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Determining Environmental Tradeoffs Associated with Low Impact Drilling Systems

Richard C. Haut, Ph.D., Houston Advanced Research Center
David Burnett, Global Petroleum Research Institute (GPRI),Texas A&M University
John Rogers, Ph.D., Houston Advanced Research Center
Tom Williams, TerraPlatform, LLC.

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ABSTRACT

An environmental scorecard is being developed to determine the tradeoffs associated with implementing low impact drilling technology in environmentally sensitive areas. The scorecard will assess drilling operations and technologies with respect to air, site, water and biodiversity issues. Low environmental impact operations will reduce the environmental footprint of operations by the adoption of new methods to use in (1) getting materials to and from the rig site (site access), (2) reducing the rig site area, (3) using alternative drilling rig power management systems, and (4) adopting waste management at the rig site.

The scorecard enables a dialog to be established and maintained among all interested, concerned and affected stakeholders. In this manner, the oil and gas industry has a new way of seeing itself within the larger network.

The scorecard presented in the paper provides the means to demonstrate the connectivity between energy production and the affected ecosystem.

The Houston Advanced Research Center (HARC) and Texas A&M University have been leading an industry consortium effort to investigate the development of low impact drilling systems.

The work originated in 2005 and funding was obtained by the U.S. Department of Energy for 2006 through 2008.

The goal of the low impact drilling systems project is to reduce the environmental impact of rig operations through integration of low-impact site access and site operations. The paper will discuss the scorecard that is being developed. The scorecard methodology presents an ecological understanding of the tradeoffs associated with producing energy. The EFD scorecard will be developed in detail for a coastal margin ecosystem and the methodology will be documented to enable the scorecard to be replicated at other ecosystems wherever reservoirs are produced. This scorecard methodology is being developed through a series of workshops being held with ecologists, botanists, wildlife management experts and others in addition to oil and gas industry experts.

INTRODUCTION

The Houston Advanced Research Center (HARC) and Texas A&M University through the Global Petroleum Research Institute (GPRI) have been collaborating with industry and environmental organizations to integrate and demonstrate current and new technology into land-based drilling systems for compatibility with environmentally sensitive or off-limits areas. The **Environmentally Friendly Drilling Systems** (EFD) Program is taking a systems approach to the integration of currently known but unproven or novel technology in order to develop drilling systems that will have very limited environmental impact and enable moderate to deep drilling and production operations and activity with reduced overall environmental impact.

The EFD Program is identifying and providing the technology to successfully produce shale gas and tight gas sands while appropriately addressing environmentally sensitive issues. The project focuses on developing drilling technologies that can be used throughout the U.S., in particular, unconventional natural gas resources as illustrated in Figure 1 and Figure 2.

The work described in this paper is focused on the development of a methodology to determine environmental tradeoffs that are related to such issues as air, water, site, and biodiversity. This methodology was developed through a series of workshops to identify what needs to be measured and how the measurements should be made to determine environmental tradeoffs. Workshops were attended by representatives from government, academia, industry and various environmental organizations.

Why create something called “Environmentally Friendly Drilling”? Because new technology will help meet the U.S. energy needs for the next century at the same time we reduce the environmental “footprint” of oil and gas operations.

Exploration and production companies are aware that minimizing their environmental footprint is crucial to reducing environmental liabilities, controlling operational costs, and encouraging public acceptance for the sustainable development of the U.S. natural resources. There are certain restrictions for habitat protection, and in some cases complete prohibitions, that prevent drilling in many sensitive areas in the continental United States. Stakeholders desire to improve energy independence and to understand the environmental tradeoffs necessary to secure energy.

Sustainable development of petroleum resources requires careful monitoring and operations over the life cycle of a development, from the initial planning through decommissioning and site restoration. According to the recent National Petroleum Council’s recommendations, access to indigenous resources is essential for reaching North America’s full supply potential. New discoveries in mature North American basins represent the largest component of the future supply outlook. However, the trend towards increasing leasing and regulatory restrictions in the Rocky Mountain region the U.S. Coastal /Margins and the Outer Continental Shelf (OCS) is occurring in precisely the areas that hold significant potential for natural gas production.[1] The NPC evaluated the effect of removing the OCS moratoria and of reducing the impact of conditions of approval on the Rocky Mountain areas – a potential addition of 3 BCF/D by 2020. This represents more than 25% of the projected growth in natural gas needs of the U.S. by 2020.[2]

Land-use policies of federal, state, and local governments have not kept pace with technological advances that allow for exploration and production while protecting environmentally sensitive areas. Technical advances have reduced the number and size of onshore drilling sites and production facilities. The federal government has continued to set federal lands off-limits to development through legislation, executive orders, and regulatory and administrative decisions without acknowledging these advances.

According to the Texas Independent Oil and Gas Association, “*New technology developed by industry, universities and the Department of Energy is needed to help industry meet our members’ goal of producing oil and gas in a safe and environmentally acceptable manner; especially when operating in environmentally sensitive areas.*” The Independent Petroleum Association of America (IPAA) has consistently stated to Congress that access to more Federal Lands is the primary way to increase domestic oil and gas production. Many of these areas are on Federal Lands currently off-limits to drilling primarily because regulators, Congress and the environmental community are not convinced that technology is sufficient to develop these resources without adversely impacting the environment. While there may be technologies available to accomplish environmentally acceptable drilling, they have to be proven to be accepted. In response to this need, this project team will work with government, industry, academia and public organizations to identify, develop, and provide industry with the tools to develop needed energy supplies.

The Bureau of Land Management (BLM), and the Forest Service (FS), is responsible for ensuring compliance with the National Environmental Policy Act (NEPA). During the review of development proposals that encompasses multiple wells in a specific area, the BLM, the surface management agency, or the agency's or operator's environmental contractor conduct an environmental analysis and prepare an environmental document in conformance with the requirements of NEPA and the regulations of the Council on Environmental Quality (CEQ). Regardless of which agency, entity, or individual prepares the environmental analysis document, the BLM (and FS, for actions on National Forest System lands) must concur with the content prior to issuing a decision document. In the case of National Forest System lands, where the environmental analysis is conducted jointly with the BLM, each agency issues its own decision. The extent of the environmental analysis process and the time frame for issuance of a decision depend upon the complexity of the proposed action and resulting analysis, the significance of the environmental effects disclosed, and the completion of appropriate consultation processes.

Policies concerning biofuels, fossil fuels and greenhouse gases are being discussed and debated across America. A recent edition of ***Science*** summed up their view about the issues as follows[3]:

> 'If the prime object of policy on biofuels is mitigation of carbon dioxide–driven global warming, policy-makers may be better advised in the short term (30 years or so) to focus on increasing the efficiency of fossil fuel use, to conserve the existing forests and savannahs, and to restore natural forest and grassland habitats on cropland that is not needed for food. In addition to reducing net carbon dioxide flux to the atmosphere, conversion of large areas of land back to secondary forest provides other environmental services (such as prevention of desertification, provision of forest products, maintenance of biological diversity, and regional climate regulation), whereas conversion of large areas of land to biofuel crops may place additional strains on the environment. For the longer term, carbon-free transport fuel technologies are needed to replace fossil hydrocarbons.'

Scharlemann and Laurance have concluded that production of various biofuels, including U.S. corn ethanol and soy diesel, Brazilian sugarcane ethanol and soy diesel, and Malaysian palm-oil diesel, have sacrificed natural forest and grassland habitats on cropland that is being converted to energy biomass fuels. The authors recommend against such conversion.

Preventing loss of habitat provides other environmental services (such as prevention of desertification, provision of forest products, maintenance of biological diversity, and regional climate regulation) and avoids the biomass environmental impact costs that represent greater costs than do fossil fuels.[4]

Conservative estimates of the near term impact of the adoption of low impact drilling technology would increase the immediately accessible resources by more than 10%, just in the Texas Gulf Coast. The Chairman of the General Land Office Jerry Patterson[5] estimated the state's Permanent School Fund received more than $450 million dollars in revenue in 2006. Future revenues will include more than $104 million in royalties from its share of gas production from gas wells on Padre Island. These funds will add to the $22 billion in the Permanent School Fund, royalties from 13 million acres where the state retains an interest in the mineral rights, land office officials said.

Having a program that has the potential to "lighten the impact" of gas drilling in environmentally sensitive areas such as coastal margins, National Forests and Parks and other public lands is extremely important. Gas leases beneath many of state and national parks and public lands are owned by private companies, not the government. Only by setting environmentally responsible standards can park managers protect the environment while providing access to these resources.

How can advancements in drilling systems and technologies reduce environmental impacts? Several new practices and processes are being developed.

THE MORE YOU KNOW, THE LESS YOU NEED

The drilling process is considered a complex activity composed of a set of processes interrelated by purpose, sequence, and time. Millheim[6] defined the drilling process as a system in the mid 1980's. The systems themselves are made up of sub systems. The rig and the surface equipment is a complex subsystem of the drilling process. Pedersen and Essendrop defined the drilling system (Millheim's rig subsystem) comprised of six subsystems[7]: drilling control system, drilling machine, pipe handling, blow-out-preventer (BOP) and handling system, mud supply, and mud return[8]. Though defined for the offshore jack up design environment, many of the concepts have transitioned to the onshore rig design.

As knowledge has increased, technology has allowed the industry to contact almost 60 times the volume of subsurface rock material that could be accessed in 1970 while occupying only one third the surface area[9] (Figure 3). The technology of drilling and production can be unobtrusive and highly efficient if the technologies are used concurrently on the same well. In the past 20 years, technology has been able to significantly reduce the impact that drilling operations have on the environment. According to the Natural Gas Supply Association, some of the key technology developments over this time period have enabled the following.

- 22,000 fewer wells are needed on an annual basis to develop the same amount of reserves as were developed in 1985.
- Had technology remained constant since 1985, it would take two wells to produce the same amount of oil and natural gas as one 1985 well.
- Drilling wastes have decreased by as much as 148 million barrels due to increased well productivity and fewer wells.
- The drilling footprint of well pads has decreased by as much as 70 percent due to advanced drilling technology.
- By using modular drilling rigs and slim hole drilling, the size and weight of drilling rigs can be reduced by up to 75 percent over traditional drilling rigs.
- Had technology, and thus drilling footprints, remained at 1985 levels, today's drilling footprints would take up an additional 17,000 acres of land.

Documented best practices and lessons learned have greatly reduced environmental issues associated with drilling operations. The oil and gas industry just needs to combine these practices into EFD systems, then demonstrate their effectiveness in real applications.

REDUCE, REUSE, RECYCLE

The energy industry has progressed in taking into consideration environmental issues. Shell Exploration and Production Company established a Rig Waste Reduction Pilot Project in 2001 to identify potential waste reduction strategies.[10] Their preferential hierarchy that they developed is: *reduce, reuse, recycle, recover and dispose.* The majority of the total waste stream was found to be drilling discharges and non-hazardous oilfield waste. Mud use was reduced by 20% and mud component packaging was reduced by 90% through a combination of solids control efficiency, cuttings dryer technology and bulk mixing equipment. In addition, Shell implemented a sorting, compaction and recycling process for solid waste (consumables and trash) to reduce landfill disposal.

Schlumberger has introduced a total waste management program to mitigate rising quantities of landfill waste.[11] Benefits included an overall improvement in general housekeeping that reduced health and safety exposure and a general increase in environmental awareness and concern. As a result, the recommendation is made to ensure that the operator establishes a waste management program that covers all exploration, drilling and production activities.

Mobil implemented a waste management program for the Hugoton field operations.[12] The waste management system decreased overall waste-related costs while improving compliance assurance and reducing potential liability. The key element was a mechanical solids control system consisting of a semi-closed loop centrifuge flocculation dewatering process that removes solids for burial on location.

Chevron has published ten years of lessons learned concerning bio-treating exploration and production wastes.[13] They have successfully implemented bioremediation in diverse climates and in remote locations. The most common biological treatment techniques in the exploration and production industry are composting and land treatment. Land farming and composting have been successfully used for drilling wastes.[14]

There is currently an industry joint venture, sponsored by GPRI and the U.S. Department of Energy – National Energy Technology Laboratory to reduce waste volume of liquids at the rig site. This "Mud Pit Cleanup and Re-Use" project aims at recovering fresh water and solids-free brine at the rig site for re-use in drilling operations.[15]

RESTORE

Reducing, reusing and recycling are all important. For sustainability, more is required. The relationship between business and a healthy environment is critical to long-term sustainability. Paul Hawken has defined sustainability as a stable relationship between human culture and the living world.[16] Business practices need to address life on earth. Ecology and commerce need to be united. As industry weighs various business practices, a systematic methodology of understanding and guiding practices may be implemented to, first, develop an understanding of the tradeoffs. To develop an understanding of what is possible, an understanding of the current situation is required.

Today's industry is accepting costs of environmental stewardship. These costs must be reconciled with commercial interests. Environmental restoration, economic prosperity and social stability may co-exist and do not have to be in conflict.

WHAT GETS MEASURED, GETS DONE

The Nutrition Labeling and Education Act of 1990 mandated that food companies were required to use a new food label on most food products beginning in 1994. This new label, as illustrated in Figure 4, provides information to enable users to make educated decisions about what they eat.

The US Green Building Council (USGBC) has develop an analogous label, as illustrated in Figure 5, for summarizing how a building measures up in their Leadership in Energy and Environmental Design (LEED) Green Building Rating System™. The LEED system encourages and accelerates the use of green building practices through the implementation of universally understood and accepted tools and performance criteria.

The methodology being developed to measure tradeoffs concerning environmental issues related to oil and gas operations can use the nutrition label and the LEED system as analogies.

USGBC LEED PROGRAM

The USGBC LEED program can serve as a model for the methodology to measure tradeoffs concerning energy production. The LEED program is a nationally accepted benchmark for the design, construction and operation of green buildings, providing a tool to measure a building's performance and impact. The LEED program measures performance in five areas: sustainable site development, water savings, energy efficiency, materials selection and indoor environmental quality. The rating systems were developed through a consensus-based process involving a diverse group of practitioners and experts representing a cross-section of the building and construction industry. The various LEED rating systems that are administered by the USGBC are illustrated in Figure 6. Figure 7 illustrates a completed scorecard for a newly constructed building.

THERE IS ONLY ONE BUS

In 1963, Buckminster Fuller published his ***Operating Manual for Spaceship Earth***[17] where he discusses the limited supply of energy onboard the spaceship and the need to harness the energy being supplied by the sun. Another way of looking at it is to realize that everyone is on the same bus and that there is a limited amount of fuel in the tank. While technologies are being pursued to harness solar energy, technologies need to be developed and implement to ensure that current energy supplies are being used efficiently and that all new fuel supplies that are tapped are done in a manner that will not be detrimental to those onboard.

There are tradeoffs between energy needs and biodiversity values. Many areas that are potentially valuable for energy are also recognized for biodiversity values. Energy development can impact biodiversity. The energy industry needs to meet public demand for energy while at the same time meet society's expectations for corporate, social and environmental responsibility. Conservation organizations need to be a voice for biodiversity protection while appropriately partnering with industry, recognizing that there is a balance to be struck between economic development, energy production and the conservation of biodiversity.

The EFD program is aimed at tapping the fuel supplies in an environmentally sound manner. The scorecard methodology aims to measure that manner that demonstrates its effectiveness.

Everyone on the bus has a vested interest in ensuring that sources of energy are produced using technologies that are not harmful. To develop the tradeoffs scorecard methodology, the decision was made to get as many stakeholders around the same table as possible, including, industry producers and service companies, ecologists, botanists, toxicologists, zoologists, wildlife managers, endocrinologists, environmentalists, regulators, and others. An initial workshop was held with representatives from government, academia, non-profits, industry and environmental organizations with the objective of discussing the tradeoffs associated with producing energy.

The focus of the workshop was the drilling systems and operations, recognizing that there is a need to also consider other oil and gas systems and operations. Environmentally Friendly Exploration and Production scorecards could be developed, as a minimum, for:

- Exploration
- Drilling
- Completion
- Processing
- Refining
- Transportation
- Distribution
- Field Development
- Field Operations

An EFD scorecard for drilling systems and operations was selected as the first scorecard to be developed due to the ease at which a boundary can be established around the time and location for the systems and operations.

WHAT GETS IDENTIFIED, GETS DEALT WITH

The objective of the EFD scorecard is to have a methodology that is meaningful, simple and easy to implement and understand. Five attributes were identified as meaningful to evaluate: site (soil/sediment), water, air, biodiversity and societal issues.

Each attribute could have several layers or sub-attributes. As an example, within biodiversity, the potential threat to wildlife due to proximity or timing of operations could be assessed and minimized. Drilling activities have the potential risk of temporarily interfering with wildlife. The risk can be mitigated through proper planning and monitoring of operations.

The EFD scorecard has two point levels. First are the prerequisites – those items that must be done. Secondly are optional credits – those items that are considered best practices, going beyond minimum operating requirements.

Prerequisites for the various attributes could be rules and regulations that govern the drilling locations. Within the United States, regulations vary by state and address various environmental issues by geographic location. Argonne National Laboratory, in conjunction with Marathon and Chevron, has developed an interactive website that summarizes state and federal regulations governing drilling waste. The website also provides descriptions of various technical options as well as case studies and other information.[18]

Interaction between operations and wildlife can vary greatly depending on the area of operation and the kind of wildlife present. There are certain times of the year when wildlife is more sensitive to external influences. Such times include migration, mating, birthing and spawning. Sensitive areas can be clearly displayed on maps and graphs. The recommendation is made to establish boundaries concerning time and distances – establishing exclusion zones at certain times of the year.

Where interaction is unavoidable, the following steps may be taken to minimize disruption:

- Scouting the sensitive areas and planning routes likely to cause least disruption.
- Staying clear of wildlife areas marked on the planning map to avoid sensitive areas.
- Banning hunting and fishing at all times.
- Instructing the crew not to intentionally harass or feed wildlife.
- Banning pets on all crew facilities.
- Reporting incidents and any significant problems with wildlife.

Conoco's St. Charles Field, located in the Aransas National Wildlife Refuge, is an example of profitable oil and gas operations co-existing with wildlife and nature.[19] The key learning from their effort is to ensure that operations are sensitive to the wildlife activities.

There are other best practices to minimize disturbances on wildlife populations that can be followed during drilling operations, including:

1. Pad locations should not be within 1,000 feet of the perimeter of an active wildlife location or within 1,500 feet of an endangered species' nest.
2. Each proposed pad location and the surrounding area should be field surveyed for the presence of endangered, threatened, and sensitive species and other environmental concerns, including water quality issues, prior to any construction activities and for final approval.
3. Pad locations should use every method and process available to minimize environmental impacts including, but not limited to:

    - A closed drilling fluid system shall be used.
    - Stockpiling topsoil and installing a silt fence around the spoils pile, the location perimeter, new access roads, and all other locations as needed.
    - Lining all pits at the location with an appropriate impervious material and ensuring that all surface runoff and fluids at the location are captured onsite and properly disposed of offsite.
    - Exposed or disturbed soil resulting from all pad construction shall be stabilized using native grasses/vegetation.
    - Reclaiming the site to its original elevations using the stockpiled topsoil and replanting the entire area with native grasses/vegetation.
    - Containment areas shall be constantly maintained and shall be periodically pumped clear of fluids and rainwater to minimize long-term soil contamination.

Texas A&M University has just announced creation of a Desert Research and Testing Center on the edge of the Chiuahua Desert near Pecos, Texas (reference). This center, created with the support from the Research Partnership to Secure Energy for America (RPSEA) aims at testing examples of low impact drilling systems in a real life demonstration, but in a controlled environment where performance can be measured more effectively with less harm to the environment.[20]

The first systems to be tested will be low impact access roads. Part of this project is a “Disappearing Roads” competition established by Texas A&M University with the support of Halliburton to identify ways to move people and material to and from drill sites with minimal impact.

Another example would be the sub-attribute of aquifer protection under the water category. During the drilling operation, several strings of casing of reducing diameter are run and cemented in place. The critical casing string with respect to potential damage to an aquifer is the casing string that is set across the aquifer. The critical issues are related to 1) the drilling through the aquifer – following best practices to ensure that the drilled hole is in the best possible condition prior to running the casing, 2) the outer surface of the casing – to enable the cement to have adequate adherence to the casing, and 3) the cementing operation – again, following best practices to mitigate potential cement column degradation during the life of the well.

For Texas, state wide rules relative to oil and gas operations fall under the jurisdiction of the Texas Railroad Commission and are found in Title 16 (Economic Regulation), Part 1 (Railroad Commission of Texas), Chapter 3 (Oil and Gas Division) of the Texas Administrative Code.[21] Rule §3.8 covers Water Protection and provides for various disposal methods that do not require a permit. These include:

- Disposal of inert wastes by a method other than disposal into surface water**;**
- Disposal of certain categories of low-chloride drilling fluid by land farming**;**
- Disposal of other drilling fluid down the annulus of a producing well or down the well bore of a dry and abandoned well prior to plugging, so long as the wastes are generated at that specific well site**;** and
- Disposal of completion workover pit wastes by burial **i**n a completion/workover pit.

Texas Railroad Commission Rule §3.8 also governs pit and surface waste management standards including standards for short-term pits such as drilling pits and completion/workover pits.

Texas Railroad Commission Rule §3.13 governs casing, cementing, drilling and completion requirements. The rule states that sufficient cement shall be used to fill the annular space outside the casing from the shoe to the ground surface or to the bottom of the cellar. This rule implies that all aquifers will have cement across the interval. Cement quality is governed by the rule. Alternative methods of fresh water protection may be applied for to the appropriate district director.

The operator is responsible to be in compliance with the Texas Railroad Commission rules. Rule §3.13 is intended to ensure that all usable-quality water zones are isolated and sealed off to effectively prevent contamination or harm and that all potentially productive zones are isolated and sealed off to prevent vertical migration of fluids or gases behind the casing. Surface casing must be set and cemented to protect all usable-quality water strata. Sufficient cement must be used to fill the annular space outside the casing from the shoe to the ground surface.

Various publications[22,23,24,25,26] discuss best practices associated with drilling operations to protect aquifers. Key items include:

- Install and cement a sufficient amount of casing from the base of the aquifers to the ground surface.
- Use pipe rotation or high annular velocities to increase the flow energy of the cement during to ensure mud displacement.
- Communication is a key – ensure that all are informed and understand daily goals and objectives. Use a cement formulation that minimizes shrinkage during setting.

Another sub-attribute related to water is surface contamination. During drilling operations, best practices need to be followed to minimize risks associated with potential surface contamination. Minimizing potential surface contamination will lower the risk of damaging artesian springs or aquifers. Large volumes of drilling fluids need to be handled correctly. In addition, rain runoff from the site must be properly contained.

A water runoff management program may be developed to control discharges of waste water to the environment.[27] Current practices typically include a moat (levy around the entire drill pad site. Any fluids collected in the moat are pumped into the reserve pit. All fluids collected in the reserve pit are then hauled off location for proper disposal. Controlling run off is one of the top environmental concerns. The program could include collection ditches/berms around all areas and equipment that could discharge contaminated water. An incentive scheme could also be a part of the program with a bonus or penalty based on the volume of water discharged and the hydrocarbon content of the discharged water.

Other industry practices were reviewed. Key best practices include:

- Whenever possible, use previously impacted terrain for access routes[28]
- Use close-looped and containerized mud system[28]
- Use 'environmentally friendly' substitutes for hydraulic fluids and lubricating compounds[28]
- Use integrated waste minimization practices and innovative restoration alternatives[28]

- Ensure that all equipment installed on the site is designed so that any effluent is caught and is not discharged directly in the environment[29]
- Use environmentally friendly drilling fluids[29]
- Establish a management system of authorized chemicals with a storage system, safety data files and a stock-management program[29]
- Reduce waste volumes at the source: water consumption, optimized recycling of mud, reduction of cuttings volumes[29]
- Establish a cuttings management plan[29]

The initial workshop identified the various attributes and sub-attributes. Based on the workshop, the need for continue dialogue among all stakeholders was strongly recognized. The scorecard development team is in the process of reviewing best practices, the literature, regulations and facilitating meetings and dialogue with various experts in order to develop the scorecard as well as how to implement the measurement process for the various credits. An initial draft of the scorecard is illustrated in Figure 8.

NOW WHAT? THE SYSTEMS APPROACH TO SELECTION

With the prototype scorecard methodology in hand, it is now time to fully develop an EFD scorecard for a given location and test it out.

The scorecard team will be working with stakeholders to apply the methodology to develop ecosystem-specific scorecards for semi-arid and wetland ecosystem locations. Over the coming year the EFD scorecard will be used to investigate the tradeoffs associated with drilling operations in a coastal margin ecosystem.

Concurrently with development of the EFD scorecard, Texas A&M, HARC and their partners are developing a number of other low-impact technologies. We expect to demonstrate these systems in upcoming field trials by our sponsors.

Finally as part of the A&M/HARC EFD program, researchers at Johns Hopkins University and Texas A&M are developing a new approach to identify the environmentally friendly technology that could be included in an EFD system. The systems approach works with matrices of many possible solutions to assist in choosing the system (or combination of technologies) that should be selected for specific drill sites. This quantitative approach to evaluate systems is being used to design preliminary plans for well sites along the Gulf Coast in Texas.[30]

A prototype web-based systems optimization program is available for industry sponsors to choose among the more than 70 technologies identified by the EFD team that reduces the environmental footprint of drilling operations.

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REFERENCES

[1] *Balancing Natural Gas Policy – Fueling the Demands of a Growing Economy Volume I Summary of Findings and Recommendations,* National Petroleum Council, September 25, 2003.

[2] International Energy Outlook 2007, Energy Information Agency, Chapter 4. "Natural Gas".

[3] Righelato, R. and Spracklen, D.: '*Carbon Mitigation by Biofuels or by Saving and Restoring Forests?' **Science**,* Aug. 17, 2007, vol. 317, p. 902.

[4] Scharlemann, J.P.W. and Laurance, W.F.: *'How Green are Biofuels?"* ***Science***, January 4, 2008, vol. 319,p. 43-44.

[5] General Land Office Annual Report, 2006, "Mineral Revenue" page 14.

[6] Millheim, K.K. and Huggins, R.L.: "An Engineering Simulator for Drilling Part I," paper SPE 12075 presented at 1983 SPE Annual technical Conference and Exhibition, San Francisco, Ca, Oct 5-8.

[7] Pedersen, Paul and Finn Essendrop: "New Jack-Up Design Improves Drilling Efficiency," *Oil and gas Journal Online* September 14, 1992.

[8] Kudsk, Carsten P., G. Lund: "Contractors Long Overdue Focus on Drill Floor and Its Equipment" paper SPE/IADC 23863 presented at 1992 SPE/IADC Drilling Conference, New Orleans, La, Feb. 18-21

[9] Harrison, William: "Current Environmental Practices in Petroleum Exploration & Production," in *Energy and the Environment: A Partnership that Works: The Actual Impacts of Oil and Gas Exploration and Development on our Environment*, Ed. By Lee C. Gerhard, et al., March 2005 American Association of Petroleum Geologists, Tulsa.

[10] Satterlee, K., van Oot, E. and Whitlatch, B.: 'Rig Waste Reduction Pilot Project,' SPE 80582, SPE/EPA/DOE Exploration and Production Environmental Conference, San Antonio, TX 10-12 March 2003.

[11] Lawrie, G. and Forbes, D.: 'Introducing a Total Waste Management Program,' SPE 98193, SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, Abu Dhabi, U.A.E., 2-4 April 2006.

[12] Robb, A.J. and Beaty, T.D.: 'Waste Management and Minimization in the Hugoton Field, Southwest Kansas,' SPE 35914, International Conference on Health, Safety & Environment, New Orleans, LA, 9-12 June 1996.

[13] McMillen, S.J., Smart, R. And Bernier, R.: 'Biotreating E&P Wastes: Lessons Learned from 1992-2003,' SPE 86794, 7th SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, Calgary, Alberta, Canada, 29-31 March 2004.

[14] Zimmerman, P.K. and Robert, J.D., 'Oil-Based Drill Cuttings Treated by Landfarming,' *Oil & Gas Journal* (1991), ***89***(32):81-84.

[15] Burnett, D. B. Department of Energy National Energy Technology Laboratory End of Year Report, 2007. DE-FC26-05NT42658

[16] Hawken, Paul: **Blessed Unrest**, 2007. p 172

[17] Fuller, Buckminster: **Operating Manual for Spaceship Earth**, 1963.

[18] Veil, J.A., Gasper, J.R., Puder, M.G., Sullivan, R.G., Richmond, P.D., Fidler, B.R., Fleming, C.N., Bernier, R.F., and Jones, F.V.: 'Innovative Website for Drilling Waste Management,; SPE 80603, SPE/EPA/DOE Exploration and Production Environmental Conference, San Antonio, TX, 10-12 March 2003.

[19] Dumas, D.: 'St. Charles Field: A Culture of Environmental Stewardship,' SPE 66573, SPE/EPA/DOE Exploration and Production Environmental Conference, San Antonio, TX, 26-28 February 2001.

[20] Burnett, D. B.: "Oil & Gas Operations in Desert Ecosystems: Creation and Long term Monitoring of New Technology to Lower Footprint of Access Roads to Well Sites**",** GPRI Announcement, March, 2007.

[21] http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC

[22] Owens, Willard G.: 'Protection of an Aquifer – A Case History,' SPE 3617, 46th Annual SPE conference, New Orleans, LA, October 3-6, 1971.

[23] Haut, R.C., and Crook, R.J.: 'Primary Cementing – The Mud Displacement Process,' SPE 8353, 54th Annual SPE conference, Las Vegas, NV, September 23-26, 1979.

[24] Cowthran, James, L: 'Technology Used to Improve Drilling Performance and Primary Cementing Success in Katy Field,' SPE 10956, 57th Annual SPE conference, New Orleans, LA, September 26-29, 1982.

[25] Chaney, M.L.: 'Back to the Basics: Planning the Operations for Drilling a Well,' IADC/SPE 19930, 1990 IADC/SPE Drilling Conference, Houston, TX, February 27 – March 2, 1990.

[26] Dusseault, M.B., Gray, M.N., and Nawrocki, P.A.: 'Why Oilwells Leak: Cement Behavior and Long-Term Consequences,' SPE 64733, SPE International Oil and Gas Conference, Beijing, China, November 7-10, 2000.

[27] Baizin, R.M. and Broucke, A.: 'Water Runoff Management: A Joint Operator/Drilling Contractor Approach,' SPE 21783, Second International Conference on Health, Safety & Environment in Oil & Gas Exploration & Production, Jakarta, Indonesia, 25-27, January 1994.

[28] Kudla, M.S., McDole, B.W.: 'Managing Drilling Operations in a Sensitive Wetlands Environment,' SPE 35780, International Conference on Health, Safety & Environment, New Orleans, LA, 9-12 June 1996.

[29] Morillon, A., Vidalie, J. Hamzah, U.S., Suripno, S. and Hadinoto, E.K.: 'Drilling and Waste Management,' SPE 73931, SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, Kuala Lumpur, Malaysia, 20-22 March 2002.

[30] Briaud, J.L., Bickel, E., Guikema, S., OK-Yuon Yu, " Systems Approach for Technology Selection in Environmentally Friendly Drilling" GPRI Presentation, March 11, 2008.

Figures

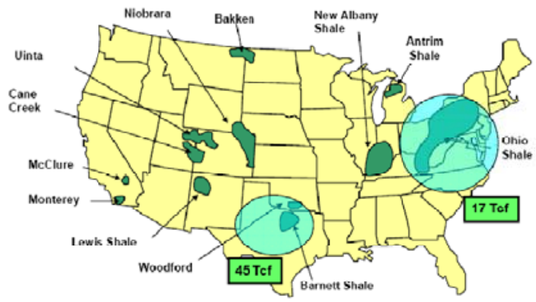

Figure 1. Shale Gas - 69 Tcf Technically Recoverable.

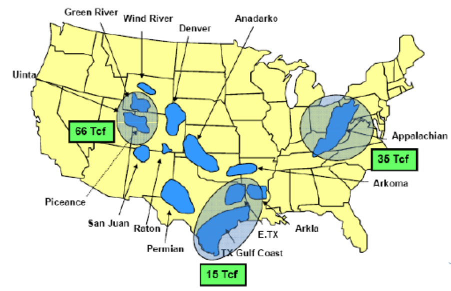

Figure 2. Tight Gas Sands - 159 Tcf Technically Recoverable.

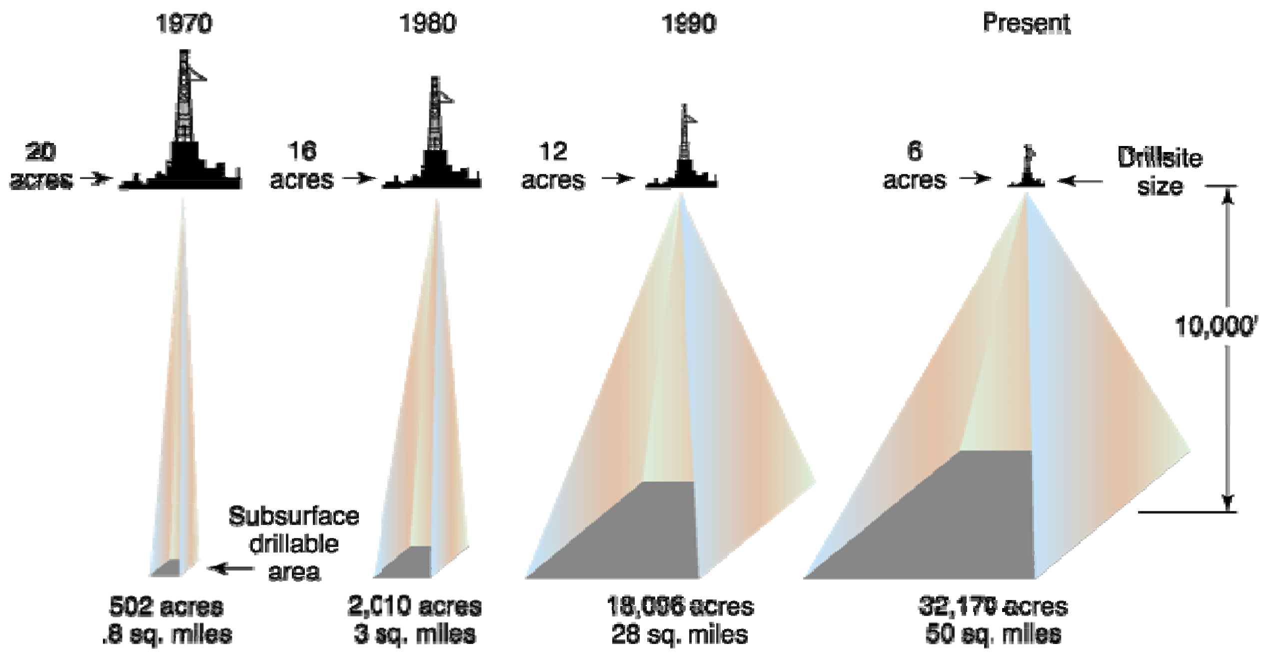

Figure 3. Technology Advancements - Decreasing Environmental Tradeoffs.
(source: William Harrison, Kansas Geological Survey)

Figure 4. Typical Food Label.

Figure 5. Typical USGBC LEED Summary.

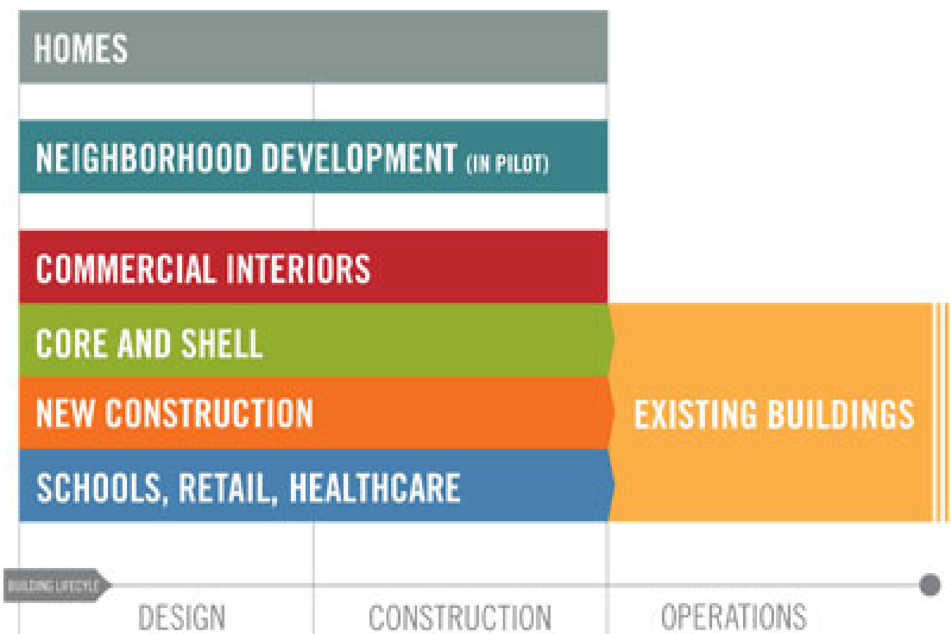

Figure 6. USGBC LEED Rating Systems.

LEED-NC

Bldg. 27 Astronuat Quarantine Facility
LEED® Project # 1486
LEED Version 2 Certification Level: CERTIFIED
2/24/2006

28 Points Achieved — Possible Points: 69

Certified 26 to 32 points   Silver 33 to 38 points   Gold 39 to 51 points   Platinum 52 or more points

6 Sustainable Sites — Possible Points: 14

Y			
Y	Prereq 1	Erosion & Sedimentation Control	
1	Credit 1	Site Selection	1
	Credit 2	Urban Redevelopment	1
	Credit 3	Brownfield Redevelopment	1
	Credit 4.1	Alternative Transportation, Public Transportation Access	1
1	Credit 4.2	Alternative Transportation, Bicycle Storage & Changing Rooms	1
	Credit 4.3	Alternative Transportation, Alternative Fuel Refueling Stations	1
	Credit 4.4	Alternative Transportation, Parking Capacity	1
	Credit 5.1	Reduced Site Disturbance, Protect or Restore Open Space	1
1	Credit 5.2	Reduced Site Disturbance, Development Footprint	1
	Credit 6.1	Stormwater Management, Rate and Quantity	1
	Credit 6.2	Stormwater Management, Treatment	1
1	Credit 7.1	Landscape & Exterior Design to Reduce Heat Islands, Non-Roof	1
1	Credit 7.2	Landscape & Exterior Design to Reduce Heat Islands, Roof	1
1	Credit 8	Light Pollution Reduction	1

1 Water Efficiency — Possible Points: 5

Y			
1	Credit 1.1	Water Efficient Landscaping, Reduce by 50%	1
	Credit 1.2	Water Efficient Landscaping, No Potable Use or No Irrigation	1
	Credit 2	Innovative Wastewater Technologies	1
	Credit 3.1	Water Use Reduction, 20% Reduction	1
	Credit 3.2	Water Use Reduction, 30% Reduction	1

4 Energy & Atmosphere — Possible Points: 17

Y			
Y	Prereq 1	Fundamental Building Systems Commissioning	
Y	Prereq 2	Minimum Energy Performance	
Y	Prereq 3	CFC Reduction in HVAC&R Equipment	
1	Credit 1.1	Optimize Energy Performance, 20% New / 10% Existing	2
	Credit 1.2	Optimize Energy Performance, 30% New / 20% Existing	2
	Credit 1.3	Optimize Energy Performance, 40% New / 30% Existing	2
	Credit 1.4	Optimize Energy Performance, 50% New / 40% Existing	2
	Credit 1.5	Optimize Energy Performance, 60% New / 50% Existing	2
	Credit 2.1	Renewable Energy, 5%	1
	Credit 2.2	Renewable Energy, 10%	1
	Credit 2.3	Renewable Energy, 20%	1
1	Credit 3	Additional Commissioning	1
1	Credit 4	Ozone Depletion	1
	Credit 5	Measurement & Verification	1
1	Credit 6	Green Power	1

5 Materials & Resources — Possible Points: 13

Y			
Y	Prereq 1	Storage & Collection of Recyclables	
	Credit 1.1	Building Reuse, Maintain 75% of Existing Shell	1
	Credit 1.2	Building Reuse, Maintain 100% of Existing Shell	1
	Credit 1.3	Building Reuse, Maintain 100% Shell & 50% Non-Shell	1
1	Credit 2.1	Construction Waste Management, Divert 50%	1
	Credit 2.2	Construction Waste Management, Divert 75%	1
	Credit 3.1	Resource Reuse, Specify 5%	1
	Credit 3.2	Resource Reuse, Specify 10%	1
1	Credit 4.1	Recycled Content	1
1	Credit 4.2	Recycled Content	1
1	Credit 5.1	Local/Regional Materials, 20% Manufactured Locally	1
1	Credit 5.2	Local/Regional Materials, of 20% Above, 50% Harvested Locally	1
	Credit 6	Rapidly Renewable Materials	1
	Credit 7	Certified Wood	1

7 Indoor Environmental Quality — Possible Points: 15

Y			
Y	Prereq 1	Minimum IAQ Performance	
Y	Prereq 2	Environmental Tobacco Smoke (ETS) Control	
	Credit 1	Carbon Dioxide (CO_2) Monitoring	1
	Credit 2	Increase Ventilation Effectiveness	1
1	Credit 3.1	Construction IAQ Management Plan, During Construction	1
1	Credit 3.2	Construction IAQ Management Plan, Before Occupancy	1
1	Credit 4.1	Low-Emitting Materials, Adhesives & Sealants	1
1	Credit 4.2	Low-Emitting Materials, Paints	1
1	Credit 4.3	Low-Emitting Materials, Carpet	1
	Credit 4.4	Low-Emitting Materials, Composite Wood	1
	Credit 5	Indoor Chemical & Pollutant Source Control	1
	Credit 6.1	Controllability of Systems, Perimeter	1
	Credit 6.2	Controllability of Systems, Non-Perimeter	1
1	Credit 7.1	Thermal Comfort, Comply with ASHRAE 55-1992	1
1	Credit 7.2	Thermal Comfort, Permanent Monitoring System	1
	Credit 8.1	Daylight & Views, Daylight 75% of Spaces	1
	Credit 8.2	Daylight & Views, Views for 90% of Spaces	1

5 Innovation & Design Process — Possible Points: 5

Y			
1	Credit 1.1	Innovation in Design	1
1	Credit 1.2	Innovation in Design	1
1	Credit 1.3	Innovation in Design	1
1	Credit 1.4	Innovation in Design	1
1	Credit 2	LEED® Accredited Professional	1

Figure 7. Typical Completed USGBC LEED Scorecard.

Environmentally Friendly Drilling Scorecard

EFD

Project:
Location:
Ecosystem:
Date:

0	Points Achieved	Possible Points:	100

★ 55 - 64 points ★★ 65 - 74 points ★★★ 75 - 84 points ★★★★ 85 - 94 points ★★★★★ 95 - 100 points

0	Air	Possible Points:	10
	Prerq 1	On-site Power - Tier 3 Engines	
	Prerq 2	Contractual Obligations for Logistics	
	Credit 1	Site Emissions - Stationary	2
	Credit 2	Site Emissions - Temporary	2
	Credit 3	Site Emissions - Logistics/Transport	2
	Credit 4	Dust Supression	2
	Credit 5	Electric Rig	1
	Credit 6	Green Completions	1

0	Site	Possible Points:	15
	Prerq 1	Regulatory Compliance	
	Prerq 2	Erosion & Sedimentation Control	
	Credit 1	Pre-Existing Site	3
	Credit 2	Pad Drilling	2
	Credit 3	Protect and Restore Habitat	2
	Credit 4	Contractor Guidelines	2
	Credit 5	Site Restoration Plan	2
	Credit 6	Match Site/Access to Topography	1
	Credit 7	Avoidance of Archeological Sites	1
	Credit 8	Logisitics Plan - Offsite Storage	1
	Credit 9	Planting of Native Vegetation	1

0	Waste Management	Possible Points:	20
	Prerq 1	Waste Management Plan	
	Prerq 2	Title	
	Credit 1	Closed Loop Mud System	5
	Credit 2	Title	2
	Credit 3	Title	2
	Credit 4	Title	2
	Credit 5	Title	2
	Credit 6	Title	2
	Credit 7	Title	2
	Credit 8	Title	1
	Credit 9	Title	1
	Credit 10	Title	1

0	Biodiversity	Possible Points:	20
	Prerq 1	Species Protection	
	Prerq 2	Habitat Protection/Enhancement	
	Prerq 3	Regulatory Requirements	
	Credit 1	Restoration/Interim Reclamation	3
	Credit 2	Reduction of Surface Disturbance	3
	Credit 3	Erosion Prevention	3
	Credit 4	Voluntary Offsite Mitigation	2
	Credit 5	Invasive Species Prevention	2
	Credit 6	Restoration of Fragmented Habitat	2
	Credit 7	Reintroduction of Species, Habitat	2
	Credit 8	Avoidance of High Value Areas	1
	Credit 9	Wildlife Protection	1
	Credit 10	Habitat Enhancement	1

0	Water	Possible Points:	15
	Prerq 1	Stormwater Mangement Plan	
	Prerq 2	Water Management Plan	
	Credit 1	Water Usage Tracking	4
	Credit 2	Setbacks from Streams/Sources	3
	Credit 3	Reduce Water Usage	2
	Credit 4	Reuse of Water/Fluids	2
	Credit 5	Recycling of Water/Fluids	2
	Credit 6	Monitor Nearby Surface Waters	1
	Credit 7	Pressure Testing of Surface Casing	1

0	Societal	Possible Points:	20
	Prerq 1	Community Engagement	
	Prerq 2	Communication Plan	
	Credit 1	Public Outreach	5
	Credit 2	Noise Control	2
	Credit 3	Training of Local First Responders	2
	Credit 4	Remote Alarms for Toxic Releases	2
	Credit 5	Emergency Management Plan	2
	Credit 6	Dispute Resolution Plan	2
	Credit 7	Land Use Damage Plan	2
	Credit 8	Landowner Indemnification	1
	Credit 9	Water Well Mitigation Agreement	1
	Credit 10	Surface Use Agreement	1

EFD Facts

Project:
Location:
Ecosystem:

	Max	Score
AIR	10	0
WATER	15	0
SITE	15	0
WASTE MANAGEMENT	20	0
BIODIVERSITY	20	0
SOCIETAL	20	0
	100	0

☆ ☆ ☆ ☆ ☆

Figure 8. Prototype Environmentally Friendly Drilling Scorecard.