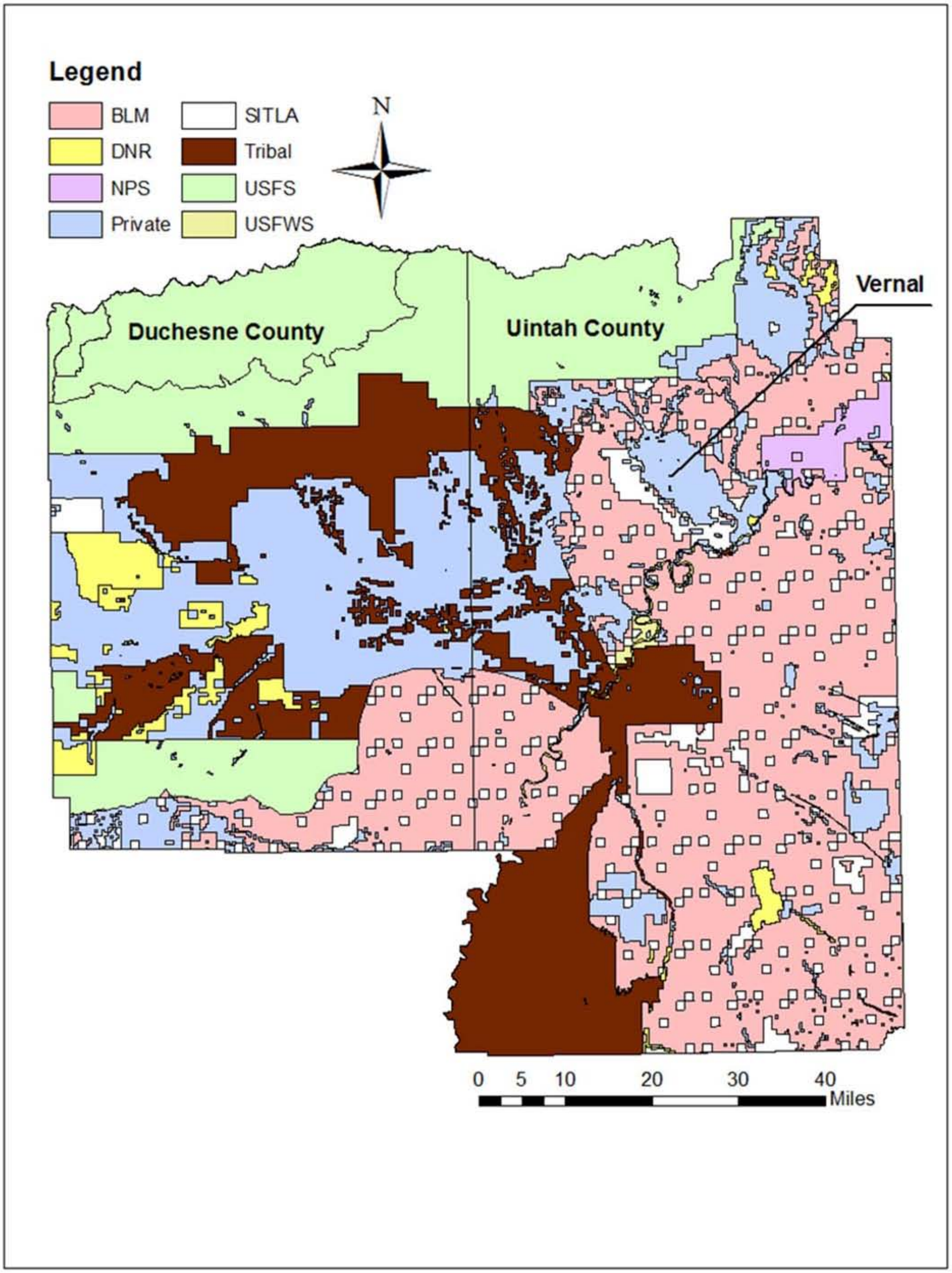


Figure 5: Land Ownership in the Uintah Basin.
Source: Utah State Geographic Information Database (SGID)

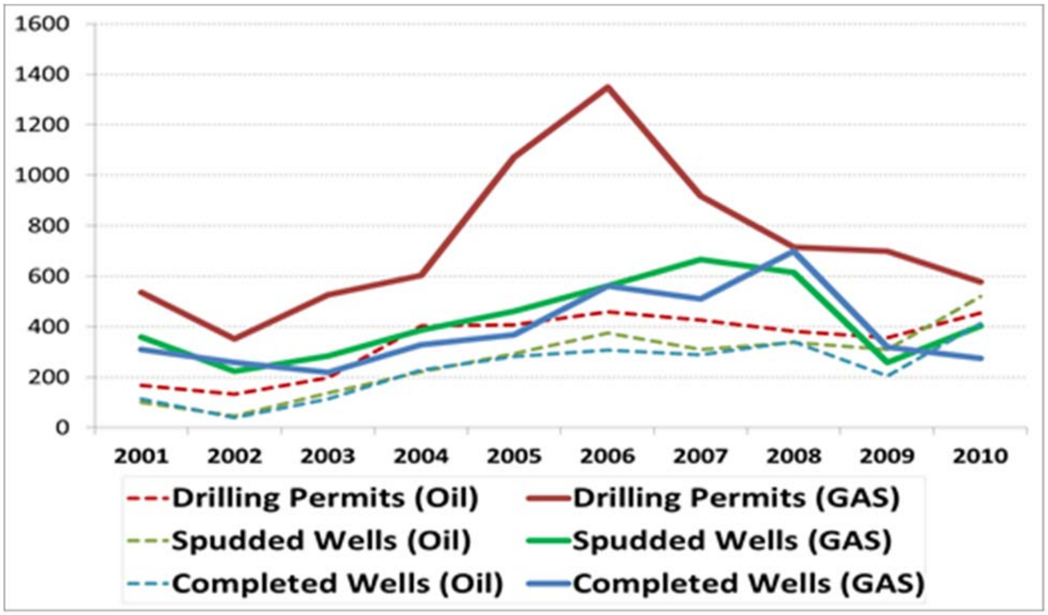


Figure 6: Trends in Oil and Gas Permits in Duchesne and Uintah Counties.
Source: Utah DOGM Permit Database.

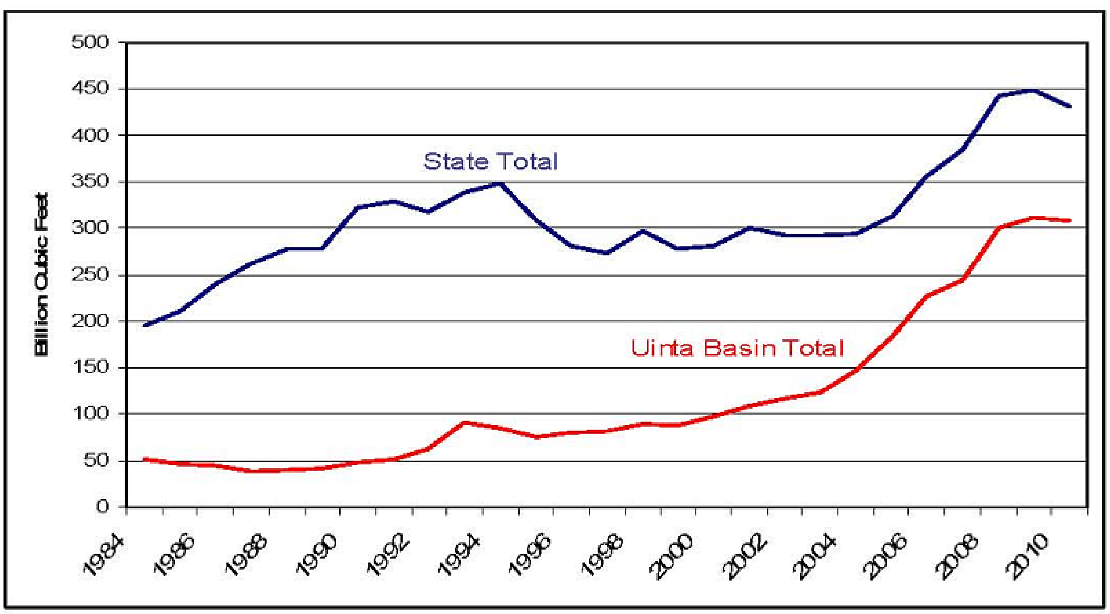


Figure 7: Natural Gas Production in the Uintah Basin and the State of Utah.
Source: Utah Department of Natural Resources, Division of Oil, Gas and Mining.

Socioeconomic Trends in the Uintah Basin

While activity has intensified in recent years, Uintah and Duchesne Counties have a long history of reliance on energy extraction to support local economic growth. As a result, trends in population have fluctuated in conjunction with boom and bust cycles in the energy sector. Between 1980 and 2009, Uintah County population grew from just over 21,000 to over 31,500 in 2009, with the majority of this growth attributable to the rapid rise in employment in the Basin during heavy exploration and production periods for both oil and natural gas.

Recent trends in direct employment in the energy sector in Uintah Basin are summarized in Figure 8. Employment rose rapidly between 2003 and 2008, with most of the jobs coming in support activities. The recent downturn in energy prices and drilling activity is reflected in a decline in total energy employment in 2009. Energy jobs provide significantly higher wages than most other job opportunities in the Uintah Basin and during the recent boom, average annual wages for drilling jobs exceeded $70,000. Those working in the support services for oil and natural gas production also saw compensation grow rapidly, reaching an average of $62,000 in 2009.

Total contributions of the energy industry to the local economy are not limited to direct employment in the energy sector jobs. A recent economic study by the University of Utah (Downen et al. 2009) suggests that each direct job in the oil and gas industry creates another 1.1 jobs in indirect and induced economic activity. Taken as a whole, the direct and indirect contributuion of the oil and gas industry accounted for almost 45% of all jobs and 50% of all wage income in the Uintah Basin in 2007.

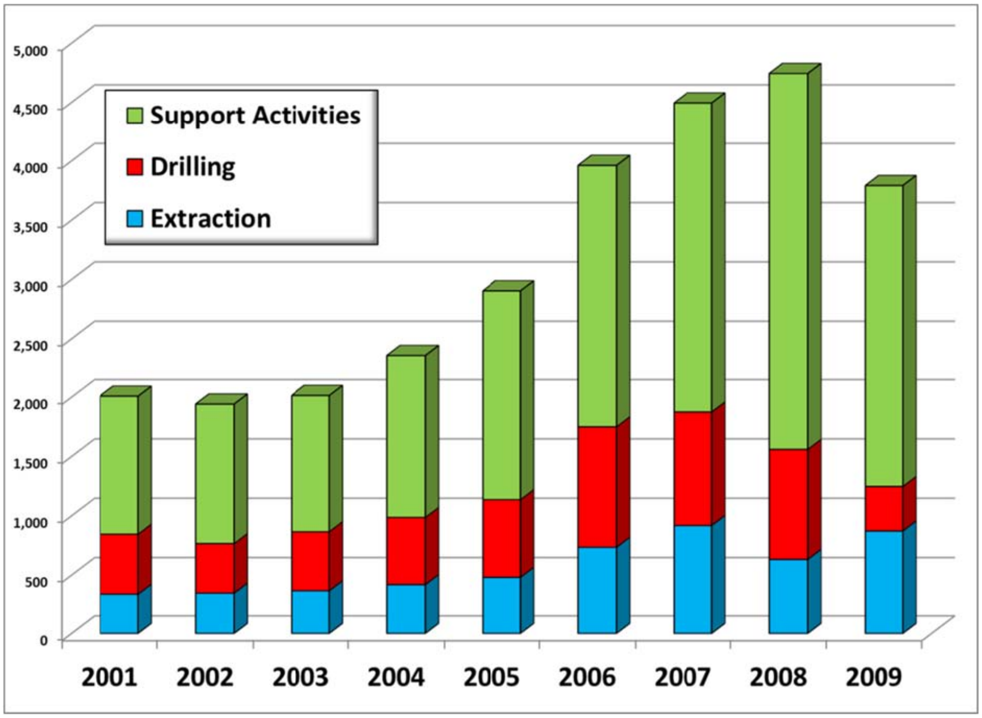


Figure 8: Employment in Oil and Natural Gas Drilling 2001 – 2009.
Source: U.S. Bureau of Labor Statistics.

National Environmental Concerns and Best Management Practices

As background to our study, we compiled information from other regions that highlighted particular areas of environmental concern and best management practices associated with natural gas exploration and production in the United States. As new techniques and technologies have allowed for greater access to previously untapped energy resources, a growing number of environmental concerns have been raised by local and national environmental groups and community leaders. This national debate has centered around issues of water quality, air quality, and the effects of energy development on wildlife. In many cases, regulatory agencies, industry leaders, and research scientists have identified technical and management strategies that can help mitigate potential environmental impacts.

National Water Quality Concerns

A key aspect of the extraction of natural gas from unconventional reserves is the use of hydraulic fracturing. The process of hydraulic fracturing involves the pumping of a fluid and sand mixture into a formation under sufficient pressure to create fractures in the rock. The result is that oil and gas flows more freely from the factures to the wellbore (EPA 2004). Since the only current alternative would be to drill multiple vertical wells in areas with low permeability, many within the energy production industry consider hydraulic fracturing to be a critical part of the process. Environmental organizations, such as the Natural Resources Defense Council (2007), have suggested that "slickwater" fractures, those which use certain types of additives, may be dangerous to human health if chemicals such as benzene migrate from the fractured zones, well bores, or fluid storage ponds into drinking water sources. The increasing public concerns over the use of hydraulic fracturing additives have prompted some development and investigation of environmentally benign fracture fluids (see Halliburton's Ultra Clean Fracturing Fluid Technology 2007).

To protect against possible contamination of groundwater aquifers, most states require operators to use cement or metal casings which extend from the ground's surface past the depth of all possible underground sources of drinking water (U.S. Department of Energy 2009). Casings provide an important barrier between freshwater zones and the fluids involved in drilling and producing from a natural gas well. The U.S. Department of Energy (2009) explains that the most important part of this process is the quality of the initial cement job. During this process it is common in a number of states for agency personnel to witness the running and cementing of casing strings, or at least require a report detailing the amounts and types of casings and cement used in the completion of the well.

A recent study conducted by the Global Water Partnership (GWP) and DOE found that the unrecovered hydraulic fracturing fluids are typically trapped via pore storage or behind healed fractures, effectively isolating the fluids from ground water (EPA 2004). The DOE (2007) goes on to suggest that implementing and following state well construction requirements, using appropriate vertical distance between the fractured zone and ground water, and ensuring the presence of vertically impermeable formations between the fracture and groundwater zones may help reduce the risk of potential drinking water contamination.

After a gas well is hydraulically fractured, the well begins to generate frac flowback and produced waters. Frac flowback is the term used to describe the injected water that returns to the surface after the fracturing procedure is completed. Produced water refers to the water present in underground hydrocarbon-bearing formations brought to the surface during crude oil or natural gas production. Operators manage and dispose of both flowback and produced waters using methods that comply with state regulatory requirements. In the Barnett, Fayetteville, Haynesville, Woodford, Antrim, and New Albany Shale regions, underground injection into saline aquifers is the preferred mode of disposal. The Safe Drinking Water Act (SDWA) regulates injection wells, and the U.S. EPA has a backlog of applied for permits for the creation and use of new injection wells. In Texas tens of thousands of licensed injection wells are in operation, but various constraints have prevented their proliferation in the Marcellus Shale and in the Intermountain West.

In some states, particularly in the arid or semi-arid West, operators have utilized open evaporation pits to dispose of flowback and produced waters. Surface pits represent potentional point sources for surface and water contamination, but are typically built with multiple layers of lining to prevent contamination.

Air Quality

Natural gas exploration and development has also been linked to potentially harmful impacts on local or regional air quality. Air quality concerns include dust and particulates generated from surface disturbances and truck traffic, fugitive and engine emissions of hydrocarbons and noxious gases, and odors associated with evaporation ponds.

Drilling operations typically require the creation of significant above ground infrastructure because established roads frequently do not exist near drilling or well sites, and the impermeability of unconventional gas reserves requires tightly spaced drilling operations. These newly created roads are also needed to transport natural gas and produced waters from the wellhead to a pipeline or disposal facility. Numerous trucks are required to carry fresh water and fracture fluids that are used during drilling and hydraulic fracturing operations. Creation of drilling pads, roads, and truck traffic have been linked to dust emissions which can create visual impairments and potential health risks, particularly in arid or semi-arid areas (EPA 2009). Recommended techniques for managing road dust include the use of water or chemical suppressants, paving of roads, and building pipelines and other infrastructure to minimize the need for truck traffic.

Aside from dust and particulates, the US-EPA has been studying the potential impact from emissions of carbon dioxide, carbon monoxide, nitrogen and sulfur oxides (NOx and SOx) associated with diesel engines used in trucks, drilling rigs, compressors and pumping stations. Similarly, wellheads and pipelines associated with natural gas operations may release hydrocarbons and related volatile organic compounds (VOCs) to the atmosphere. A number of state and federal agencies have begun to require the use of newer, less polluting types of diesel engines, or innovative valve and pipeline systems that leak fewer hydrocarbons to the atmosphere. Efforts to electrify production fields also reduce the need for diesel engines.

Wildlife, Plants, and Habitat Concerns

As natural gas exploration has increased, the opportunity for energy activities to interact with or interrupt wildlife has been a growing public concern. The dense networks of roads and well-pads associated with unconventional natural gas exploration and development can fragment wildlife habitat, disrupt migration routes, affect breeding success, and increase predation from human-adapted predators. Similarly, threatened or endangered plant species that coexist in areas of intensive activity can be negatively impacted by natural gas production activities.

Efforts to address these concerns have involved the use of multi-well pads (which reduce surface disturbance at a landscape scale), limitations on the timing of drilling activities, mandatory setbacks from sensitive areas, and efforts to reclaim surface vegetation conditions after initial drilling activities are concluded. Multi-well pads use specialized rigs that drill multiple wells that fan out in different directions from a single pad, gradually turning to reach numerous target areas beneath the surface. Specific strategies to reduce wildlife impacts have included limiting drilling operations to specific time windows when wildlife are not present, using enclosed surface pits surrounded by chicken-proof wiring and netting, and employing the use of buried underground power and telephone lines to reduce and prevent predator perches. Other actions include limiting lights, sounds, roads, and traffic. Surveys of threatened and endangered plants have been used to identify sensitive areas around which buffers may be created to protect populations from potential impacts.

PART IV

RESULTS

The following sections present the results of our fieldwork and are based primarily on interviews with key informants from industry, state and federal government, and the local community. Our interviews were complemented by an examination of publicly available reports and documents from the state and federal agencies that are responsible for overseeing energy exploration and development in the Uintah Basin. Our research in the Uintah Basin focused on four core questions:

1) What environmental concerns are most relevant and important to local stakeholders and actors?
2) What types of innovative technical or management strategies are already being used by the natural gas industry in the Basin?
3) What factors have driven the adoption of current practices designed to reduce the environmental footprint of natural gas development?
4) What barriers or obstacles hinder more widespread use of innovative environmental practices by the energy industry in the region?

Environmental Challenges Identified by Stakeholders in the Uintah Basin

Water Quality and Supply

Potential impacts to water resources in the Basin mentioned by key informants included disposal of produced waters, the loss of contaminants from pits, possibility of contamination of both surface and ground water from spills, sediment loading in watersheds, and competition for scarce water supplies in an arid region.

The most common concerns about water quality in the Basin related to the disposal of produced waters. Industry is faced with multiple challenges related to management, treatment, and disposal of the vast quantities of water produced as a byproduct of drilling. Produced water, although it comes from natural sources deep beneath the earth, is generally very poor quality and contains many dissolved salts as well as hydrocarbons, like oil. It flows up the wells with the extracted natural gas. Oil and gas production companies in this region have primarily relied on evaporation ponds and, to a much lesser extent, injection wells to dispose of the large volumes of saline water produced as a byproduct of oil and gas extraction. Evaporation ponds were most commonly identified as a source of potential concern, particularly over the potential for ponds to leak if not properly lined or monitored. Injection of produced waters into deep formations was widely – but not uniformly -- viewed to be a more environmentally sound method, but use of this disposal method is limited by the availability of permits from the U.S. Environmental Protection Agency. Relatedly, a number of respondents believe that evaporation ponds were unsightly and generated noxious odors. As one person put it, evaporation ponds are “an eyesore, grow algae and smell, and it takes a lot of work to get the condensate or liquid hydrocarbons off the top of the water.”

A separate environmental concern relates to the use of temporary on-site storage pits for the large volumes of water used for hydrofracturing operations when wells are 'stimulated' to initiate flows of natural gas. Some respondents expressed concern about methods used to reclaim or remediate these temporary pits once the water has evaporated, particularly with regard to possible concentrations of contaminants in the bottom of pits. One regulator commented that it was common practice to "roll up the sheets" and either put it in a landfill or refill and re-landscape.

Just a few respondents expressed concerns about the large volumes of water required for drilling and well stimulation procedures. One industry actor acknowledged that the "allocation of water resources is an issue" but explained that economically it is safer and easier to "get rid of all produced water, and then use only fresh water for everything when it's possible."

Subsurface groundwater quality concerns associated with hydrofracturing techniques, although prominent in the national dialogue, did not arise as major concerns in our interviews. They were also not a focus of Environmental Impact Statements for major energy field developments in the Basin. It appears that current conservation protocols are viewed as adequate to mitigate most groundwater-related concerns – including agency requirements for casing wells and locating facilities away from areas where contamination of drinking water aquifers would be more likely to occur. Moreover, the lack of human settlement or private uses of subsurface drinking water aquifers on public lands (where most of the gas exploration and development activity occurs) results in fewer opportunities for drilling to directly affect residential wells, or garner public attention about the potential issue.

More minor concerns brought up during the interviews included surface water contamination concerns, primarily focused on potential impacts of sediment erosion and spills from pipelines on the Green and White Rivers and their tributaries. In the former case, the general view of respondents was that soil erosion is largely contained by standard best management practices for natural gas drilling pad designs required by state and federal agencies and outlined in the Bureau of Land Management's "Gold Book" (BLM 2007). Informants mentioned several instances of surface spills of oil or produced waters from pipelines or trucks, but indicated that these tended to be spatially isolated and mostly occurred along roads or in dry or intermittent minor streams. Recent efforts to exclude drilling pads and storage facilities from the floodplains of major rivers reflect recognition that past drilling practices may have posed a threat to surface water quality during periods of high water flows.

A handful of respondents noted that growing demands for water for drilling and hydrofracturing operations by the oil and gas industry may eventually compete with traditional uses of water in this region for irrigated agriculture and urban consumption. To date, sufficient water has been made available for these purposes through the use of temporary permits and/or leasing of water rights.

Air Quality

One of the predominant concerns about energy-industry impacts on air quality in the

Basin have focused on the windblown dust particles generated from drilling pad and road network surface disturbances, as well as the large volumes of heavy truck traffic on dirt roads in the region. One individual we interviewed explained that the regulatory requirements around dust were very limited despite evidence of large occurrences of dust plumes around the oil and natural gas fields. Residents expressed frustration with the effects of dust on grazing quality.

Attention has also focused on the potential air quality impacts of emissions associated with truck and large diesel engines, leaky storage tanks, compressors, pipelines, and other potential production-related sources of air pollution. State and federal agency reports discuss efforts to measure particulate matter (PM10), nitrogen dioxide (NO2), carbon monoxide (CO), sulfur dioxide (SO2), and hazardous air pollutants like benzene and formaldehyde. A few recently published Environmental Impact Statements suggest that criteria pollutants in the Basin have been below the designated threshold levels of the National Ambient Air Quality Standards (NAAQS) established by the U.S. Environmental Protection Agency and the Utah Department of Environmental Quality.

Meanwhile, multiple respondents indicated concerns about levels of ozone pollution in the Basin. Ozone pollution results from a chemical reaction likely driven by increased hydrocarbon releases. One respondent cited the “twenty-one incidents of ozone spikes this year. That is a dramatic increase to having had only one three years ago.” Recent detections of high levels of atmospheric ozone in the winter of 2009/10 were cited by several respondents as indicators of a potentially more widespread problem associated with the aggregated impact of the large number of new wells drilled between 2003 and 2009.

With growing measurement of air quality problems, local discussions have increasingly focused on fears of possible future regulatory restrictions on industry activity. Several industry representatives indicated that air quality was becoming their largest environmental concern. As one noted, “the 100-pound giant the BLM is wrestling with now...is air quality.” Regulators echoed this sentiment, saying that “air quality...will continue to be a driver” of future regulatory actions. Several respondents cited a recent collaborative effort by the BLM and EPA to expand air quality monitoring stations in the Basin (and to develop better statistical models of air quality for the region) as evidence of growing concerns about air quality issues. Ongoing air quality concerns were also reflected in efforts cited by agency and industry informants to encourage the use of more efficient and less polluting diesel engines, the electrification of well pads, and reductions in the number of trucks or volume of truck traffic.

Wildlife, Plants, and Habitat Concerns

A number of respondents discussed concerns about the impacts of energy activities on threatened and endangered plant and animal species and other important wildlife populations. Removal of vegetation during initial construction and drilling operations means that local vegetative communities are disrupted. Within the Uintah Basin, two plant species – the hookless cactus and horseshoe milkvetch -- are both protected under the federal Endangered Species Act and grow in areas within and nearby oil and natural gas developments. Concerns over their removal or the encroachment on their habitat were cited by one industry respondent who noted that “for the last five or six years, one of our bigger issues has been surface disturbance.” These concerns have led to specific protective buffer provisions being included in all recently issued exploration and development permits.

In addition to sensitive plant species, big game (like deer and elk), raptors, upland game birds, migratory birds, and species like the black-footed ferret, bald eagle, and greater sage-grouse may be located around current or proposed drilling projects. According to our respondents, energy activities have the potential to impact these animal species through disruption of local vegetative communities or via nuisance impacts associated with drilling activities and truck traffic during critical breeding or overwintering periods. A critical impact of concern for wildlife is the impact of surface disturbance on wildlife habitat. Despite growing efforts to reclaim disturbed drilling sites and roads, vegetative communities in this arid region take significant time to recover: around 30-40 years for local sagebrush vegetation and potentially 75-150 years for pinyon-juniper woodlands (BLM 2003). Mitigation efforts such as time-restricted drilling and the greater use of multi-well pads were discussed by several informants as a means to avoid displacement of wildlife breeding grounds and fragmentation of habitat.

Along with the potential for disruption of habitat and mating activity, some forms of energy activities can post direct threats to wildlife species. Several respondents discussed the potential for collisions with vehicles and heavy equipment. Others mentioned that migratory birds can be killed if they land in reserve pits. Industry representatives indicated that waterfowl and bird issues have been a major focus for their preventative practices. As one put it, "it is very much in our interest to not have waterfowl issues." These comments were echoed by state and federal representatives. One industry informant explained that "we work with Fish and Wildlife [Service] to try and make sure ponds are netted... (migratory) birds dying in the ponds is a big, big deal." The possibility of a future listing of greater sage-grouse as a federal threatened or endangered species drew comments from several respondents who felt that a listing would require significant changes in location options and operational practices in the industry. Meanwhile, accidental spills were mentioned by one respondent as a potential threat to aquatic species, including a number of federally-listed Colorado River fish species.

Examples of Environmental Innovation in the Uintah Basin Energy Industry

The previous section detailed the primary environmental concerns related to natural gas industry activities in the Uintah Basin that were expressed in our interviews with local key informants. In this section, we summarize information from our interviews and secondary documents that illustrate the kinds of innovations that are already being used in the Basin to address environmental concerns associated with natural gas exploration and production activities.

Water Protection and Disposal of Water

As noted above, the issue of produced water management arose in most of the interviews we conducted. Produced water first becomes a potential environmental challenge as it comes up the well. Preventing this flow from contaminating near-surface drinking water aquifers is typically done through the use of sealed well casings, a practice that is heavily regulated by state and federal agencies. Multiple industry representatives discussed the importance of using steel casings and sealing them with a bentonite and concrete mix. As one industry representative noted, "casings need to be good. The technology continues to get better, and that is what protects our water." This was confirmed by regulatory officials who agreed that the industry does "an awful lot of work to not have contamination. They know it's a bad thing and they work really hard to not do it." Government oversight of methods used in 'downhole' operations appears to be quite extensive, and all companies are required to case wells appropriately to avoid groundwater contamination. A few respondents noted that older abandoned wells in the Basin may not have been constructed using modern best practices. Efforts to 'restimulate' these wells using modern hydrofracturing techniques may require new environmental management strategies.

Once at the surface, a number of environmental management practices are used to prevent produced waters from contaminating surface water resources. As indicated above, two primary methods of produced water disposal are used in the Basin. The most common is to truck water from the well sites to evaporation ponds. Some industry respondents discussed the use of specific techniques for managing their evaporation ponds to minimize the potential for environmental impacts. Some utilize pretreatment facilities that extract valuable hydrocarbons and potentially harmful pollutants before releasing produced waters into evaporation ponds. Some use monitoring systems to detect and fix leaks that could contaminate groundwater. One interviewee explained that "[our] ponds have multiple layers, leak detection, and other preventative measures. If there's a leak we have to drain the pond to fix it and... that is a pain in the neck." This same informant discussed how making sure they take every step possible to prevent leaks makes it easier on them and the environment.

The preferred method for handling produced waters is re-injection into deep geologic formations. While respondents identified this technique as their preferred option, only four injection wells were currently permitted and operating in the Basin at the time of our study. Transportation of produced waters to reinjection wells is almost always done by truck, though one industry informant discussed a project whereby pipelines were used to connect well pad sites to injection wells. This project reduced truck traffic and the footprint of their injection facilities, and also helped curtail the likelihood of ground and surface water contamination. If the EPA and State agencies that permit injection wells determine that this practice is environmentally benign, then we would expect more widespread use of this water management technique.

A number of respondents mentioned that there are several private companies seeking to develop on-site water treatment units that would allow the extraction of salts, hydrocarbons, and other contaminants from produced waters at the well-pad, leaving water that meets water quality standards that would allow its use for other purposes. While experimental units have been developed and are being deployed in the Basin, most respondents felt that these were at present impractical or uneconomical for widespread use.

A final environmental strategy designed to protect water quality addresses the potential for contamination associated with temporary fluid storage pits used during well drilling and hydrofracturing operations. To minimize the number of such facilities, a few operators in the Basin are exploring the use of centralized water storage facilities from which water can be piped to and from individual drilling pads (as opposed to having multiple containers present at each well pad). At least one company has begun reusing the water from its hydraulic fracturing processes, with one informant noting how "we take the water, clean it up, and then use it on other pads. This reduces the need for fresh water, our truck traffic, and keeps dust down."

Air Quality

A number of innovations are used to minimize impacts on air quality. Dust reduction is addressed through a variety of mechanisms that reduce truck traffic. Specifically, the use of more pipelines and closed-loop systems had the effect of reducing the need to haul water and created a situation where "dust is not as bad as it was three years ago." Dust is also reduced by applying water or magnesium chloride to dirt roads, or actually paving the main roads that are traveled most frequently. One company innovation came about from a recognized need to improve well monitoring. Originally trucks inspected each well site on a rotating basis, but the installation of computer aided monitors at the wells eliminated the need for frequent truck visits and resulted in reduced traffic and dust disturbances. Efforts to reclaim drilling pads by reestablishing vegetation also provide dust minimization benefits.

Concerns about air quality have also stimulated efforts to reduce engine emissions. Aside from strategies to reduce vehicle traffic (mentioned above), air quality management strategies in the Basin include the growing use of natural gas to run compressor engines in lieu of diesel engines, and incorporation of more efficient engines into exploration and production equipment. The uses of tier 2 engines and motors that can run off of their produced natural gas were all mentioned as a means of trying to reduce CO2 emissions. Installing electric power lines can also reduce the need for diesel motors on drilling rigs.

A variety of approaches to detect and reduce fugitive emissions from pipelines, compressors, and storage tank vents have been used to address air quality concerns. Some companies have used combustors on storage tanks to burn off fugitive emissions. In some cases, blasts of natural gas have been used to help start compressor engines, but result in a loss of all the gas used. As one person explained, "Every time they needed to open a valve or something, someone would throw a switch... and gas would make the valve turn... but be exhausted into the air." In response, some companies have started using pneumatic control technologies that are "low-bleed" or "no-bleed" systems so that gas is no longer continuously vented into the air. A handful indicated they also started reclaiming some of this vented gas, and can run compressors using gas when electricity is not available. Regulatory staff pointed out that most companies are doing "a better job of taking vents and rechanneling them back into the engine as fuel." Other comments centered on the advances made by engine manufacturers to include air-fuel controllers as a standard, and noted that overall the industry has done a better job capturing emissions.

Surface Disturbance

Many informants discussed how industry is actively addressing habitat fragmentation and surface disturbance concerns. Reclamation, erosion control, strategic well-pad siting, and multi-well pads all help address concerns about surface disturbance.

Industry informants explained that "reclamation is important... [the] critical thing is to do it fast." In some cases, reclamation begins as soon as drilling is finished. Restoration often involves recontouring, loosening packed soil, seeding, and managing weeds, among other tasks. The push to rehabilitate as soon as possible allows for companies to "take advantage of the soil in the area... since it still has moisture and seed banks." In addition, some companies are using snow fences to trap water, applying mulch to help with the soil moisture, and using shot rock to create landscape diversity and microhabitats. One respondent explained, "we call these 'advanced reclamation' since they are not required by agency regulations." Others explained that while some reclamations may never be as good as what was originally there, it is still important to reclaim everything. As one informant noted, "About 90 percent of what we use is federal ground, meaning other people use it too. We reclaim because someone else's livelihood depends on that grass."

In addition to reclamation, most industry actors have been required by state and federal agencies to incorporate techniques to help prevent or slow soil erosion. Many of these techniques are outlined in the BLM's 'Gold Book' (BLM 2007) which offers guidelines on standard road and pad construction.

The combination of multiple wells on a single pad is perhaps the most direct way to reduce the footprint of energy activities. Regulators like them because multi-well pads reduce surface disturbances and the need to provide an expansive utility infrastructure. Industry informants expressed similar sentiments, with one explaining how "everyone is mostly switching over... to six to eight wells per pad... at this point [it's] almost an industry standard."

At the same time, a handful of observers suggested that multi-well pads were still relatively rare in the Basin, and highlighted potential problems associated with directional drilling and multi-well pads, including concerns about losing production efficiency in non-vertical sections of wells, difficulties in loading and unloading, and safety concerns due to crowded pads. Nevertheless, most interviewees recognized that multi-well technologies "for the most part are pretty good and have a lot of upside. It's much easier to move a rig ten feet instead of three miles."

Some companies are increasingly interested in the reuse of old well pads, particularly since it enables additional drilling with the potential to avoid new surface disturbance. One regulatory official pointed out that new directional techniques have been used such that "in some places all wells are drilled from existing pads so the footprint doesn't increase." In some cases, using old pads provides new opportunities to reach reserves that previously were inaccessible, particularly when multiple wells can be drilled from an old site.

Drivers and Barriers to Change

The central focus of our study was to better understand the factors that are both driving and constraining the use of practices that could reduce the environmental footprint of the energy industry in the region. The responses we heard in the Basin underscore the complexities faced by both industry and regulators with regard to environmental concerns. The following sections summarize the major examples of drivers and barriers reported by key informants in our study.

Drivers of Change

The methods used to explore and develop natural gas resources in the Uintah Basin have changed constantly over the last few decades, including many innovations designed to reduce environmental impacts. In order to understand how changes occur in the energy industry, we asked respondents to identify the specific factors that have encouraged the more widespread use of various kinds of environmentally-oriented practices in this region. Their responses were diverse, but clustered around seven major categories: regulations, technological change, economics, corporate culture, feelings of responsibility to the community, public relations, and a desire to avoid legal battles. In the following section we provide examples and explanations of the kinds of 'drivers' mentioned in each category.

Regulatory Atmosphere

Not surprisingly, many of the specific environmental practices adopted by the energy industry have come about in part because of state or federal regulatory requirements. Agency employees provided numerous examples where specific types of technologies were required to be used before issuing new drilling permits. Most industry respondents were frank in noting that the industry will always do what they have to meet standards set by the state and federal government. In this sense, regulations set the 'floor' for environmental behavior. One agency staffer noted that while "it's clear that some good companies come up with ideas on their own, without regulations... they wouldn't do it if they didn't have to." Another agency informant explained that "it's because of self-preservation. They want their permits... they aren't out here to reclaim the land, they're out here to make money for their shareholders." One industry informant explained how they felt change happens: "bad things happen, regulations occur, and companies figure out how to deal with those regulations."

Some of the clearest examples of regulation-led environmental behavior lie in the area of endangered and threatened plants and animal species. Because of the rigidity of the rules under the Endangered Species Act (ESA), regulatory agencies have placed clear timing restrictions on drilling activity and strict and inflexible setback or surface occupancy requirements, such as for a particular cactus species. As one regulator noted in our interview, the "plant issue is contentious. Operators don't like it but they know they have to do it." Industry informants pointed out how companies, in response to strict regulations, now spend more time exploring the potential impacts on wildlife, and may even support research or provide data to agencies to ensure that their ESA-mandated practices will have their desired impacts.

Similarly, industry respondents felt that many of their innovative approaches to managing produced waters came directly from regulators pushing for their use. Natural gas developers are required to identify any aquifers they may go through, and are then required to case their wells to protect them. These respondents believed that specific innovations to deal with produced water came from the need to comply with the US Clean Water Act.

While environmental regulations are obviously a significant driver, the links between regulations and the use of concrete environmental innovations can be complex. This is partly because many regulations are written to require attention to various potential environmental impacts, but allow significant flexibility in how these end points are met. A good example is the environmental review required under the federal National Environmental Policy Act (NEPA). Industry respondents often pointed to NEPA as a major driver of environmental behavior. Said one, "NEPA is a big driver. When we fail to [address NEPA requirements], we are subject to fines." Yet while NEPA requires government agencies to assess and address the potential environmental impacts of major projects on federal lands, the law does not prescribe specific steps that must be taken to avoid or mitigate serious impacts.

Most respondents felt that this flexibility was important because of the differences in scale and underlying biophysical conditions associated with various proposed projects. A lot of discussion appears to take place around what practices are good, feasible, or cost effective for particular locations, but agencies appear to try to work with industry, keeping in mind that not all technologies fit all situations. For example, geologic differences between gas fields can influence which technologies are cost effective or even feasible given current technology.

Even when regulations do not prescribe exact practices or procedures, the fact that federal and state governments own most of the land on which drilling takes place creates a situation where industry actors seek to maintain a good relationship with regulatory agencies. In addition, industry informants expressed that in many ways the oil and gas industry has begun policing itself in order to speed-up the regulatory process and maintain positive relationships with regulators. A representative of a regulatory agency suggested that "about the only time I've seen them willingly adopt conservation measures... [is] if it improves or keeps good relations with an enforcement agency."

According to many of the people we spoke with, companies working hard to avoid negative environmental impacts in order to minimize future regulatory restrictions. Specifically, some industry respondents indicated that their companies had been more proactive in developing environmental innovations *in anticipation* of future regulatory requirements, figuring that it would save money and avoid bottlenecks in production if they stayed ahead of the regulatory standards. One indicated that they wanted to "meet or beat the regulatory standards" to better position themselves for future changes in regulation. In response to air quality, regulators who we interviewed indicated that the industry "sees the writing on the wall. If they want to develop these fields as densely and concentrated as they want, they're going to have to think about emissions or we're going to have air quality issues."

Stories about the role of governmental environmental regulatory oversight also highlighted the ways in which the use of specific environmental practices may depend on negotiations between agencies and industry actors and long-term patterns of environmentally responsible behavior by particular companies. It is clear that novel environmental practices that at one time were 'recommended' or optional can become 'mandatory' or standard practices years down the road. One regulatory official discussed how a company was given a set of stipulations to meet once it was discovered that dust would be an issue for nearby petroglyphs, but the allowed them to figure out the best way to meet these requirements. "The company had to figure out how to better do it or risk getting restrictions placed on them." Another regulator explained how a company may be invited to provide input into how best to address a certain problem:

> *"[They] come in with a first cut proposal, and if looks reasonable then the permitting authority will say OK. But, if they bring in something we determine is inadequate then we'll tell them why, and explain that we're aware of certain technologies that they should maybe consider. We don't dictate the technology, but we do dictate that someone has to do an evaluation and come up with what they consider the best controls, so there is some flexibility."*

Other agency respondents talked about working in partnership with industry in order to encourage innovation and meet environmental objectives in advance of formal regulations. Said one, "we try to get innovative technologies from the R&D status to a fully mature and ready to be used everywhere status." Similarly, innovations surrounding management of surface water ponds emerged as industry actors came to believe the EPA was not going to give them injection well permits.

Good working relationships between regulatory agencies and industry were also cited as important to identifying win-win situations, such as helping both agencies and industry improve air quality and operational efficiencies. For example, natural gas losses, intentional or otherwise, both cause a loss in otherwise marketable product and create an environmental concern. Emissions reduction technology and opportunities for emission reclamation can remedy both problems.

Engineering and Technology

Progress in reducing the environmental footprint from energy development also hinges on the development and availability of appropriate technologies and engineering techniques. This is particularly true if new technology can be shown to both improve environmental quality and efficiency of industry processes.

Recent growth in the use of multi-well pads and increasingly distant pad spacing were linked by several respondents to advancements in directional drilling technology that provided environmental benefits while also making it easier to reach resources that might otherwise be inaccessible with traditional vertical drills due to difficult terrain. Noted one respondent, "Everything is either in the bottom of a wash or the top of a ridge; we've pretty much used all the flat spots." Improvements in the technology for casing wells were also mentioned as important because they enhanced the ability of the industry to protect aquifers and fresh water sources in the Basin. Regarding innovations in air quality, one agency informant asserted that “the technology has to evolve, at some point the tech was maybe not there, so operators were resistant to using it.” At the same time, they felt that as new diesel engines, compressor valves, and other forms of technology improved, businesses have been more willing to implement and use them.

Economics

Of course, technical feasibility alone is unlikely to ensure adoption of new environmental practices. All respondents noted that economic considerations help explain the timing, pace, and direction of environmental innovation in the Basin.

Broadly speaking, energy commodity prices were linked to the level of interest in and active development and implementation of new environmentally-oriented practices. During periods when energy commodity prices are high, companies have been more willing and able to pay the extra costs associated with some environmental innovations. As one industry representative put it, "if the price of oil and gas is high enough, we'll jump through any hoop." Regulatory agency informants expressed similar sentiments: "as long as there's money there, new technologies will come along." Indeed, the relatively high natural gas prices throughout the mid-2000s provided liquidity and economic justification for the use of more extensive efforts to minimize environmental impacts in the Basin. Conversely, recent market downturns have generated stronger pushback by industry against rigid environmental regulations due to perceptions that these requirements are prohibitively expensive and might slow the pace of new exploration and resource development.

The costs associated with many environmental practices may also hinge on a company's cumulative experience with the new innovations. Greater familiarity and adoption at a larger scale were often associated with reduced expenses. Respondents noted that some of the technologies that industry players originally viewed as cost prohibitive turned out to save money in practice. One industry informant discussed how the smaller footprint associated with multi-well pads proved to be better, not just because of the reduced surface disturbance, but because it can save money. As they explained,

> *"We thought [multi-well pads] were going to break us... but we got going on it and saved money in areas we weren't even considering. Don't have to move the rig every time you go to another pad and with the new style rigs there is no need to relay pipe. Just pick it up and drop it in where it needs to be, either 10 or 20 feet apart."*

New technology (such as multi-well pads and improved directional drilling equipment) can also change the economics of accessing reserves previously thought to be unrecoverable or impractical while reducing the environmental footprint of drilling activity."

Corporate Culture

Changes in leadership and the corporate culture within some energy companies may help explain adoption of many of the environmental innovations in the Basin. Agency informants indicated that a handful of companies are more motivated to be environmentally friendly because "they have more of a vision of where [things] are going without being told or led." They felt that the "best innovators at the end of the day are because you've got a *leader* somewhere that's innovative, and a thinker, willing to take a risk." This kind of leader is viewed as key because having the "right person in the position... who's thinking ahead" creates an atmosphere where new technologies and techniques are significantly more likely to be implemented. As evidence of changes in leadership, some companies now invite regulators to company planning meetings, explaining that "[Environmentally friendly] is our ethic now, we want to hear what we should do." These sentiments then trickle down to employees in the field.

Interviewees speculated on reasons why some corporate cultures value environmental stewardship more highly than others, noting that in industry, environmental changes "seem to be a personal choice with some companies going the full extent to protect the environment." Several people we spoke with indicated that the retirement of an older generation of oil and gas company leaders has allowed a more "environmentally adept and concerned" new generation to move into positions of management. "Their corporate ethic... I think it comes from the newer generation who is just more environmentally aware."

Community Responsibility

Several industry informants expressed feelings of personal or corporate responsibility to local communities in driving their adoption of as a major reason for taking extra steps to protect the environment. One interviewee relayed a story about how a handful of residents living near an evaporation pond began to smell strong odors. These residents "were very diligent in tracking down the source of the odors and became credible even in the eyes of the industry." As a result, the involved industry actors voluntarily began mixing in dissolved oxygen and bacteria that eat hydrocarbons into the evaporating water as a method of minimizing negative impacts on these local residents.

Industry practices may also reflect an appreciation that there are other uses of the public and private lands on which natural gas development takes place. In reference to reclamation processes, one agency employee claimed, "we reclaim because someone else's livelihood depends on that grass. We don't want to be the bad guy." Others felt that simply living in the community and engaging in local hobbies and outdoor activities created a sense of community responsibility. In particular, many of those working in the energy industry participate in outdoor recreation and hunting. As one informant noted, "People that love the outdoors would be pissed if you're out there frickin trashing it... you don't get people who love the outdoors going out and trashing it."

Public Image

A number of informants discussed the role of public relations in driving the use of environmental innovations in the Basin. One industry respondent mentioned concern about their company's public image as a major factor in their use of techniques to reduce visual impacts and to voluntarily go beyond regulatory requirements in reclaiming land. Another noted that this is related to the emergence of a "green ethic that's grown within the U.S. over the last 40 years. We have no desire to rape and pillage."

Some felt that the attention drawn by outside environmental groups to industry actions helped make the public more aware of their activities, which places pressure on agencies and industry actors to find a better way to do things. Regulators explained that innovations tend to come from the largest companies because they are more likely to be in the public eye and to care about their image. As one informant put it "big companies are more likely to try new things and publicize it for the PR value of looking greener." Others felt that the nature of the areas the industry was operating in probably had a lot to do with the increased focus on public relations. Citing one recent company decision to voluntarily agree to stringent environmental constraints on developing a proposed new gas field, the respondent explained that the area is very well known and "because they are drilling in such a sensitive area, an awareness has been forced on them, probably more than they would want."

One local informant described how the industry tries to be conscious of things on the whole because "they'd rather it not become an issue. They are facing so much opposition that I think they try and avoid creating more issues." An agency employee pointed out that "spills are costly, bad PR is costly. It's better to be a green company now, politically and every other way." An industry respondent agreed that "energy companies must understand that what other people say about you is what your brand is." Another noted that "most people who run these companies aren't there to destroy things. If they did, there would be a media frenzy... no one wants that….you do not want to be tried in the media."

Lawsuits

While not mentioned as frequently, legal rulings (or a preemptive desire to avoid legal battles) can also drive the use of environmental innovations in this region. Respondents described how environmental groups, like the Southern Utah Wilderness Alliance (SUWA), regularly use lawsuits as a means of forcing agencies to adopt higher environmental standards. One regulator suggested that "if a practice is going to be changed, it's going to happen because SUWA took the BLM to court and the courts ruled that yeah, you need to do this. Then it becomes a regulation."

Industry informants described the varying ways lawsuits and their avoidance played a role in their permitting process. In one case, a particular company included

SUWA in discussions early in their planning stages and negotiated concessions before they applied for new drilling permits. This prevented a costly and time-consuming appeal of the agency's decision to approve the development proposal. As a result, this company regularly tries to bring environmental group leaders "up to our field to show them around. This company has nothing to hide. We try and work with them."

Barriers to Implementation of Environmentally Friendly Practices

While the use of some practices to reduce the footprint of the energy industry is becoming more common, it was clear from our interviews that there are many possible practices that are not yet used in the Basin and others have only been adopted by one or two companies. A key objective of this project was to identify the obstacles that prevent the more widespread use of environmentally friendly practices. In our analysis of the respondents' comments, we identified three major categories of barriers to adoption: the complex local regulatory context; adverse economic conditions; and engineering or technological limitations.

Regulatory Context

While state and federal regulations are seen by many as important drivers of new environmental practices, the complexity of regulatory authority and overlapping jurisdictions in the Uintah Basin also create disincentives to adoption of other innovative approaches. In our interviews, problems related to ambiguous or conflicting regulatory jurisdiction and a perceived lack of consistent regulatory implementation frustrated industry actors, regulatory agency staff, and local government officials alike.

As noted earlier, the Uintah Basin has a diverse mix of landownership, with significant portions owned by federal agencies (53%), tribal governments (16%), the Utah state government (10%), and private landowners (21%). The complexity is increased because ownership of subsurface mineral rights is often different from the ownership of the land's surface. A large proportion of non-federal land has federal mineral rights that require companies to engage the federal environmental review process while at the same time negotiating with non-federal landowners for surface access. As the individuals we interviewed explained, the complexity of jurisdiction and ownership makes it unusually difficult to understand and negotiate environmental regulations in the area.

A particularly thorny issue in the Uintah Basin is the complex relationship between state and federal agencies and tribal authorities. On official tribal reservations, local tribal governments have some direct authority to establish environmental rules for activities that take place on tribal trust property. In the case of the Uintah-Ouray reservation, some aspects of environmental oversight responsibilities lie with the tribal Energy and Minerals Department, while a separate tribal Business Committee approves the formal contracts with companies to lease mineral rights and approve energy development projects. Meanwhile, the Bureau of Indian Affairs (BIA) (a separate federal agency) retains some statutory authority as the federal trustee designated to protect tribal natural resources and assets. The BIA must approve lease agreements negotiated by the tribe[3] and is involved in the process of reviewing permit applications to explore and develop energy resources (though final approval of permits on Indian trust leases is granted by BLM, after receiving concurrence from the BIA). In addition, where tribal trust lands are underlain by federally-owned mineral rights, the BLM is directly involved in the

[3] Except on special property called the "Naval Oil Shale area" that was returned to the Tribe as trust fee lands

permitting process as the owner of the mineral rights. Recent agreements have shifted some of the BIA's authority and role to tribal government officials, in which case the BLM can be required to obtain the concurrence of the tribal authority to approve permit applications.
Environmental review by the BLM and BIA is not only governed by specific agency rules and policies relating to development of federal and Indian trust minerals, but also by the broader National Environmental Policy Act (NEPA) requirements that mandate the assessment of many types of possible environmental impacts, require a formal evaluation of management alternatives, and often involves the use of systematic public input processes.

Another layer of complexity is the fact that the federal Environmental Protection Agency (EPA) – which has no local office in the Basin – is the lead agency on issues of air and water quality protection on tribal lands. However, in some cases, local agencies are given some authority to handle the duties on behalf of the lead agency, handling monitoring or emergency response efforts, but may not have authority in situations such as deciding whether to fine a company for violations. Finally, because of complex local legal rulings, the lead EPA authority on water and air issues in the Basin extends into a larger geographic area (called 'Indian Country') that reflects the original boundaries of tribal lands in the early 20th century that existed before large swaths of land were privatized through sale to non-tribal settlers.

Given this complexity, industry informants expressed frustration over what they perceived as particularly unclear lines of regulatory authority on tribal lands and in Indian Country. One interviewee explained that when they moved from operating on federal to tribal lands, there was considerable debate and disagreement about which state, federal, or tribal agencies would be involved in reviewing and approving their applications for exploration and drilling. The frustration was not limited to industry players, however. State regulators recognized that addressing accidents or spills that occurred within or along the boundaries of tribal lands (e.g., in Indian Country) were particularly muddled. In one example, an informant felt that the scale of a particular spill merited a notice of violation and a fine, but the unique aspects of tribal authority meant that "this would be like suing Spain. We can't even fine them." As a result, regions where regulatory authority is uncertain or complex may become a lower priority for allocating scarce time and staff resources in some state and federal agencies. This has led to problems for some tribal representatives interested in enforcing stronger environmental standards, who indicated that the "biggest problem with feds is inconsistency. Getting the BLM to come down hard on a company is like pulling teeth."

To further complicate matters, as one regulator described, "there are something like twelve agencies intermixed here." This situation has made it difficult for another respondent "to figure out what agency is in charge... someone must have the rules and regs on who enforces [what], but we haven't seen it." These concerns appeared to be a major concern for both industry and regulators. One regulatory informant noted that, although "operators would like a one-stop shop... that's not the reality of the situation and they have to answer to multiple masters." Federal regulators commented on how the fractured jurisdictional situation meant that they could only regulate what they were given authority over, and there was little opportunity for coordinating the efforts of multiple agencies.

Aside from ambiguous agency authority, industry informants frequently complained about a perceived lack of consistent implementation of regulations. One felt that "so much of what the BLM does is discretionary, and there really aren't that many regulations about what needs to be done environmentally." The specific practices required by both state and federal agencies of different energy companies are often negotiated through the planning and permitting process. While this may make sense (since different projects pose different threats and require different solutions), it produces situations where competing companies feel that they are being treated differently. One industry informant's comments represent the frustration expressed in several of our interviews:

> *"One of the huge problems we have in Utah is we can't get [Agency X] to write down the stinking regulations. It's all verbal... from our perspective, we don't have a problem dealing with meeting a certain regulation, so long as my competition... has to jump through the same hoops."*

Other informants discussed how this moving regulatory target made it difficult to plan for the future. As one put it, "regulatory uncertainty is scary. It's no fun to go to an agency... and have them say they don't know if they can approve that or not."

In at least one instance, changes in regulatory approaches are related to growing concerns about the aggregate impact of energy industry activities (as opposed to the incremental impacts of individual wells or smaller projects). Regulators explained that rapid increases in exploration and production activity have forced them to rethink their assessment techniques. Said one, "the more gas we produce, the more water comes with it. We've had all these rules and regulations that served us well until... volumes overwhelmed our rules." In general, the rapid growth in applications for permits and attempts to get approval for innovative (yet unconventional) approaches to managing environmental challenges has also overwhelmed regulatory agency staff in recent years. With respect to constraints on the expanded the use of injection wells to dispose of produced waters (considered more environmentally friendly than using evaporation ponds), another respondent explained that "more than anything the EPA delay was just a backlog due to being understaffed in Denver."

While the ambiguity of regulatory expectations produced universal frustration, most respondents were not clear about what approach might work better. One agency informant believed that setting performance standards or goals that allowed industry to be innovative in designing approaches will be the most technically and economically efficient solution. However, the use of flexible performance standards means that industries proposing to use particular behaviors or technologies will not know in advance if their efforts have met regulatory expectations.

Economics

Much as strong energy prices facilitated adoption of environmentally-oriented practices, weak macro-economic conditions were cited as a barrier to the increased use of technologies to reduce the environmental impact of drilling. This is due to the combination of recent price declines in the natural gas sector, as well as the fact that producers in the Basin receive lower prices than other regions in the U.S. (due to limited pipeline infrastructure to deliver natural gas to major urban markets, which are also more distant from Utah than other natural gas sources). Low prices for natural gas (overall and relative to oil) discourage investment in new technology for natural gas exploration. As one industry informant put it, now that "the money is not in natural gas, most of our [company's] resources are now going to the Dakotas for oil." Another informant noted that "directional drilling is only affordable at certain gas prices. The technology is there, but utilization is cost dependent." The general message was that as the price of natural gas goes up, the ability to implement better technologies becomes more affordable. Industry informants discussed how the economic downturn in natural gas forced a number of the companies in the Basin to cease drilling and exploration activities. One agency respondent claimed the use of optional environmentally-friendly technologies "depends, of course, on the price of oil and gas." In other words, a poor economy is a bad time to adopt what many view as practices that involve high costs.

Most specific instances of 'non-adoption' were explained by perceptions that particular environmental practices were not yet economically viable. Some pointed to the importance of scale economies and the fact that some new technologies are too expensive or inappropriate for smaller operators in the region. They felt that larger companies "know what they've got, and it's easier to do an eight well pad in an established field." Others discussed how many local service companies have already invested in older technology and cannot afford to jettison those sunk investments. They also have trouble raising capital for purchasing the expensive cutting edge drilling rigs that are required for directional drilling or multi-well pads. For these companies, until better and cheaper exploration equipment comes out, "going straight down is easier."

In one case, an agency respondent noted that disposal of produced waters could be technically solved through the use of available onsite water treatment technology, but that the cost for such systems is prohibitive. The industry would "all switch tomorrow if there were an economic way." In a discussion about the recycling of water another respondent suggested that "until there is an economic benefit, it will be more on the fringe." Industry informants agreed, with one detailing how the biggest barrier to improved water management was always money. Despite preferences of regulatory agencies for the use of closed-loop systems (instead of evaporation pits or injection wells), the cheaper cost of using evaporation ponds, even when employing leak prevention and detection, was significant enough to prevent companies from recycling their drilling and hydrofracturing water. As one industry respondent related, while "there are areas where [water recycling] gets used... it adds a lot to the cost of drilling a well."

In discussions about directional drilling, most of our informants recognized that from a surface management standpoint, multi-well pads offered many advantages. The problem, as one informant explained, is that "for operators it has to be economics. Drilling superintendents would rather do vertical because it's easier" and better able to recover more gas than angled wells. They felt that smaller companies have a much harder time adopting and disseminating many of the new drilling techniques and technologies. As one regulatory informant illustrated, the costs of these practices manifest themselves in many ways, such as training employees in the use of new equipment. Regulators may ask the industry to engage in new practices, but they often find the industry response to be, "who will train our guys?"

In terms of air quality issues, agency informants believed that progress on adopting new environmentally-friendly approaches will depend on financial considerations. One explained that "even though you can make money by reducing emissions, [industry] has to demonstrate a rate of return for these projects, and they compete against one another for money." In air quality discussions as well as conversations regarding retrofitting or restimulating older wells using modern hydrofracturing techniques (which could reduce the footprint of new exploration activities), respondents explained that drilling new wells had a much higher rate of return than retrofitting equipment. The problem, as they saw it, was that the capital investment required for retrofitted wells in the Basin had a lower rate of return relative to improvements in efficiency than either the industry and regulators had hoped to see.

Engineering and Technology

Engineering and technology barriers came up least frequently in the interviews, but a handful of informants did identify a few key problems. One regulatory informant asserted that the biggest potential for environmental improvements in the Basin lies in the expanded reuse and recycling of water by the energy industry. They discussed types of new technologies they were hearing and reading about from other regions, but explained that these technologies were not well adapted to production conditions in the area and were either impractical or not cost-effective in this Basin. As another informant put it, “the holy grail would be small portable units that you could use to treat the water onsite, and then discharge it into a nearby stream. Whoever invents that would be a billionaire.”

Other limitations had more to do with the current state of drilling technology. Several informants thought local geologic formations were not appropriate for directional or horizontal drilling technologies. One argued that to be practical, “with today’s technology, [you] have to be going vertical to hit where you want to drill.” They explained that directional wells lose out on production potential through the zones of sandstone where they not drilling vertically. Another informant made the link between geology and economics more explicit by claiming that the “topography and underground geology will be what drives costs.” Several industry informants claimed that vertical drilling was required in much of this region due to the presence of corrosive salts and large geologic holes, and to ensure there was “any hope of hitting the target resource.”

The specific geologic formations that characterize the Uintah Basin were cited by respondents as one of the reasons injection wells are not more widely used. The absence of proven suitable geologic formations in the area left them with “no guarantee that the well will take water for long.” Others explained that while “the public perception is that you ought to make more injection wells... the geology just isn’t right.” Regulatory informants expressed similar feelings stating “there aren’t that many zones geologically that can take a lot of water.”

A final geologic or technical concern reflects the uneven, steep topography of this region. A handful of regulators and industry informants explained that options for consolidated multi-well pads and centralized hydraulic fracturing operations may be limited in areas that lack sufficient areas of flat land.

PART IV

IMPLICATIONS AND CONCLUSIONS

As noted at the outset of this report, our research project was designed to identify opportunities and barriers to reducing the environmental footprint of natural gas extraction in the Uintah Basin. The results presented above suggest that the techniques used for natural gas exploration and development have changed in important ways over the last two decades, and that many of those changes have been motivated by efforts to reduce environmental impacts and externalities. Prominent examples of environmental innovation include the use of multi-well drilling pads and directional drilling techniques to reduce surface disturbance, and the pre-treatment and careful management of produced waters prior to disposal in injection wells or evaporation ponds. Compared to standard practices in place a decade ago, there is much greater attention to protection of wildlife and threatened and endangered plants and animals. Similarly, upgrading access roads, electrification of some drilling pads, and new technologies (like improved diesel engines) have been used to improve air quality.

At the same time, the rate of adoption of different environmentally-oriented technologies or management practices has been uneven (both across companies working in the Basin and also compared to other natural gas production areas in the United States). Examples of approaches that are less widely used in the Basin are closed loop or recycled hydrofracturing water systems, aggressive treatment systems for cleaning and reusing produced waters, the use of drilling pad mats or disappearing roads, and the capture, testing and treatment of drilling muds and cuttings.

The natural gas industry in the Uintah Basin represents an important case study of how environmental practice ‘adoption’ occurs in a major industrial sector. Clearly, changes in production practices have occurred and there are important lessons to be learned about how these examples of environmental innovation have come about. In the interviews, our informants identified a wide range of drivers and barriers which they believe have affected the specific rate and direction of environmental innovation in the natural gas industry working in this region.

A simple theoretical model listing the important influences likely to shape changes in production practices is illustrated in Figure 9 below. The model shows that scientific research and technical innovation may be a key step in facilitating changes in behavior, but that economic factors will influence whether industry actors find it worthwhile (or possible) to utilize new technologies. Beyond the role of technology and economics, it is likely that regulations and public policies will shape the kinds of practices that are used in the natural gas industry (mainly by establishing a regulatory floor or creating incentives to encourage greater attention to environmental impacts). Regulations themselves often evolve because of changing societal and political demands for environmental quality and protection of natural resources. Finally, there is a potential role for corporate leadership to drive innovation by adopting new practices that go beyond regulatory requirements. This may occur because they believe it is the right thing to do (as a reflection of their corporate ethos), to improve public relations, to allow for faster regulatory approvals, or to prevent lawsuits in the future.

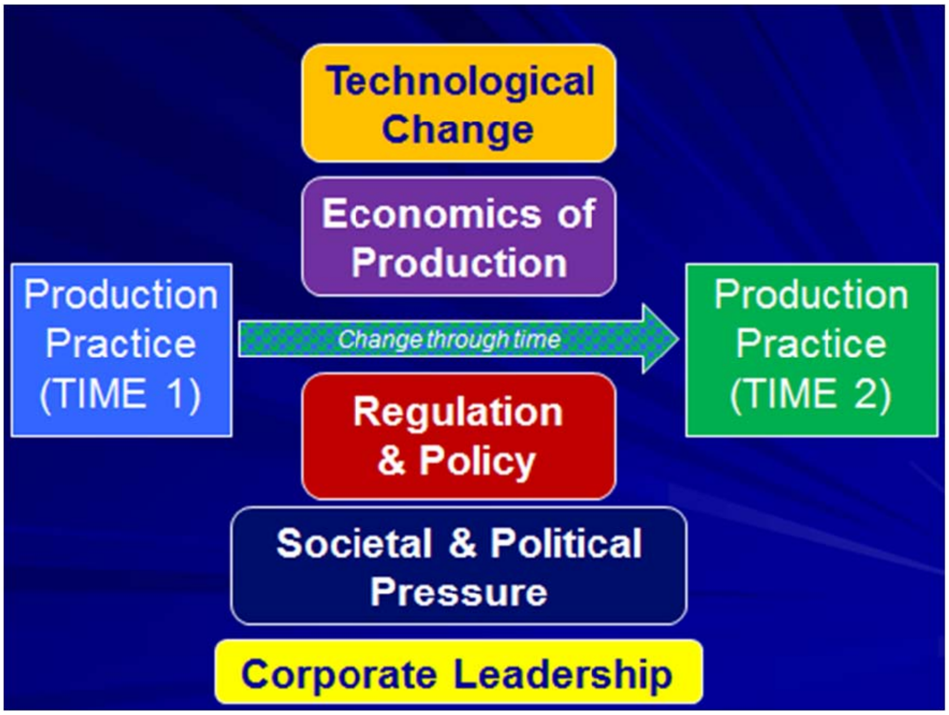


FIGURE 9: Factors Influencing Changes in Production Practices in the Energy Industry

Our research findings suggest that while technological innovation is an important link in the chain of events that lead to adoption, technical or engineering discoveries alone were rarely the primary driver of changes in behavior in this region. Put differently, sudden technical breakthroughs or cutting edge engineering advances were rarely cited as the event that allowed industries to change their practices. Also, there appears to be a long lag time between initial development of new approaches (by scientists or industry engineers) and the willingness of industry actors to deploy these on a large scale. Our industry respondents indicated a familiarity with many examples of environmentally-oriented technologies or practices being used in other areas, but perceived most of these to be impractical or too expensive for widespread use in the Uintah Basin.

We found that technology serves less as a driver of changes than as a mechanism to help remove obstacles or barriers to reducing the environmental footprint of the energy industry activities. It is clear that the absence of practical, reliable, and economically viable technical options can be a barrier to addressing some environmental concerns. The most common instances of voluntary adoption of environmental innovations – such as the recent adoption of multi-well pads and centralized hydrofracturing water systems by one company – were examples of “win-win” solutions where greater environmental protection could be accomplished using mature technology that simultaneously saved the company money.

The results indicate that public agency regulation and oversight are important drivers of changes in industry practice. However, the role of regulation is much more complex than appears on the surface. While a few instances of the adoption of environmentally-friendly practices could be directly linked to the passage of new rules or regulations, there were even more cases where industry leaders were 'ahead of the regulatory wave' and were exploring and testing new practices in advance of being required to do so. Some of the more innovative companies explained that they were voluntarily adopting new practices now in anticipation of future regulatory mandates because it was easier to experiment and refine their approaches without the constraints of strict agency rules. Similarly, most state and federal regulators were reluctant to require the use of specific practices until they were convinced that they were technically and economically viable. Examples of innovative companies successfully using these practices were important to increase the confidence and willingness of agency actors to adopt stricter environmental standards.

The complexity of state, tribal, and federal regulatory jurisdiction over energy development in the Basin further complicates the story. While one agency may feel they are sending clear regulatory signals to encourage (or require) changes in industry practices, other agencies may be sending contradictory signals. Moreover, most regulatory agencies have flexible standards that required project-specific site assessments and negotiations with individual companies to determine the specific mix of environmentally-protective practices that would be required in order to receive permits to drill or produce energy. The combination of complex jurisdictions and negotiated practice standards caused many of our industry respondents to express frustration and confusion about just what was being required of them. As a result, the direct impact of regulation on changes in environmental behaviors in the Basin is complex and difficult to document.

Social and political pressures provide an important backdrop to the ways in which technical, economic, and regulatory factors work to change industry practices. The dominant pattern of federal ownership of land and mineral rights in the Basin shapes the ways in which public concerns and pressures for change are expressed. Unlike natural gas development that has generated intense public debate and local environmental opposition in the northeastern United States (Barnes 2010, Robinson 2011), local social and political pressure in the Basin has not been a primary driver of increased environmental standards.

The prominent role of the federal government in the Uintah Basin translates to frequent requirement to use standard NEPA procedures that engage a wide range of stakeholders in a structured public input and review process. The respondents in our study frequently talked about how most environmental stakeholders who participate in that process are not from the local area, and instead represent statewide, regional or national environmental interest groups. At the same time, the tremendous importance of the energy industry to the local economy has led most local stakeholders to express formal concerns in the NEPA process that environmental issues be balanced against the economic benefits associated with resource development. Similarly, local and state elected representatives in the area express serious concerns that excessive environmental oversight might make energy companies shift their attention to other regions. Our informants suggested that political pressure to increase environmental regulation in the area has come from national elected officials and agency leaders, not from grassroots local organizations.

Finally, aside from the factors mentioned above, our study results suggest that some of the changes in environmental behavior originated from key actors within particular energy companies working in the Basin. Specifically, we found that concerns about public relations and the desire to cultivate a public image as a 'green' company with a national or international audience were often part of the motivation for particular companies to adopt new practices. In other cases, genuine corporate values in support of environmental responsibility and a desire to avoid negative impacts on the local community were part of the decision-making calculus when changes in industry practices were made.

Working Model for How Change Often Happens

Taken as a whole, our research suggests a somewhat complicated model for how important changes in production practices designed to minimize environmental impacts take place in the Utah energy industry. The first step in this model begins with growing awareness of and concern about a potential environmental issue (by industry, by agencies, and by societal actors). An example might be growing awareness of the aggregate or cumulative impact of drilling activities on dust and air quality conditions in the Basin. As awareness and concern about this issue become more widespread, a few companies proactively identify the need to come up with strategies to mitigate these problems. While new research or technical innovation can be required, it seems most typical for companies to mainly draw from existing proven technologies and practices that had been developed and tested by other industry players, universities or in other production regions. Simultaneously, regulatory agencies engage in both internal agency staff discussions and informal conversations with key industry actors to evaluate the seriousness of the issue and the possible changes in production practices that might improve the situation. The experiences of early innovators in industry often contribute to growing confidence at the agencies that (a) it is possible to address the concerns in a way that is technically and economically feasible; and (b) that some approaches are more likely to be viable and/or effective than others. Formal changes in state and federal regulations appear to influence behavior relatively late in the process, and seem to normalize emergent changes in behavior and extend them to actors who had (to that point) not voluntarily adopted these new approaches. Overall, the pace of these kinds of changes in the Uintah Basin are only indirectly affected by pressure from environmental groups, and most of that pressure filters through national organizations, federal agency administrative directions, and local formal processes for environmental review under NEPA.

Implications

There appears to be a high level of interest by nearly all parties to accelerate and facilitate efforts to reduce the environmental footprint of fossil fuel production in the Uintah Basin. Our research suggests that investments in new technical and engineering innovations are important to help reduce logistical and economic barriers to adoption. However, new technology alone is unlikely to generate changes that are not already of interest to (and demanded by) industry and agency actors. Market factors appear to affect the pace of change: robust economic conditions in energy commodity markets make it easier for industry actors to experiment with and invest in new technology and practices, but are not likely to be a primary driver for change. The role of regulation in driving future changes is likely to be mixed. On the one hand, if there were no possibility of stricter environmental rules and regulations in the future, the willingness of industry actors to incur costs to meet environmental objectives might be much lower. However, movement to reduce the environmental footprint of the industry will likely occur in ways that are not simply dictated by clear environmental laws and requirements. Conversations between regulators and industry are critical to clarify which kinds of environmental impacts are of most concern and to create the space for environmental innovation to occur. In addition, the perception that stricter regulatory standards will be coming down the pipe in the near future will likely serve as a major motivator for companies to proactively develop new strategies. It is likely that a handful of larger industry actors will provide a leadership role in generating and adopting environmental innovations, with smaller firms and local service contractors following their lead (perhaps only when such changes become mandatory).

The link between regulation and behavior is made more complex because of uncertainties about regulatory jurisdiction and authority in the Basin, and perceptions of variability in federal agency practices across political administrations in Washington. If they continue, these uncertainties will make it more difficult for industry actors to make informed judgments about which kinds of environmentally-oriented change are most likely to be required. A number of industry informants suggested that they would be happy to live with stricter environmental rules if (a) all relevant agencies would agree to follow the same rules, (b) they know they could get decisions on applications for leases and permits more quickly and in a predictable manner, (c) they could be assured that these rules would be stable for the foreseeable future.

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Appendices

Table A-1: Uintah Basin Natural Gas Production, 1984-2010 *(Gross Withdrawals, MCF).*

Year	Duchesne County	Uintah County	Uintah Basin	State Total	Basin Share %
1984	16,635,636	33,843,635	50,479,271	194,446,539	26.0%
1985	18,035,067	28,721,729	46,756,796	210,266,787	22.2%
1986	16,594,450	27,445,347	44,039,797	239,259,285	18.4%
1987	14,870,376	24,056,594	38,926,970	262,084,427	14.9%
1988	15,356,855	23,971,638	39,328,493	278,578,413	14.1%
1989	15,452,052	26,316,449	41,768,501	278,321,040	15.0%
1990	19,554,495	29,007,555	48,562,050	323,028,470	15.0%
1991	20,168,073	31,248,012	51,416,085	329,464,328	15.6%
1992	19,877,439	42,911,913	62,789,352	317,763,088	19.8%
1993	17,640,155	73,518,068	91,158,223	338,276,008	26.9%
1994	16,750,850	67,275,895	84,026,745	348,139,804	24.1%
1995	17,582,965	57,143,899	74,726,864	308,694,651	24.2%
1996	19,332,426	60,051,360	79,383,786	280,438,951	28.3%
1997	20,631,221	60,599,426	81,230,647	272,553,774	29.8%
1998	19,204,848	70,603,801	89,808,649	297,503,246	30.2%
1999	15,352,521	72,190,796	87,543,317	277,494,312	31.5%
2000	13,934,444	83,100,193	97,034,637	281,170,016	34.5%
2001	13,933,698	93,909,207	107,842,905	300,975,578	35.8%
2002	12,476,159	104,385,705	116,861,864	293,030,079	39.9%
2003	11,954,655	111,242,334	123,196,989	293,030,079	42.0%
2004	14,642,364	132,682,346	147,324,710	293,832,276	50.1%
2005	20,077,706	164,133,003	184,210,709	313,563,064	58.7%
2006	22,530,227	203,629,241	226,159,468	356,442,840	63.4%
2007	25,336,254	218,563,830	243,900,084	385,540,208	63.3%
2008	26,575,078	273,658,822	300,233,900	442,524,364	67.8%
2009	28,805,123	283,383,299	312,188,422	449,573,832	69.4%
2010	28,075,846	280,259,594	308,335,440	430,551,694	71.6%

Source: Utah Department of Natural Resources, Division of Oil, Gas and Mining

Table A-2: New, Spudded, Wells in the Basin from 2001-2010.

Year	Duchesne County	Uintah County	Uintah Basin	State Total	Basin % of Total
2001	74	390	464	631	73.5%
2002	44	226	270	391	69.1%
2003	89	333	422	480	87.9%
2004	166	441	607	660	92.0%
2005	184	570	754	890	84.7%
2006	281	656	937	1068	87.7%
2007	271	705	976	1137	85.8%
2008	234	719	953	1144	83.3%
2009	161	315	476	513	92.8%
2010	306	355	661	704	93.9%

Source: Utah Department of Natural Resources, Division of Oil, Gas and Mining