Probabilistic Risk Based Decision Support for Oil and Gas Exploration and Production Facilities in Sensitive Ecosystems

Annual Management Progress Report

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Abstract

This report describes work performed during the initial period of the project "Probabilistic Risk Based Decision Support for Oil and Gas Exploration and Production Facilities in Sensitive Ecosystems." The specific region that is within the scope of this study is the Fayetteville Shale Play. This is an unconventional, tight formation, natural gas play that currently has approximately 2 million acres under lease, primarily to Southwestern Energy Incorporated and Chesapeake Energy Incorporated. The currently active play encompasses a region from approximately Fort Smith, AR east to Little Rock, AR approximately 50 miles wide (from North to South). The initial estimates for this field put it almost on par with the Barnett Shale play in Texas. It is anticipated that thousands of wells will be drilled during the next several years; this will entail installation of massive support infrastructure of roads and pipelines, as well as drilling fluid disposal pits and infrastructure to handle millions of gallons of fracturing fluids. This project focuses on gas production in Arkansas as the test bed for application of proactive risk management decision support system for natural gas exploration and production.

The activities reported on in this period include meetings with representative stakeholders, development of initial content and design for an educational web site, and development and preliminary testing of an interactive mapping utility designed to provide users with information that will allow avoidance of sensitive areas during the development of the Fayetteville Shale Play. Both of these tools have been presented to both regulatory and industrial stakeholder groups, and their feedback will be incorporated into the project area.

Executive Summary

Exploitation of a large natural gas reserve in central Arkansas, the Fayetteville Shale Play, will necessarily require development of significant infrastructure. Thousands of wells and hundreds of miles of roads will be constructed, as well as reserve pits and disposal options for fracture fluids. The project, "Probabilistic Risk Based Decision Support for Oil and Gas Exploration and Production Facilities in Sensitive Ecosystems," was proposed to develop modules for a web-based decision support tool that will be used by oil and gas exploration and production companies as well as environmental regulators and other stakeholders to proactively minimize adverse ecosystem impacts associated with the recovery of oil and gas reserves in sensitive areas in the Fayetteville Shale Play in central Arkansas. An additional goal of this project is to provide a mechanism that will help to streamline the process of acquiring the necessary permits for drilling in the play.

The first phase of the project resulted in identification of and contact with stakeholders involved in the Fayetteville Shale Play (FSP). The principal stakeholders and their affiliations are presented in Table 1.

Stakeholder meeting discussions were positive and indicated a willingness of the industrial and regulatory parties to collaborate with each other and the project team. The major themes that emerged as areas where the greatest benefit to the stakeholders would be felt were education and integration. We have also identified, through discussions with regulators and other governmental agencies, what the principal roles of each agency are. These are briefly described in Table 1 above and were discussed in detail in a previous management report.

Table 1. Fayetteville Shale Play Stakeholders

Regulatory/Governmental Stakeholders		Role
Larry Bengal	Arkansas Oil and Gas Commission	Primary regulatory body for exploration, drilling and production
Mo Shafii	Arkansas Department of Environmental Quality	Regulates reserve pits
Ed Ratchford	Arkansas Geological Commission	Repository of geological data
Todd Fuggit Chris Kelly	Arkansas Natural Resources Commission	Well head and water well protection
Bill Holiman Cindy Osborne Chris Colclasure	Arkansas Natural Heritage Commission	Maintains database of endangered species
Ken Adams	Bureau of Land Management	Oversees resource extraction on all federal lands
Wayne King	US Forest Service	Defines allowable surface impacts on federal land
Chris Davidson	US Fish and Wildlife Service	Enforcement of Threatened and Endangered Species Act
Sara Usdrowski Marc Fossett Elaine Edwards	US Army Corps of Engineers	Enforces section 404 of the Clean Water Act
Industrial Stakeholders		
John Thaeler Mike McAllister	Southwestern Energy	Resource extraction
Paul Hagemeier John Satterfield	Chesapeake Energy	Resource extraction

Based on the guidance of the stakeholders we have created a mock-up website which was presented to the stakeholder groups to solicit their feedback. In addition we have also created a preliminary version of a web-based mapping decision support tool that will allow better planning for development in sensitive locations by providing a map of the intersection of proposed features such as drilling pads, roads or gathering lines with those of sensitive locations . These features were well received by the stakeholder groups.

Conclusions

Initial feedback from the stakeholders on our work product was very positive. Suggestions regarding ways to clarify the roles of the various agencies were received and will be implemented as the project moves forward. Additional data layers that will provide further guidance on sensitive locations will be acquired and incorporated into the web based mapping utility. We are working with the Arkansas Natural Heritage Commission and the U.S. Fish and Wildlife Service to add data layers that they consider important for inclusion in decisions regarding environmentally friendly development.

Probabilistic Risk Based Decision Support for Oil and Gas Exploration and Production Facilities in Sensitive Ecosystems

INTRODUCTION

The Fayetteville Shale play is an unconventional natural gas play across central Arkansas. It is a tight formation and requires fracturing to produce economic quantities of gas. Initial estimates are that it may rival the Barnett Shale play in Texas. Currently there are about two million acres under lease in this play. It is anticipated that thousands of wells will be drilled during the next several years; this will entail installation of massive support infrastructure of roads and pipelines, as well as drilling fluid disposal pits and infrastructure to handle millions of gallons of fracturing fluids. This project is focused on gas production in Arkansas as the test bed for application of proactive risk management decision support system for natural gas exploration and production.

The project will develop a series of web-based application modules that will allow mid- and small-sized exploration and production companies to generate development plans for resource extraction in sensitive ecosystems in a manner that will meet regulatory requirements and proactively minimize risks to the ecosystem through implementation of best management or development practices implemented on a site specific basis. The program will be built from a database of existing technologies that can be implemented in ecosystem friendly ways. The principal objective of this project is development of tools that will allow industry to rapidly evaluate alternative leases through a GIS-based information support system so that location-specific environmental concerns can be identified early in the permitting process.

This project is an extension of a recently completed DOE-funded project, "Risk Reduction and Soil Ecosystem Restoration in an Active Oil Producing Area in an Ecologically Sensitive Setting," (DE-FC26-01BC15332). This project was focused on mitigating environmental impacts associated with the aging infrastructure of much of the domestic petroleum production industry. The risk reduction portion of the project was built on probabilistic reliability analysis of equipment used in the field to predict the probability of a release of produced fluids. This analysis was coupled with a GIS-based fate and effects model which is linked to a natural resources damage assessment and remediation model to generate a ranked risk index map of the lease as a decision support tool for allocation of maintenance resources. The basic approach was to link the likelihood of a piece of equipment experiencing a failure and releasing produced fluids with the calculated cost to clean-up the hypothetical spill at the location of that equipment. The combination of the likelihood of failure with the financial consequence of the failure defines the risk at that location; risks can be ranked and compared across an entire lease. The prediction of risk allows for *proactive* risk management. The general framework of this approach can be extended and adapted to a proactive risk management decision support tool throughout the entire lifecycle of exploration and production activities in other sensitive ecosystems.

Exploring for oil and gas involves subsurface seismic mapping which can result in surface disturbance; it often involves small explosive charges placed in patterned grids. If potential oil or gas deposits are identified, exploratory drilling begins. This phase frequently requires constructing, operating, and maintaining a system of access roads, local pipelines to connect well sites to storage facilities and dispose of drilling wastes, and gravel pads for wells and to

house equipment. In addition, the production phase normally requires storage tanks, separating facilities, and gas compressors. Finally, gathering lines are needed to transport gas to cross country transmission pipelines and ultimately to users. Pipeline operation may require additional pumping stations and storage tanks.

Habitat fragmentation is one of the environmental concerns associated with the development of new oil and gas infrastructure. It can change the hydrology of the basin, potentially introducing toxic substances and sediment into surface waters. Fragmentation may exacerbate disturbances from human activities, may provide corridors for predators, and potentially helps spread invasive non-native plants.

Impacts in the drilling stage include disturbed land, which can be significant depending on the length of roads, size of equipment, and other factors. The movement of heavy vehicles and drilling can create continuous noise potentially disturbing wildlife behavior patterns. Emissions from diesel engines and turbines that power the drilling equipment can pollute the air with particulates and carbon monoxide.

This project will provide oil and gas planners, engineers, developers, cultural resource managers, and researchers with a geospatial decision support system able to present information and maps from a variety of geospatial data, for any proposed site or corridor location within the Fayetteville Shale Play. The system will be used in the planning process to quickly evaluate the potential of alternatives, to highlight sensitive areas and features, and to minimize adverse environmental impacts by allowing diversion of development projects away from sensitive areas. Implementation of the tools assembled for this project will lead to a streamlined permitting process for well placement and infrastructure development. As the

Fayetteville Shale play develops, the number of drilling and reservoir pit permits will increase and may ultimately lead to a situation similar to that found in the Rocky Mountain region where the regulators are unable to keep up with permit processing with the result that environmental monitoring responsibilities are not effectively executed.

In this report we summarize the work performed during the first year of the project, which has focused on the identification of stakeholders and solicitation of feedback on the proposed project objectives, technology identification, identificaiton of best practices, creation of a prototype educational website, and a prototype geospatial decision support system.

PROJECT TASKS

Task 0: Identify and establish contact with stakeholders.
Task 1: Technology Evaluation
Subtask 1.1 Analysis of existing practices
Subtask 1.2: Identification of best practices
Task 2: Delineate regulatory and environmental concerns in the region and database development .
Task 3: Adapt fate and effects and ecosystem effects models
Task 4: Update and expand financial impact models.
Task 5: Integrate map products with risk analysis modules
Task 6: Web deployment
Task 7: Testing and technology transfer

Results

On October 11, 2006 we held the first stakeholder meeting. A summary of participants and details of the outcomes has been reported in an earlier management report. A brief summary of the results follows. Three areas were identified in which this project have a significant impact. These were education, integration, and data sharing. Overall the discussions were

positive and indicated a strong willingness of the industrial and regulatory parties to collaborate with each other and the project team.

Education: We have created a mock-up website as a central location where interested parties can access information about development in the Fayetteville Shale Play. We have received educational information from some of the industrial participants that will be included in the final website. An important aspect of this site will be to provide a forum where questions regarding the development of the Fayetteville Shale Play can be answered. The structure of the website is shown in Figure 1. Examples of screenshots from the website are provided in Appendix A. While all development carries an environmental cost, the use of minimally damaging modern technologies needs to be explained in a straightforward manner.

Integration: Improving inter-agency communication during the permitting process would

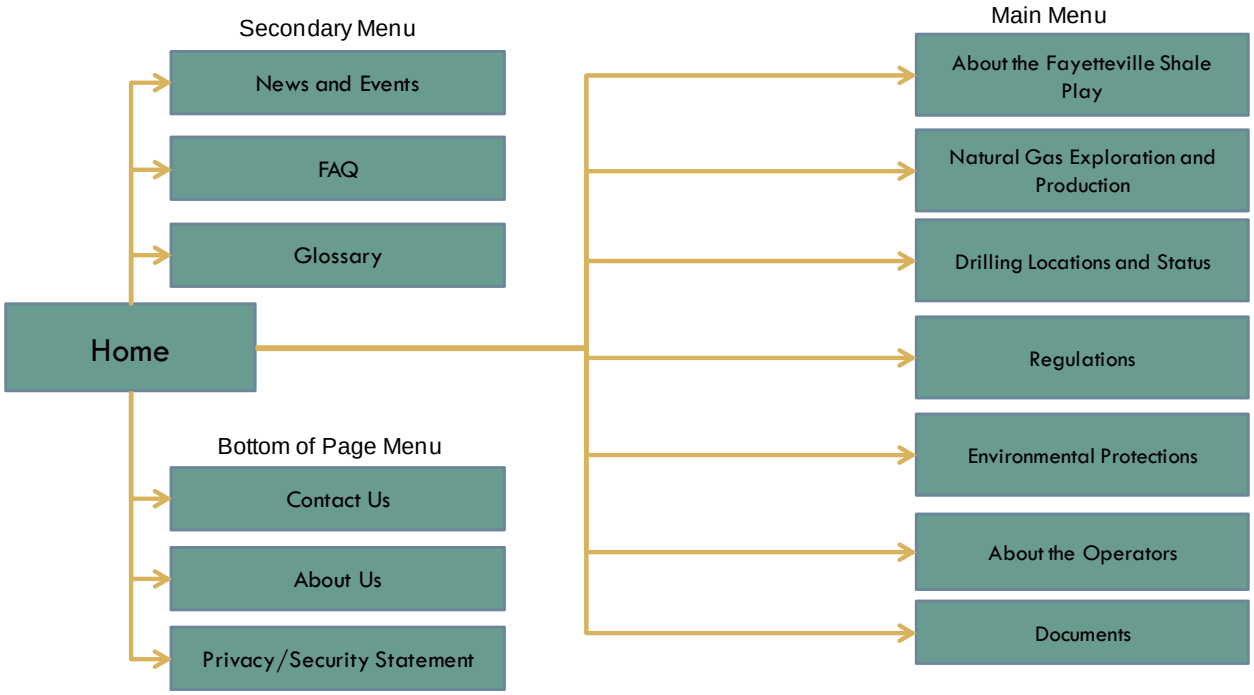

Figure 1. Structure of the educational website

result in a more streamlined mechanism for the cooperation of the agencies involved in the regulation of the FSP. We have agreement in principle with the Arkansas Oil &Gas Commission and the Arkansas Dept of Environmental Quality to mine their data sites for current information regarding permits that can be integrated to an interactive online mapping utility. The information can be screened for active or inactive status as well as the current well status at a particular location. The ready availability of this information will allow other interested agencies to make recommendations based on current activity.

Data sharing: We have an agreement in principle with the Arkansas Natural Heritage Foundation to provide information regarding the location of sensitive species in the Fayetteville Shale Play. The U.S. Fish and Wildlife Service has also indicated interest in providing data for this project that will allow users to identify sensitive areas prior to proceeding with any development. This information will be made available through an interactive web mapping service, which will allow users to determine the intersection of, for example, a drill pad with a sensitive location in the play area.

A second stakeholder meeting with the regulatory/governmental agencies was held on December 18, 2006 at the ADEQ offices in Little Rock, Arkansas. At this meeting, additional stakeholders who had been identified during the October meeting were included. The primary outcomes of this meeting were identification of specific agencies roles and an understanding of the interaction between these agencies. The details of this meeting were summarized in the previous management report.

On March 16, 2007 a third of stakeholder meeting with representatives from Chesapeake Energy and Southwestern Energy was held. At this meeting the role of county judges with

regard to roads in the Fayetteville Shale Play was discussed. There was support of the concept mentioned above of pooling of existing permits into a single easily accessed location. However, there was concern regarding the recommendation via the decision-making algorithm of specific BMP's at specific proposed sites. The specific concern was that voluntary BMPs might be stipulated in permits (for which regulatory authority does not currently exist), which would remove operational flexibility from the developer in implementing site specific best practices.

During a subsequent one-on-one meeting with the Arkansas Oil &Gas commissioner, Larry Bengal, the roles of state agencies were clarified. In addition the commissioner indicated an interest in having the ability to include a notification in the letter of transmittal that the permitted activity was in close proximity to a sensitive location. In part to address this need, we have developed a prototype web mapping decision support tool that will identify the intersection of proposed features such as drilling pads, gathering lines or access roads with sensitive locations. The data layers currently used for this intersection demonstration were obtained from the Arkansas Natural Heritage Commission.

The prototype decision support tool and mock-up educational website were presented to regulatory and governmental stakeholders on October 10, 2007 and were presented to the industrial stakeholders on October 12, 2007. Both groups indicated that further development of this tool would be beneficial.

Conclusions:

While there are two state agencies with regulatory authority (ADEQ and AOGC), and the BLM with regulatory authority over federal lands, several of the other agencies have the potential to become involved on a case by case basis. We have developed a prototype website

to help explain the various roles of those involved with the development of the Fayetteville Shale Play. In addition, the website details the lease development process. A prototype model that computes the intersection of proposed development features with sensitive landscapes features has been created and presented to both regulatory, governmental, and industrial stakeholders. All of the groups who are shown both the prototype website and the prototype decision support mapping tool during stakeholder meetings in October, 2007 were very supportive of the direction that the project is moving.

Progress on task completion:

Phase 1: Development of Environmentally Friendly Technologies Database

Task 0: Identify and establish contact with stakeholders.

This task is complete. Stakeholders include those listed in the February Project Summary. In the March meeting with industrial stakeholders, there was a passing suggestion that county judges should also be considered stakeholders because of their role in the construction of roads. However, we have decided not to include these individuals to maintain manageability of the groups.

Task 1: Technology Evaluation

Subtask 1.1 Analysis of existing practices

This task is complete. In June and July, 2007 we visited both SEECO sites in Conway County and Chesapeake sites in White County. The trip reports from these two visits are included in this report as Appendices B and C. Appendix B is available as a separately published report at: http://www.ead.anl.gov/pub/doc/ANL-EVS_R07-4TripReport.pdf

Subtask 1.2: Identification of best practices

The US Fish and Wildlife Service (USFWS) finalized a BMP document for the Fayetteville Shale Play in the spring of 2007. We (Thoma) were invited to participate on the panel and review the BMP document during its preparation. This USFWS document forms the basis for the work on this task. We have analyzed the USFWS BMP document and defined the GIS data layers that will be necessary to include BMP information in the decision support tools. The summary of this information is presented as Appendix D. We do not envision making specific BMP recommendations; however, it is likely that we will indicate which BMP's should be considered for a specific development application.

Task 2: Delineate regulatory and environmental concerns in the region and database development

The data collection activities associated with this part are substantially complete; however, a full report has not been written. The results are briefly summarized below. This task is closely linked with the USFWS BMP document that has been prepared for the Fayetteville Shale Play. We have initiated discussions with regulatory and other data managers to implement data sharing that will allow site-specific 'flags' to be generated, so that industrial developers will have an early warning of particularly sensitive locales. One challenge associated with this effort is that the information regarding the locations of threatened or endangered species is not (and will not be made) publicly available. We currently have a 'low level' data sharing agreement in place with the Arkansas Natural Heritage Commission that will allow a "red flag" identification of sensitive locations. This level of warning will allow developers to avoid environmentally sensitive locations, or plan appropriate protective measures in advance of development.

A prototype of a Geospatial Decision Support System (GDSS) was presented to stakeholders during meetings held on October 10 and October 12 for governmental and industrial stakeholders respectively. More details of the GDSS are given below in “Phase 2”.

We have had extensive discussions with regulatory agencies, and have a clear understanding of the regulatory concerns in the Fayetteville Shale Play. As indicated in the previous reports, Arkansas Oil &Gas Commission has primarily governing authority regarding the development of natural gas resources in the Fayetteville Shale Play, beginning with seismic exploration and ending with well closure. The Arkansas Dept of Environmental Quality has jurisdiction over construction, operation and closure of reserve pits. This authority derives from its responsibility for maintaining the quality of surface waters in the state of Arkansas. The other major regulatory activity in the Fayetteville Shale Play is associated with the U.S. Army Corps of Engineers enforcement of section 404 of the Clean Water Act. This is associated with the construction of small reservoirs for collection of surface water necessary for fracture jobs, and for other infrastructure development that has the potential to generate sediment loading in streams.

Also through discussion with regulators and industry representatives, we have identified the major concerns that are raised associated with the development of the Fayetteville Shale Play. These include water supply and water quality both for surface waters and groundwater. Many residents in the area are concerned about potential impacts to drinking water wells; while others are concerned about adverse impacts to fishing streams. Another concern that has been identified is noise pollution associated with the large compressor stations necessary to deliver the natural gas from the field to the transmission lines. Of course, there are concerns about the

impacts of development on rare species that are found within the Fayetteville Shale Play. This is particularly true for aquatic species that may be impacted by sediment runoff from the development of roads and drill pads.

Task 3: Adapt fate and effects and ecosystem effects models

Based on industrial stakeholder feedback during the first six months of the project, this task had been placed on hold. At present, we have not begun work on this task; however, at our last meeting with industry, some support was expressed for the development of these types of models under the presumption that they would be used not to make recommendations but primarily as a means of providing additional information that can be used for planning the location of specific developments. As indicated above,an environmental concern is sediment runoff, and models designed to predict levels of runoff could be useful in determining how the development should proceed. Other predictive models that were viewed as potentially very beneficial included habitat prediction models. Briefly, these models will use available information from known locations of sensitive species to develop a co- variance matrix that can use to evaluate whether or not a specific development location has a high probability of containing that species. Of course, it is not possible to predict the location of sensitive species but is possible to make recommendations that cautious development occur. These warnings would have a “yellow flag” level. Manual collection of habitat distribution data throughout two million acres (approximately under lease) of the Fayetteville Shale Play would be cost prohibitive. Therefore, it is desirable to develop a modeling strategy which can predict areas most likely to contain sensitive species. Development of a habitat distribution model would require following information:

1. Important habitat characteristic data, and
2. Spatial distribution of the characteristics on the study site

The important habitat characteristics may include all or some of the following factors: vegetation type, distance from water body, soil type, availability of nesting spots, topography, population density, etc. The characteristics of a field site in question can be compared with the characteristics of the habitats known to have target specie(s). Sites having strong covariance with the known habitat characteristics of target specie would be yellow flagged so that additional care can be taken to ascertain if a sensitive species is in fact present.

Task 4: Update and expand financial impact models.

This task has not been initiated because it is dependent on the approach taken for the Bayesian analysis, and the ultimate decision regarding fate and effects modeling (which provide the consequences of development actions for which the costs need to be estimated).

Phase 2: Preparation of decision support software tools

Phase 2 work is well underway with the development of the Geospatial Decision Support System (GDSS). This GDSS will provide regulators and gas producers, operating in the Fayetteville Shale Play, a platform to assess potential environmental impacts of proposed well pad, reserve pit, compressor station, gathering line and road placements. The system is web-based and will provide access to current geospatial data layers from a variety of sources. A creenshot of the current interface is shown in Figure2. A list of available data layers is provided in Table 1.

Approximately 1000 lines of code have been generated within the ARC server environment. A graphical user interface has been created in which standard map navigaion tools as well as

special icons are available to activate a Feature Placement Tool.

This tool allows users to propose a location for well pad (with associated drill and reserve pit), gathering line or road using all available layers as a guide. After placement, the system will report potential environmental impacts. In addition the user will be able to see areas of potential environmental impact. As a simple example, all areas upslope and within a certain distance from a perennial stream may be highlighted as a translucent layer over the aerial imagery. More complex "impact surfaces" will take into account soil type and land cover.

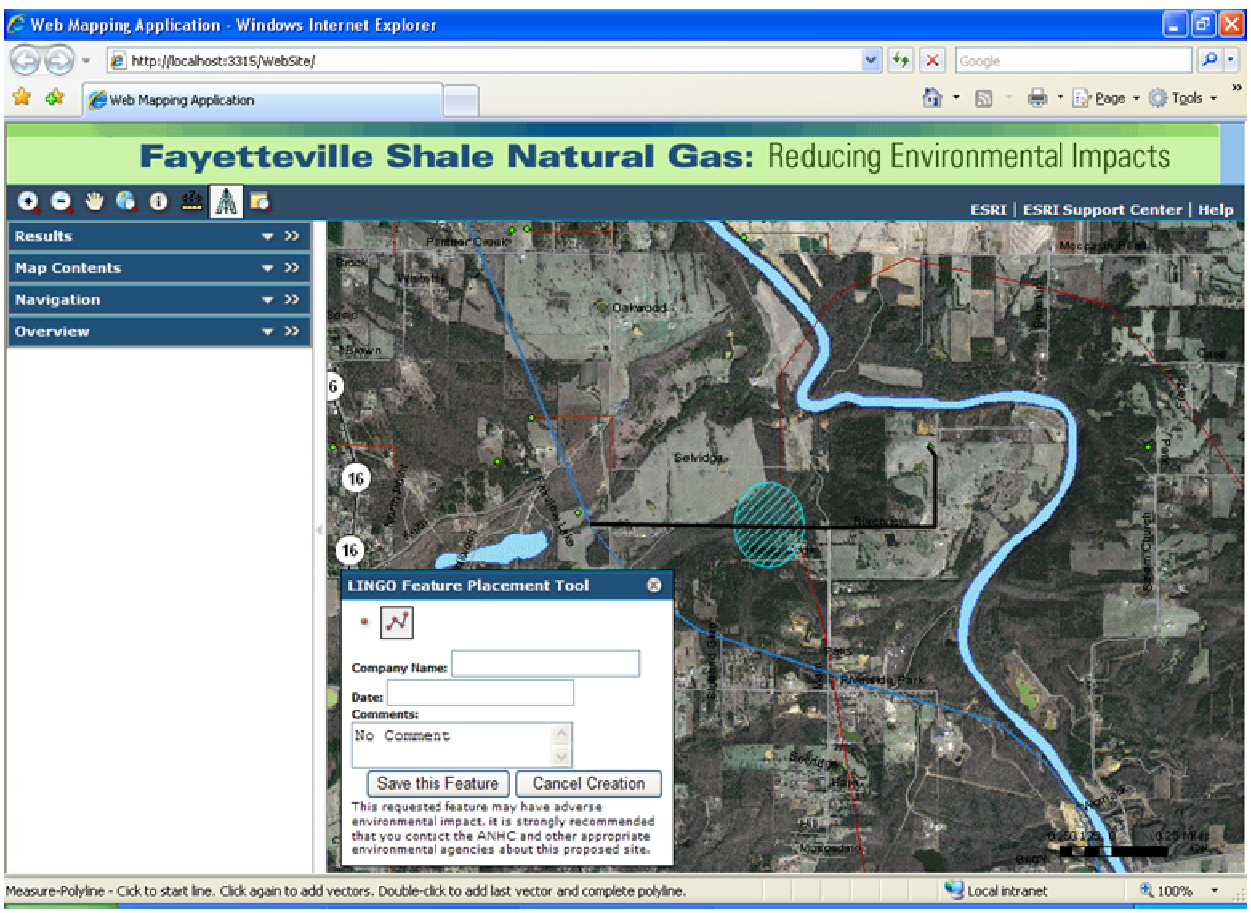

Figure 2. Fayetteville Shale Natural Gas GDSS. The Feature Placement Tool has been used to propose a gathering line, which crosses a (fictitious in this case) threatened and endangered "red flag" (shown as the cross-hached ellipse) area provided the Arkansas Natural Heritage Commission.

Table 1. Partial list of data layers available in the Fayetteville Shale Natural Gas GDSS.

Source	Layer
US Geological Survey	National Elevation Dataset (NED will serve as the basis for all terrain based decisions such as slope, aspect and flow)
US Geological Survey and US Environmental Protection Agency	National Hydrology Dataset (1:24,000 scale)
Arkansas Geographic Information Office	Arkansas Road Centerlines
Arkansas Geographic Information Office	Public Land Survey System (Township, Range and Section corners)
Arkansas Geographic Information Office	2006 Orthophoto Image Base (0.33 – 1.0 meter GSD)
Arkansas Geographic Information Office	Arkansas political boundaries (county, city)
Arkansas Natural Heritage Commission	Threatened and Endangered Species (Red Flag version)
Arkansas Natural Resources Commission	Location of known wetlands
Arkansas Natural Resources Commission	Watershed boundaries
US Forest Service	Public forest boundaries
US Census Bureau	TIGER Road Features
Bureau of Land Management	Public land boundaries
Arkansas Oil and Natural Gas Commission	Existing drill pad and well locations (permit status and production history)
Arkansas Oil and Natural Gas Commission	Locations of major gas transmission lines
Arkansas Department of Environmental Quality	Locations of reserve pit locations and permit status
Arkansas Natural Resources Commission	2006 Land Cover
Natural Resources Conservation Service (US Department of Agriculture)	State Soils Geographic Data (STATSGO) and Soil Survey Geographic Data (SSURGO)
US Fish and Wildlife Service	Threatened and endangered species sensitive areas

Two primary users are envisioned: 1) regulators at AOGC, ADEQ and ANRC who will have easy access to complex geospatial analysis to inform permitting decisions, and 2) producers who wish to vet infrastructure placement proposals and expedite permitting by efficiently communicating with regulators. After several meetings with both regulators and producers, it

is clear that the data layers underlying the system must be recognized by both parties as current and accurate. Therefore, we have placed a high priority and expended significant effort to develop technical relationships with AOGC, ADEQ, ANHC and ANRC to ensure the currency of geospatial layers available to the GDSS.

The Layers which are not developed by these agencies are recognized components of the Arkansas State and US Federal infrastructure and will be accompanied by Federal Geographic Data Committee (FGDC) metadata. The system will complement existing Fayetteville Shale Play informational websites, such as the Arkansas Oil and Gas Commission (AOGC) map service (http://www.geostor.arkansas.gov/apps/aogc/index.htm) which provides access to well permit and production status. It will complement the Arkansas Department of Environmental Quality (ADEQ) site (http://www.adeq.state.ar.us/compsvs/webmaster/databases.htm) at which users can search for NPDES Permits by county, organization or permit number. ADEQ issues permits related to reserve pit construction and removal. Another component of the GDSS is an integrated view of the permit status of wells and reserve pits. .

In additional to providing a contextual view of proposed infrastructure placement, the systm will provide quantitative assessments including, but not limited to,

1. Proximity to threatened and endangered species habitats,
2. Delination of potential run-off areas based on local terrain, soil type and land cover,
3. Proximity to bodies of water and a traces from that body throughout the hydrologic system,
4. Required stream crossings, and
5. Infiltration potential.

Potential environmental impacts identified by the GDSS can be electronically forwarded to a variety of agencies or individuals for review. Impact information will include detailed reasons

behind the assessment, an estimate of the likelihood of the impact and a URL which will direct the recipient to the same map view (including active layers) used to generate the report. Producers and regulatory officials with whom we've met all agree that this immediate electronic exchange of detailed information will increase the speed with which various permits can be submitted, reviewed and issued. Producers of natural gas in the Fayetteville Shale Play will be able to better plan drilling activities, reducing costs caused for example, by scheduling delays of scarce equipment. Regulators can likewise better manage environmental impacts by immediately having access to a sophisticated analysis of impacts within the scope of their regulatory authority.

Despite the scope and sophistication of the GDSS it is clearly designed to be a planning tool and is not intended to replace on-site surveys, which are required to establish applicable best management practices. As an example of the limits of the tool, consider proximity of a placement to a local water body. Proximity to down-slope surface water is a major limiting factor in road construction but existing hydrographic layers only locate streams to within 100 feet. Likewise, knowledge of local elevation is limited to heights at 30 meter intervals. Aerial imagery can, in some cases, be used to reduce error in relative distance measurement but only an on-site survey can accurately establish proximity. In addition, terrain relief and soil type used to assess run-off can only be accurately surveyed on site. However, because the system will take into account imprecision and uncertainty (using "fuzzy" and/or "Bayesian" techniques) in the underlying geospatial data layers it will provide enough information to filter for (or perhaps rank order by) potential for environmental impact the full set of possible infrastructure locations and thus limit the number of required on-site surveys. The GIS layers listed in Table 1

also reflect information required to recommend a BMP based on the US Fish and Wildlife document mentioned as part of Tasks 1.2 and 2. A summary of the USFWS BMP document is provided in Appendix D, in which the purpose and layers required for BMP decision are listed. Again, due to concerns about the accuracy of the available data, the uncertainty of these layers may included in "fuzzy" or "Bayesian" approach to analysis.

Finally, because many of the geospatial layers listed in Table 1 are from national datasets or layers readily available in most states, the GDSS can be exported to other regions of the country where the environment impact of drilling activities is a concern. The key to the success of this system in any play area is acceptance of an agreement between state and federal regulators on the one hand and producers on the other.

We are considering ways to address the industry concerns regarding the inherent uncertainty in GIS data and still provide an effective decision-support system. Our current focus is on assessing the feasibility of building a "fuzzy-logic" system that takes into account the uncertainty associated with the various GIS layers used as input. So, for example, if a BMP selection depended on the distance to body of water whose location was only known with 90% certainty to be within 75' (this is typical of 1:100,000 scale map layers) of the reported location, the model would propagate this uncertainty into a probability that a particular BMP would be recommended. Only after an on-ground survey could a more precise BMP be chosen. However, providing a range of possible environmental impacts and subsequent BMP prescriptions would help industry and government stake-holders focus on potential drilling areas with the least likelihood of adverse environmental impact. This approach could take the form of a "risk" map showing the probability of a particular adverse impact across the shale.

Task 5: Integrate map products with risk analysis modules

The geospatial decision support system described above represents the current use of map products in the project. As indicated previously, we intend to include uncertainty analysis based at a minimum on buffer zones that are related to the inherent uncertainty of the data layers that are used in the decision making process. A would include both the likelihood of occurrence and the cost consequences of a specific event. In the current context a traditional risk analysis is not necessary to provide adequate decision support. This arises from the fact that, for example, the likelihood of erosion associated placement of a pad or access road is essentially certain. Therefore the risk can be directly correlated with the consequences. These in turn are directly related to the geospatial characteristics of the site being developed, and these data are represented by the GIS data layers available in the project. It is thus envisioned that the geospatial decision support system will satisfy the requirements of task five.

Task 6: Web deployment

This task is awaiting the development of both the Educational website and the Geospatial Decision Support System. Both of the web-based applications are currently being developed on internet servers not open to the public but can be easily transferred to a public site when they are complete.

Task 7: Testing and technology transfer

The preliminary testing of the geospatial decision support system is necessarily integrated with the development of this system. Beta testing of the system by representative stakeholders will not be initiated until later in the development cycle. This technology transfer aspect of task has not yet started. As the education and decision support components of the

project progress we will hold demonstrations for the stakeholders. These updates are planned to occur in mid spring 2008, late summer 2008, and finally as a presentation/workshop at the International Petroleum Environmental Conference in the fall of 2008.

Conclusions

Overall the project is close to the proposed schedule. Some uncertainties in the regulatory climate and stakeholder concerns have resulted in parts of the project moving more slowly than originally planned, while other aspects of the project had been moved forward in the timeline. Specifically, the fate and effects modeling has been postponed to the second project year, while certain aspects of the development of the geospatial decision support system have been moved forward into the first year.

Funding

This project was selected under DOE's Low Impact Natural Gas and Oil solicitation, February 2006.

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Performer Contribution: $136,832 (30% of total)
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Appendix A:

Screen shots and initial content of the educational website.

A series of screenshots of the educational section of the website follow. These mock-up documents were presented at stakeholder meetings in October 2007.

Figure A1 LINGO website home page. This mockup shows the menu structure and initial content for the home page of the website.

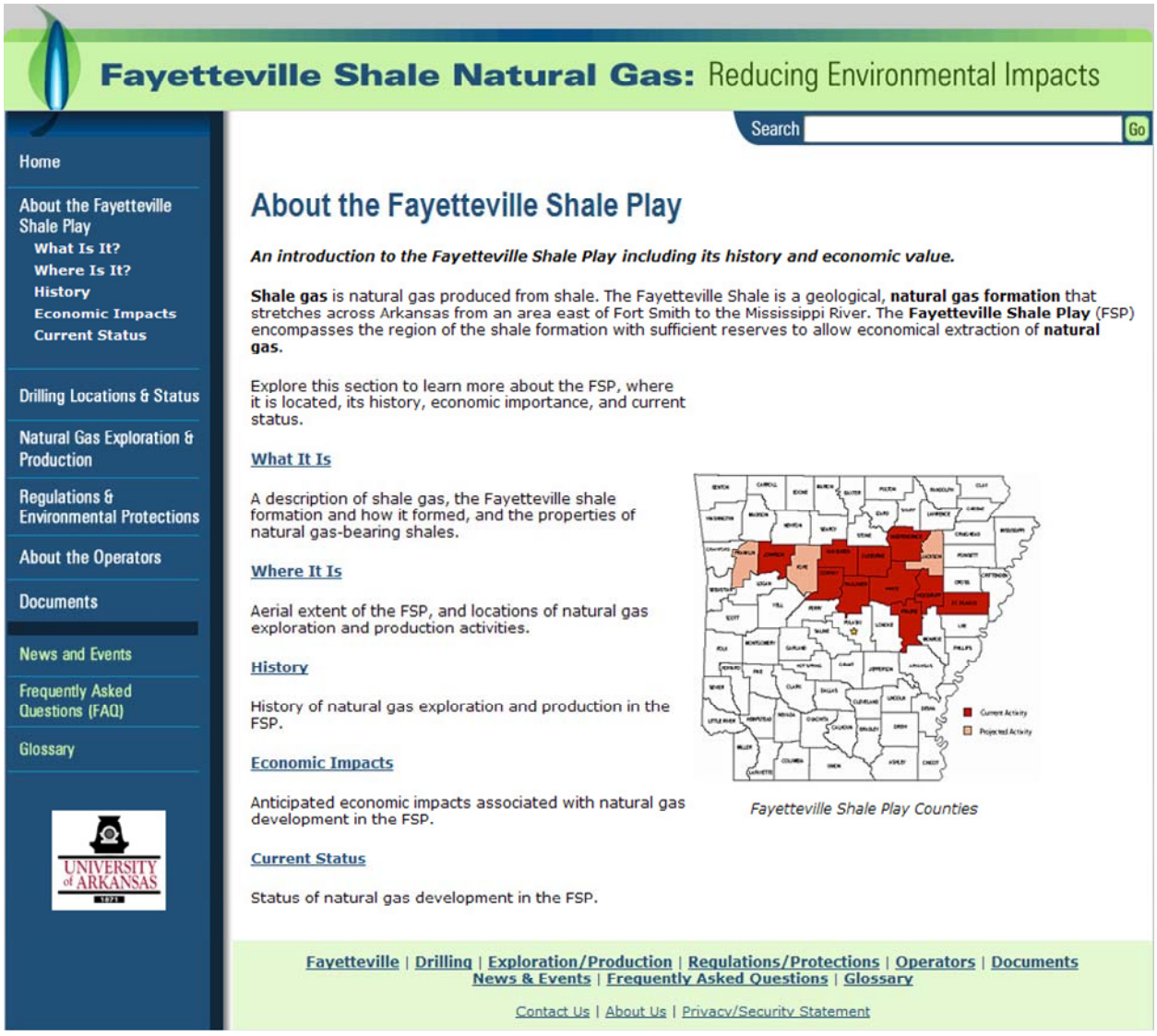

Figure A2. Draft of LINGO website Homepage.

Draft Content for "About the Fayetteville Shale Play" section of the website

The Fayetteville Shale is an unconventional gas reservoir located on the Arkansas side of the Arkoma Basin, ranging in thickness from 50 to 550 feet and ranging in depth from 1,500 to 6,500 feet. The shale is a Mississippian-age shale that is the geologic equivalent of the Caney Shale found on the Oklahoma side of the Arkoma Basin and the Barnett Shale found in north Texas.

The Fayetteville Shale is aerially extensive and may be present across numerous counties in central and eastern Arkansas, including the counties of Cleburne, Conway, Faulkner, Independence, Johnson, St. Francis, Prairie, Van Buren, White, and Woodruff (Figure A3).

To date, energy exploration companies have acquired leases related to the Fayetteville Shale gas discovery in 19 counties — Cleburne, Conway, Crawford, Cross, Faulkner, Franklin, Independence, Jackson, Johnson, Lee, Lonoke, Monroe, Phillips, Pope, Prairie, St. Francis, Van Buren, White and Yell.

Organic-geochemical and thermal-maturity data from Fayetteville Shale well cuttings indicate the formation is thermally mature and is restricted to dry gas resources. A highly

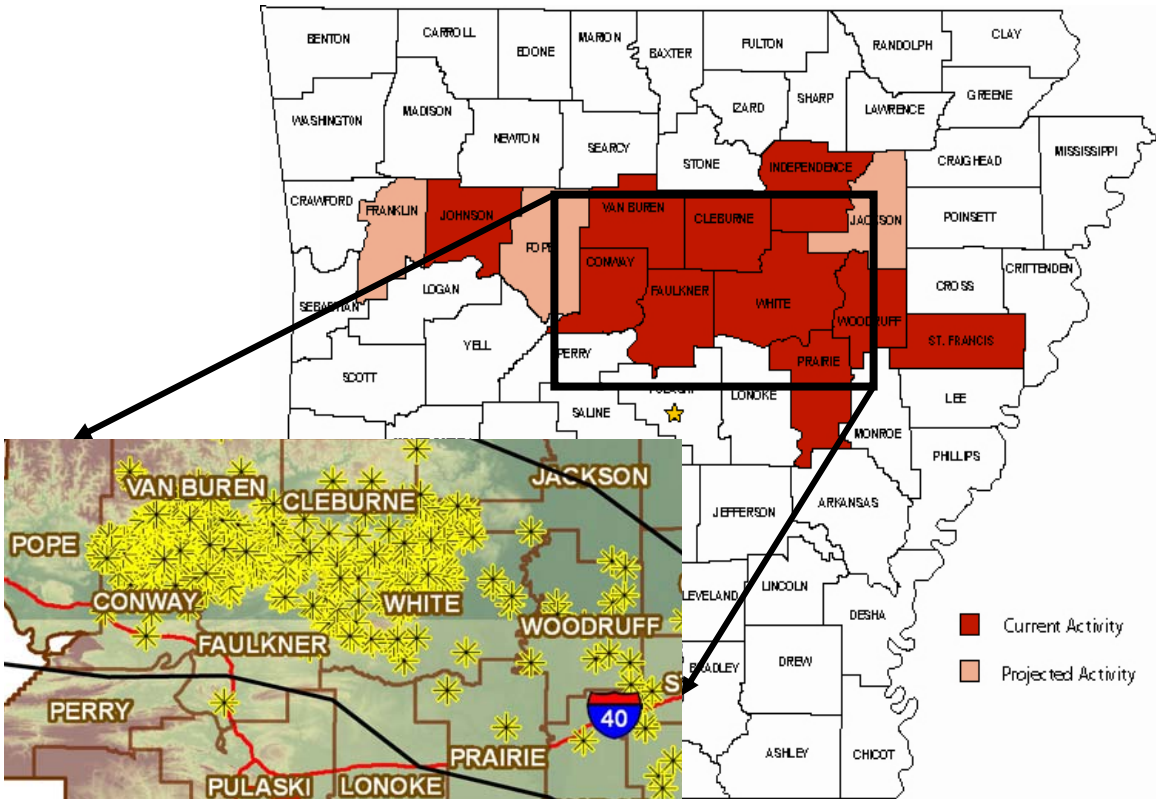

Figure A3. Counties in the Fayetteville Shale Play. Inset shows most active area is currently from western Conway County through eastern White county. Development further to the east is anticipated to proceed very slowly because the shale is considerably deeper, making gas extraction less economical.

organic-rich facies within the Fayetteville Shale is the stratigraphic interval that currently produces natural gas from wells in north-central Arkansas and is characterized by very high radioactivity and resistivity log signatures, which differentiate it easily from the overlying upper Fayetteville Shale and from the underlying Batesville Sandstone, Moorefield Shale, and Boone Formations (Figure A4).

The middle to lower stratigraphic section of the Fayetteville Shale is represented by an organic-rich facies consisting of black and pyritic shale, with subordinate amounts of interbedded, siliceous chert and siltstone. The most-prolific gas production from the Fayetteville Shale is associated with horizontal wells that have been completed with multi-stage fracs in the middle to lower portions of the formation.

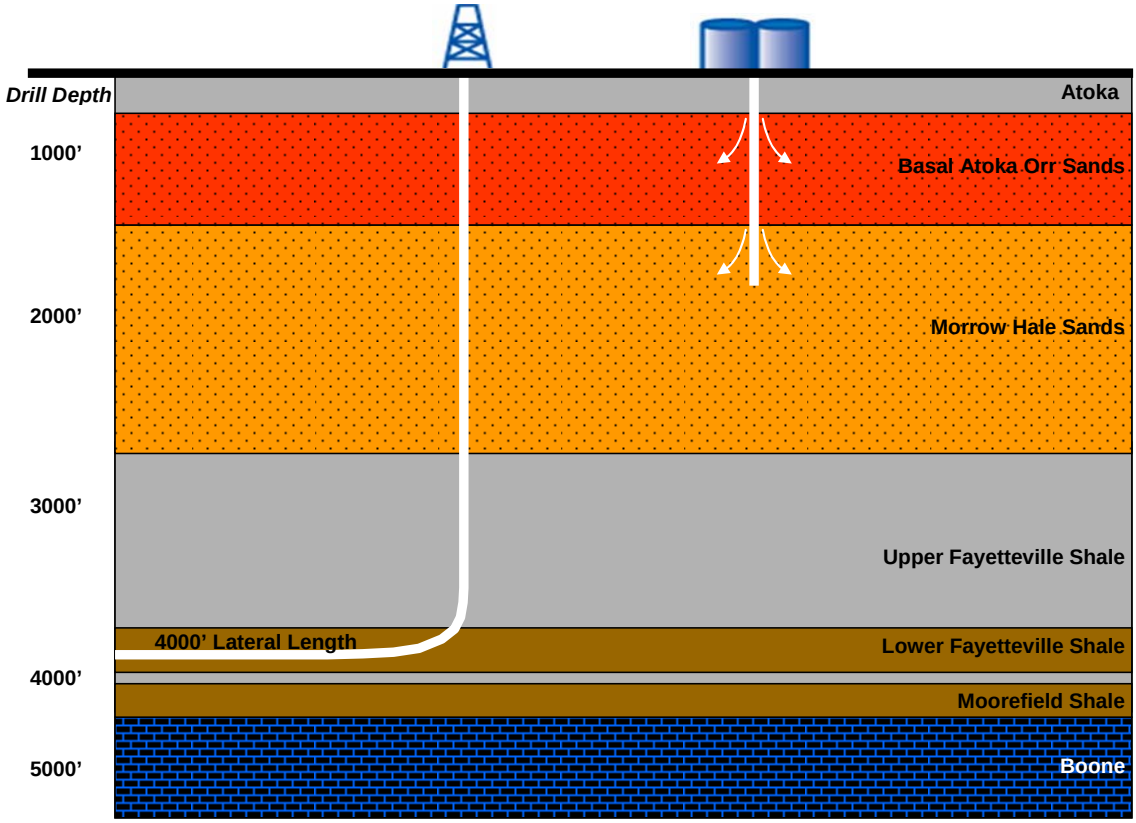

Figure A4. Major stratigraphic layers surrounding the Fayetteville Shale layer. (Graphic courtsey of Chesapeake Energy, Inc.)

The Arkansas Geological Service has posted on its website the following information related to the geology of the Fayetteville Shale gas:

Geology: Fayetteville Shale/Formation

Age: Late Mississippian Period

Distribution: Northern Arkansas, Ozark Plateaus; southern Missouri, eastern Oklahoma

Geology: The Fayetteville Shale is black, fissile, concretionary, clay shale. Dark-gray, fine-grained limestones commonly are interbedded with the shales in north-central Arkansas. The Wedington Sandstone Member, known from west Arkansas outcrops, is composed of gray to brown, fine-grained, sometimes calcareous sandstone. Septarian concretions are common in lower beds of the Fayetteville, but may be found throughout the formation. Fossils are abundant in some intervals and in local areas. Most of the fauna recovered is pyritic, but some silicified material is found. The formation is considered to rest conformably on the Batesville Sandstone (and Hindsville Member). The Fayetteville Shale ranges in thickness from 10 to 400 feet.

Original reference: F. W. Simonds, 1891, Arkansas Geol. Survey Ann. Rept. 1888, v. 4, p. 26, 42-49

Type locality: Named for Fayetteville, in the valley of the West Fork of White River, Washington County, Arkansas.

Shale gas:

Shale is a fine-grained sedimentary rock whose original constituents were clays or muds. It is characterized by thin laminae breaking with an irregular curving fracture, often splintery and usually parallel to the often-indistinguishable bedding plane. This property is called fissility. Non-fissile rocks of similar composition but made of particles smaller than 1/16 mm are described as mudstones. Rocks with similar particle sizes but with less clay and therefore grittier are siltstones. Shale is the most common sedimentary rock.

Shale gas is natural gas produced from shale. Because shales ordinarily have insufficient permeability to allow significant fluid flow to a well bore, most shales are not sources of

natural gas. Shale gas is one of a number of "unconventional" sources of natural gas; other unconventional sources of natural gas include coalbed methane, tight sandstones, and methane hydrates.

Shale has low matrix permeability, so gas production in commercial quantities requires fractures to provide permeability. Shale gas has been produced for years from shales with natural fractures. Horizontal drilling is often used with shale gas wells.

Fayetteville Shale Gas History

While shale gas has been explored for and tested as a gas resource since the 1980s, it has only been in recent years that it has become an economic source of gas supply due to the advent of better oilfield service and drilling technologies and higher natural gas commodity prices.

Southwestern Energy is credited with demonstrating the economic viability of natural gas production from the shale by successfully drilling the first test wells in 2004. Since 2004 SEECO has pioneered much of the research and development of the play.

Economic Impact:

According to a recently completed economic impact study conducted by the Center for Business and Economic Research (CBER) in the Sam M. Walton College of Business at the University of Arkansas and funded by Southwestern Energy Company, development of the Fayetteville Shale Play will have an estimated $5.5 billion total economic impact on the state of Arkansas through 2008 and has the potential to be one of the most significant tax revenue generators in Arkansas history over the next 10 to 15 years.

The study also projects the natural gas play will have the greatest impact in at least 10 counties throughout the central part of the state, creating 9,683 full-time equivalent jobs and generating $357.7 million in state and local tax revenues. In addition, the study estimates companies from the oil and gas industry will make direct expenditures from 2005 through 2008 of approximately $3.8 billion in leasing land and mineral rights, drilling and other activities.

Key numbers from the study which estimate the play's total projected economic impact for the years 2005 through 2008 are as follows.

Table A1. Projected Economic Impact of the Fayetteville Shale Play In the State of Arkansas [a]

	2005	2006	2007	2008	Total 2005 - 2008
Economic Impact	$520.7 million	$1.1 billion	$1.6 billion	$2.3 billion	$5.52 billion
Employment Impact	2,160	4,394	6,661	9,683	9,683 FTE*
State and Local Tax Impact	$28.14 million	$69.5 million	$105.93 million	$154.1 million	$357.7 million

*Total employment by 2008, full-time equivalent jobs

a. Source: Arkansas Oil and Gas Commission: http://www.aogc.state.ar.us/Fayprodinfo.htmUniversity of Arkansas Fayetteville Shale Economic Impact Study.

It is estimated that the typical Fayetteville Shale well would return five times its initial investment over its lifetime and pay back investors in less than one year.

In general, investments related to the development of the Fayetteville Shale Play will include, but not be limited to, capital invested in leasing land and mineral rights, drilling, completion and production activities, as well as the potential for the installation of major gas

gathering and transportation systems. As such, the residents, businesses, and governments of the Fayetteville Shale Play counties and the State of Arkansas as a whole are and will be experiencing an unprecedented natural gas mineral leasing and drilling boon and the economic impact of a new set of industries in the area.

Current status

As of June 30, 2007, Southwestern held approximately 900,000 net acres in the Fayetteville Shale play area (699,000 net undeveloped acres, 76,000 net developed acres held by Fayetteville Shale production and approximately 125,000 net acres held by conventional production)., and had drilled and completed a total of 303 operated wells in the Fayetteville Shale play, of which 246 were horizontal. Of the 246 horizontal wells, 219 wells have been fracture stimulated using slickwater or crosslinked gel fluids. The wells are located in 33 separate pilot areas in eight counties in Arkansas.

As of July 28, 2007, Southwestern's gross production rate from the Fayetteville Shale play area was approximately 200 MMcf per day, including approximately 10 MMcf per day from five wells producing from conventional reservoirs in four pilot areas.

Companies exploring in the Fayetteville Shale area

1- David H. Arrington, Oil & gas Inc.: www.arringtonoil.com
2- CDX Gas LLC: www.cdxgas.com/index.htm
3- Chesapeake Energy: www.chkenergy.com
4- Edge Petroleum Operating Company, LLC. : www.edgepet.com
5- Hallwood Petroleum Inc.: www.hallwoodenergy.com/
6- J-W Operating Company: www.jwoperating.com/index.cfm
7- KCS resources Inc.: www.petrohawk.com/home/
8- Maverick Operating Company, LLC:
9- Pathfinder Exploration, LLC:
10- Penn Virginia MC Energy, LLC: www.pennvirginia.com/index.html
11- SEECO, Inc.: www.swn.com
12- Tepee Petroleum Company, Inc.: http://tepeepetroleum.com/

13- XTO Energy, Inc: www.xtoenergy.com/en/home.html

Figure A5 Main page for the section describing current activity in the Fayetteville Shale Play.

Figure A6 Screenshot of GoogleMaps® mashup showing the with sample well information mined from the AOGC web based database. The maps will be interactive, allowing users to pan and zoom to identify locations of interest.

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Natural Gas Exploration and Production

How natural gas resources are developed in the Fayetteville Shale Play, from exploration to sending gas to market.

Natural gas exploration and production in the Fayetteville Shale Play (FSP) is a multistep process that starts with **leasing** a parcel that may contain gas resources. The parcel is explored via **seismic survey** to determine if gas resources are present and can be recovered economically. After obtaining a permit, a well is then **drilled** and put into production. The natural gas is sent to market via **pipeline**.

Explore this section to learn about each step in the natural gas development process in the FSP.

Leasing

The operator must **gain access** to the property under which the prospective natural gas resources are located.

Seismic Surveys

Companies typically perform **seismic studies** to help characterize the size, shape, and depth of the formations that may hold recoverable natural gas.

Well Drilling

After a company has identified a desired location for locating a well, it gets permits, **prepares the site**, and **drills a well**.

Preparing a Well for Production

A newly drilled well must be **properly completed** to allow gas to enter the well and move to the surface.

Water Management

Water is generated in three ways - **ground water, flow-back water, and produced water**. Water management is an important part of natural gas production.

Well Production, Maintenance, and Closure

Gas initially flows to the surface by reservoir pressure, but may require **stimulation** to stay productive.

Sending Gas to Market

Natural gas is produced at the wellhead, moves to a metering station, and then is transported by **pipelines** to market.

Drilling a Well in the Fayetteville Shale Play

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FigureA7 Mockup of main page for the section describing the process of exploration and production in the Fayetteville Shale Play.

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Leasing

The operator typically uses a lease to gain access to the property under which the prospective natural gas resources are located.

The first step towards producing natural gas involves **gaining access** to the property under which the prospective natural gas resources are located and on which surface facilities will be located. Unless the operator owns the mineral rights for a piece of land, the company must **lease the mineral rights** from the owner. A lease is a **legal agreement** that allows the company to explore for and produce gas from a tract of land in exchange for paying royalties. Leasing does not require petroleum technology or field work.

The mineral lease is an agreement between two parties and although there is a **standard lease form** utilized by most companies there is no "one size fits all" lease agreement, and specific terms and conditions contained in the lease are subject to negotiation by the Lessee and Lessor.

Following are explanations of some of the major components of a mineral lease:

Cash Bonus

The **cash bonus** is also known as a lease bonus or bonus consideration. It is **money paid up front** to a Lessor by a Lessee as an incentive to sign a mineral lease. The dollar value of the cash bonus is paid on each mineral acre owned by the Lessor. The price paid per acre can vary between geographic regions and although many factors influence the price paid, generally the value of the mineral rights is relative to the potential for resource development in that area.

Primary Term of the Lease

The **primary term of the lease** is the **duration** of time a lease agreement will be in effect. A common industry standard for primary term is **three to five years** although depending on circumstances terms of less than three years are not uncommon. This window of time is intended to allow a Lessee to explore for mineral resources before the leased mineral rights transfer back to the mineral owner. The duration of the mineral lease is automatically extended if the drilling operations are commenced before the primary term expiration date or if a successful well has been completed during the time covered under the primary term.

Figure A8. The leasing page

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Seismic Surveys

Operators typically perform seismic studies that help in characterizing the size, shape, and depth of the formations most likely to hold recoverable natural gas.

Companies can make educated guesses about which tracts of land within a field hold recoverable natural gas. But before making large financial investments, they typically perform **seismic studies** that help in characterizing the **size, shape, and depth of the formations** most likely to hold recoverable natural gas. The use of 3-D seismic to image subsurface rocks increases geologic knowledge, improves drilling accuracy, and lowers risks in exploration.

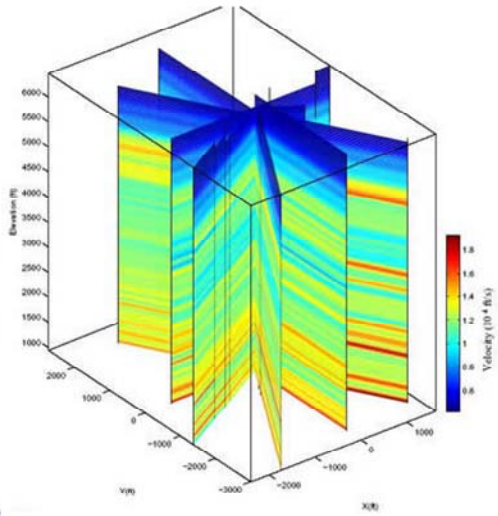
Seismic Study Design

The **size of a survey** depends on depth objective, lease position, available funds, and complexity of subsurface (e.g., dipping event) geology. The **pattern in which sources and receivers are laid out** is used to optimize the way sound waves hit the reflectors. Recommended recording geometries account for offset (distance that a trace travels from source to detector) and azimuth (direction that a trace travels from source to detector). Modern techniques using multiple frequencies can be used to determine **reservoir properties** such as **porosity, permeability, saturation, stress, and pore pressure**.

Seismic Study Field Operations

A typical seismic study in the Fayetteville Shale Play includes the following steps:

- Contractors utilize trucks and helicopters to move equipment into the field and collect data.
- The contractors drill a grid of 20-foot-deep holes and place an explosive charge of one pound of dynamite in each hole.
- The charges are detonated under controlled conditions, and
- the resulting vibrations are detected by a network of seismic sensors.



3-D Seismic Survey Data

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Figure A9. Mock-up page describing seismic surveys.

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Well Drilling

How a natural gas well site is constructed and a well drilled in the Fayetteville Shale Play.

Access Road, Gravel Pad, Reserve and "Rig Ditch" Pits

After the company has identified a desired location for a well, it obtains permits to drill a well and construct a **reserve pit** (a pit located next to the drilling rig to catch the drill cuttings, used drilling mud, rainfall, and other materials). Before drilling can begin, the company clears vegetation and constructs a **pad** for the drilling rig and other equipment used in preparing the well and an **access road** to get from the county road to the well site. SEECO pays a use fee to the landowner for disturbing an area of 500 ft by 500 ft, plus the area of the access road. In practice, SEECO generally clears only 300 ft by 250 ft for the pad and the reserve pit plus two adjacent smaller "**rig ditch pits**," which collect fluids that fall onto the footprint area beneath the rig. SEECO lines the pits with a plastic liner and covers the pad and access road with gravel.

Drilling the Well

Next the **well is drilled**. Oil and gas wells are constructed with multiple nested concentric layers of pipe known as **casing** (an entire length of casing is known as a **casing string**). The top interval is drilled starting at the surface and has the largest diameter hole. After a suitable depth has been reached, the hole is lined with casing that is slightly smaller than the diameter of the hole. Then cement is pumped into the space between the wall of the drilled hole and the outside of the casing. Next, a smaller diameter hole is drilled to a lower depth. Another casing string is installed to that depth and cemented. This process may be repeated several more times. The final number of casing strings depends on the regulatory requirements in place at that location. It reflects the total depth of the well and the strength and sensitivity of the formations through which the well passes.

Newly constructed well showing gravel pad.

SEECO drills a relatively large diameter hole from the surface down to about a 40-ft depth. This is lined with large casing called **conductor pipe**; the conductor pipe is cemented in place. Next SEECO uses an **air-drilling rig** to drill a hole to about a 500- to 550-ft depth. Surface casing is installed and cemented in place. SEECO continues with an air-drilling rig to drill deeper until the hole is about 600 ft above the top of the shale.

Reserve pit.

Horizontal Drilling

At this point, SEECO moves in one of its larger conventional **drilling rigs** to drill the horizontal section. The larger rig uses drilling mud to lift cuttings from the well, lubricate the drill bit, and to serve other functions. Using the larger drill rig allows SEECO to deviate the well (i.e., instead of drilling vertically, the well bore curves off at an angle). Nearly all of SEECO's Fayetteville Shale wells are **horizontal wells** that reach out laterally

Figure A10. Mock-up page describing the drilling process.

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Preparing a Well for Production

A newly drilled well must be properly completed to allow gas to enter the well and move to the surface.

Perforations

A newly drilled well must be properly completed to allow gas to enter the well and move to the surface. In a well that has casing along the gas-producing section, holes or **perforations** ("perfs") are made in the casing using small explosive charges or guns. The perfs allow gas to enter the well.

The Fracturing Process ("Frac Job")

Because shale gas is held within a nonporous medium, it is necessary to **fracture the shale** so that gas has a conduit or pathway to move from the shale to a production well. The fracturing process (a "**frac job**") injects water, sand, and other ingredients at very high pressure into the well. The high pressure creates small fractures in the rock that extend out as far as 1,000 feet laterally away from the well. The vertical extent varies, but is related to the thickness of the shale layer. After the fractures are created, the pressure is reduced. Water can be removed from the well ("**flow-back water**"), but the sand grains remain in the rock fractures, effectively "propping" the fractures open and allowing the gas to move. **Fracturing is a critical step** in producing the Fayetteville Shale wells.

Water pipeline conveying water for frac job.

"Fraccing Fluid"

Originally, SEECO used nitrogen foam as its "**fraccing fluid**". They found that wells fracced in that way did not yield long enough fractures and did not remain productive for as long as the company hoped. SEECO now uses "**slick water**" - water with some surfactant additives to help the flow-back water return from the well at the end of the frac job.

"Frac Job" Stages

SEECO conducts its frac jobs in stages. The length of the horizontal section of the well is divided into several sections by plugs. The outermost section is fracced first. First water is injected at increasingly higher pressure until a pressure chart shows that the bottom-hole pressure makes a sudden drop, indicating that the rock has fractured. At this point, sand is added to the injected water and the pressure is maintained until a desired dimension of fraccing is completed.

Row of frac tanks.

FigureA11. The description of the fracturing process.

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Water Management

Three types of water are generated during well drilling and production; water management and disposal methods are regulated.

Ground Water

Water is generated in three ways - **ground water, flow-back water, and produced water**. First, as the well is drilled with air drilling rigs, the borehole passes through **shallow water-bearing formations**. A substantial amount of water collects in the wellbore. SEECO is working with the **Arkansas Department of Environmental Quality (ADEQ)** to capture this water and treat it with an aluminum-based flocculant. If the chlorides concentration is less than 1,500 ppm, ADEQ allows the water to be applied to roads for dust control.

Flow-Back Water and Produced Water

A large volume of water is used to make up the **frac fluid**. Much of the water flows back out of the well immediately following the frac job. A significant volume comes out of the well at a slower rate over an extended period of time. The Fayetteville Shale generates very little **produced water** (i.e., water naturally in the shale rock along with the gas). The combined water flowing out of the well when the well is producing gas is a blend of flow back water and produced water. If this production-phase water has a chloride concentration less than 5,000 ppm, it can be sent to a **land application** site. If the chloride concentration exceeds 5,000 ppm, the water must be transported to distant **commercial disposal wells**. The cost of disposing the high-chloride water, including transportation can exceed $6/bbl, a very high cost. SEECO has recently drilled some of its own water disposal wells that are closer to their active sites. Active well sites generally have **water storage tanks** onsite.

A water storage tank.

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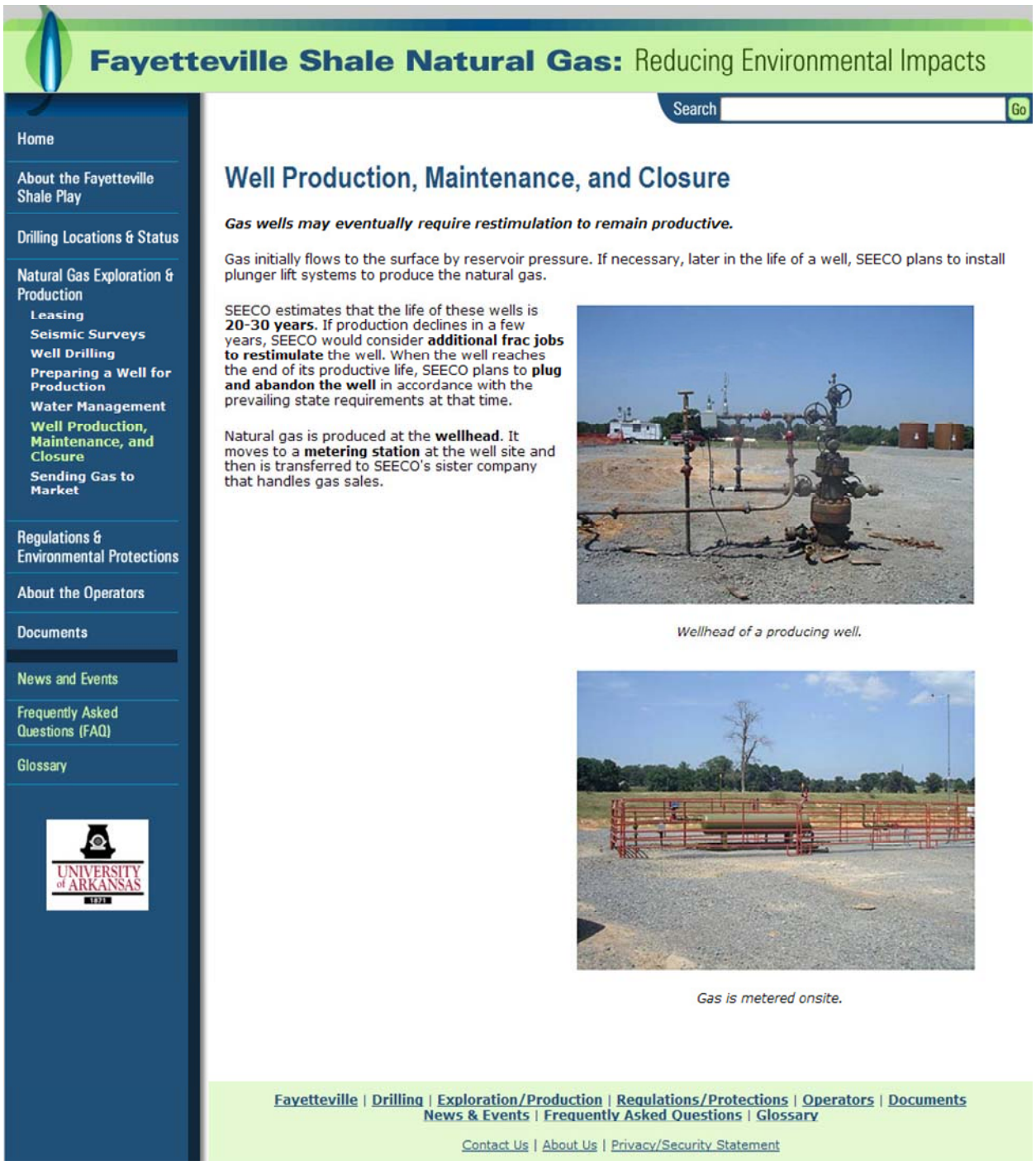
Figure A12. Water management is a significant concern for both regulators and residents of the Fayetteville Shale Play.



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Well Production, Maintenance, and Closure

Gas wells may eventually require restimulation to remain productive.

Gas initially flows to the surface by reservoir pressure. If necessary, later in the life of a well, SEECO plans to install plunger lift systems to produce the natural gas.

SEECO estimates that the life of these wells is **20-30 years**. If production declines in a few years, SEECO would consider **additional frac jobs to restimulate** the well. When the well reaches the end of its productive life, SEECO plans to **plug and abandon the well** in accordance with the prevailing state requirements at that time.

Natural gas is produced at the **wellhead**. It moves to a **metering station** at the well site and then is transferred to SEECO's sister company that handles gas sales.

Wellhead of a producing well.

Gas is metered onsite.

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Figure A13. Well production, maintenance, and closure.

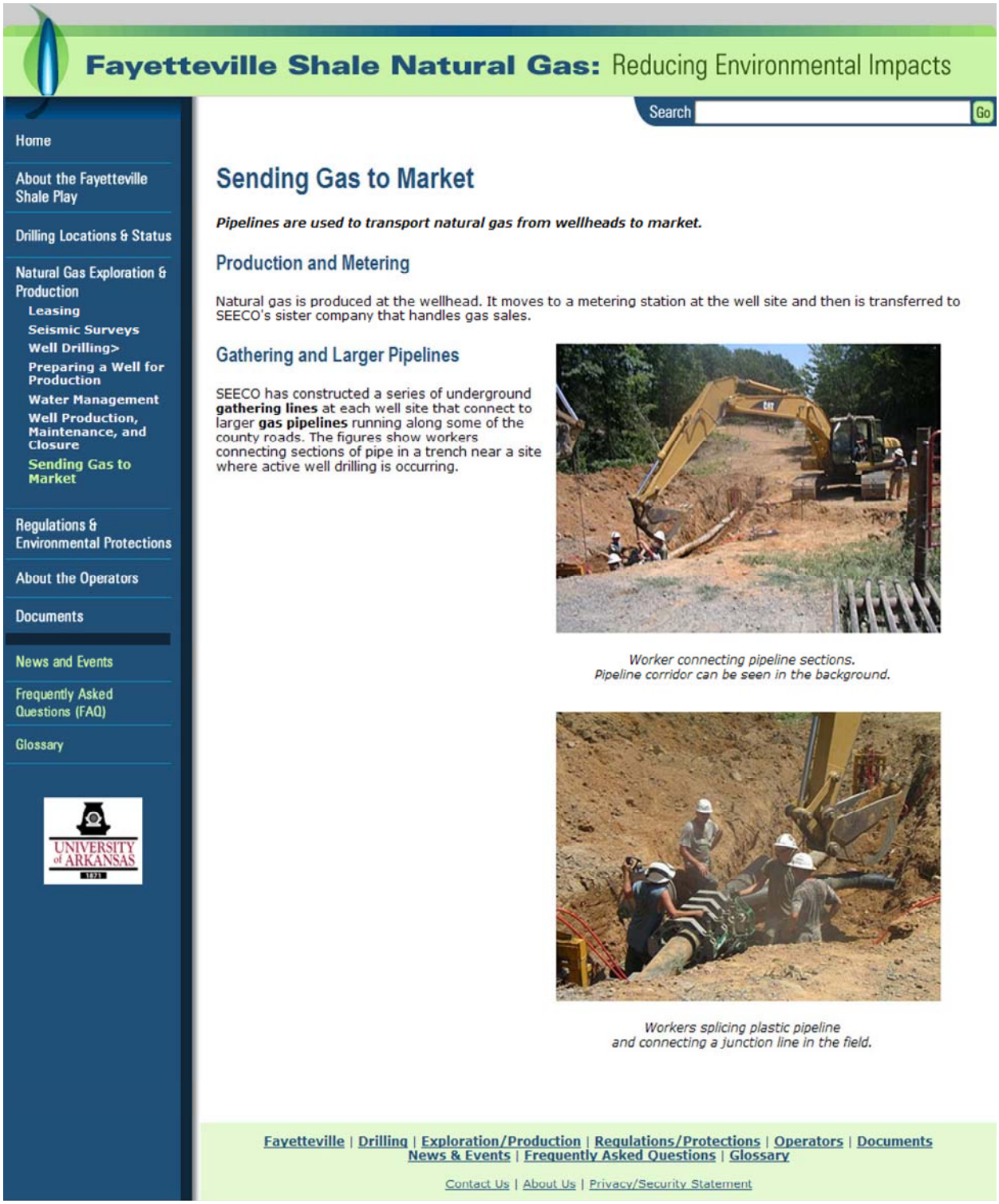

Figure A14.. Sending gas to market. Further content will be developed in this section dealing with alloction of royalties.

Figure A15. . Mock-up main page describing the main operating companies in the Fayetteville Shale Play.

Appendix B:

Trip Report for Field Visit to Fayetteville Shale Gas Wells (SEECO)

http://www.ead.anl.gov/pub/doc/ANL-EVS_R07-4TripReport.pdf

Argonne NATIONAL LABORATORY

ANL/EVS/R-07/4

Trip Report for Field Visit to Fayetteville Shale Gas Wells

Environmental Science Division

The report was prepared as part of Low Impact Natural Gas and Oil project DE-FC26-06NT42930, which is funded by the U.S. Department of Energy, National Energy Technology Laboratory. The overall project is managed by the University of Arkansas at Fayetteville.

About Argonne National Laboratory

Argonne is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC under contract DE-AC02-06CH11357. The Laboratory's main facility is outside Chicago, at 9700 South Cass Avenue, Argonne, Illinois 60439. For information about Argonne, see www.anl.gov.

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ANL/EVS/R-07/4

Trip Report for Field Visit to Fayetteville Shale Gas Wells

by
J.A. Veil
Environmental Science Division, Argonne National Laboratory

August 2007

Introduction

This report describes a visit to several gas well sites in the Fayetteville Shale on August 9, 2007. I met with George Sheffer, Desoto Field Manager for SEECO, Inc. (a large gas producer in Arkansas). We talked in his Conway, Arkansas, office for an hour and a half about the processes and technologies that SEECO uses. We then drove into the field to some of SEECO's properties to see first-hand what the well sites looked like.

Purpose of the Field Visit

In 2006, the U.S. Department of Energy's (DOE's) National Energy Technology Laboratory (NETL) made several funding awards under a program called Low Impact Natural Gas and Oil (LINGO). One of the projects that received an award is "Probabilistic Risk-Based Decision Support for Oil and Gas Exploration and Production Facilities in Sensitive Ecosystems." The University of Arkansas at Fayetteville has the lead on the project, and Argonne National Laboratory is a partner.

The goal of the project is to develop a Web-based decision support tool that will be used by mid-and small-sized oil and gas companies as well as environmental regulators and other stakeholders to proactively minimize adverse ecosystem impacts associated with the recovery of gas reserves in sensitive areas. The project focuses on a large new natural gas field called the Fayetteville Shale.

Part of the project involves learning how the natural gas operators do business in the area and the technologies they employ. The field trip on August 9 provided an opportunity to do that.

Fayetteville Shale

Unlike more traditional oil and gas fields that hold hydrocarbons in porous rock formations, shale holds natural gas in a fine-grained rock matrix. Until recent years, most shale formations were not considered profitable areas for gas production. With new technology and elevated natural gas prices, companies have made the Barnett Shale play in north Texas one of the hottest production fields in the country. Encouraged by the success in the Barnett Shale, operators looked at other large shale formations. The Fayetteville Shale play spans much of the northern and central portions of Arkansas. The Fayetteville Shale ranges in thickness from 50 to 325 ft and ranges in depth from 1,500 to 6,500 ft. The Arkansas Oil and Gas Board shows the locations of all the gas wells in the Fayetteville Shale play on its Web site (http://www.geostor.arkansas.gov/apps/aogc/index.htm).

Area Visited during the Field Visit

During the August 9, 2007, trip, we drove through Conway and Van Buren Counties, located north and west of Little Rock. After leaving the town of Conway, which was heavily developed with commercial activity, we drove mostly through rural and agricultural areas. Route 65 is a four-lane road leading north from Conway. After about 45 minutes, we exited onto two-lane paved roads, which make up the main road network in these areas. At times, we turned onto some of the numerous “county roads” that were unpaved and had dirt and gravel surfaces. An example is shown in Figure 1. Those county roads were not designed to accommodate heavy traffic of large trucks and other oil field machinery.

Figure 1 – View of typical "county road" that is the primary route used to get to gas well sites.

How Does SEECO Produce Natural Gas?

This section of the report describes the steps followed in producing natural gas. I did not personally observe all of the steps during the field visit. However, I did talk with Mr. Sheffer about how SEECO conducts each step in the process.

Leasing: The first step toward producing natural gas involves gaining access to the property under which the prospective natural gas resources are located and on which surface facilities will be located. Unless the operator owns the mineral rights for a piece of land, the company must lease the mineral rights from the owner. A lease is a legal agreement that allows the company to explore for and produce gas from a tract of land in exchange for paying royalties.

Leasing does not require petroleum technology or fieldwork. Therefore, it is outside the scope of this project.

Seismic Surveys: Companies can make educated guesses about which tracts of land within a field hold recoverable natural gas. Before making large financial investments, however, they typically perform seismic studies that help in characterizing the size, shape, and depth of the formations most likely to hold recoverable natural gas. SEECO uses 3D seismic technology. When conducting a seismic study, contractors utilize trucks and helicopters to move equipment into the field and collect data. The contractors drill a grid of 20-ft-deep holes and place an explosive charge of 1 lb of dynamite into each hole. The charges are detonated under controlled conditions, and the resulting vibrations are detected by a network of seismic sensors.

SEECO has an in-house geophysical group to analyze the data collected in the field. Mr. Sheffer did not have detailed familiarity with seismic methods and technologies, but noted that I could have a further conversation with Mike Rhoads, the head of SEECO's geophysical department. During the field visit, we passed a seismic crew working in a field several hundred meters back from the road. We also observed several long cables crossing the road, which were connected to seismic sensors in fields on the opposite side of the road.

Mr. Sheffer noted that in some heavily wooded areas, SEECO's field teams would hand-cut trees and bushes to clear access ways for seismic lines rather than bulldozing. This is somewhat more labor intensive, but it creates less environmental impact.

Well Drilling: After the company has identified a desired location for a well, it obtains permits to drill a well and construct a reserve pit (a pit located next to the drilling rig to catch

the drill cuttings, used drilling mud, rainfall, and other materials). Before drilling can begin, the company clears vegetation and constructs a pad for the drilling rig and other equipment used in preparing the well and an access road to get from the county road to the well site. SEECO pays a use fee to the landowner for disturbing an area of 500 ft by 500 ft, plus the area of the access road. In practice, SEECO generally clears only 300 ft by 250 ft for the pad and the reserve pit plus two adjacent smaller “rig ditch pits,” which collect fluids that fall onto the footprint area beneath the rig. SEECO lines the pits with a plastic liner and covers the pad and access road with gravel. Figure 2 shows the gravel pad at a recently completed well site. Figure 3 shows the gravel access road, Figure 4 shows the reserve pit, and Figure 5 shows one of the adjoining rig ditch pits.

Next the well is drilled. Oil and gas wells are constructed with multiple nested concentric layers of pipe known as casing (an entire length of casing is known as a casing string). The top interval is drilled starting at the surface and has the largest diameter hole. After a suitable depth has been reached, the hole is lined with casing that is slightly smaller than the diameter of the hole. Then cement is pumped into the space between the wall of the drilled hole and the outside of the casing. Next, a smaller diameter hole is drilled to a lower depth. Another casing string is installed to that depth and cemented. This process may be repeated several more times. The final number of casing strings depends on the regulatory requirements in place at that location. It reflects the total depth of the well and the strength and sensitivity of the formations through which the well passes.

Figure 2 – Newly constructed well showing gravel pad.

Figure 3 – Gravel access road.

Figure 4 – Reserve pit.

Figure 5 – Rig ditch pit.

SEECO drills a relatively large diameter hole from the surface down to about a 40-ft depth. This is lined with large casing called conductor pipe; the conductor pipe is cemented in place. Next SEECO uses an air-drilling rig to drill a hole to about a 500- to 550-ft depth. Surface casing is installed and cemented in place. SEECO continues with an air-drilling rig to drill deeper until the hole is about 600 ft above the top of the shale.

At this point, SEECO moves in one of its larger conventional drilling rigs (according to Mr. Sheffer, the company has 11 of its own rigs in the area) to drill the horizontal section. The larger rig uses drilling mud to lift cuttings from the well, lubricate the drill bit, and to serve other functions. Using the larger drill rig allows SEECO to deviate the well (i.e., instead of drilling vertically, the well bore curves off at an angle). Figure 6 shows three diagrams of directionally drilled wells. Nearly all of SEECO's Fayetteville Shale wells are horizontal wells that reach out laterally thousands of feet. Initially, wells were constructed with 2,200 to 2,500 ft of lateral reach. More recently, the wells are completed out to 3,000 to 4,000 ft. SEECO also tries to drill multiple wells from a single well pad, thereby minimizing surface disturbances.

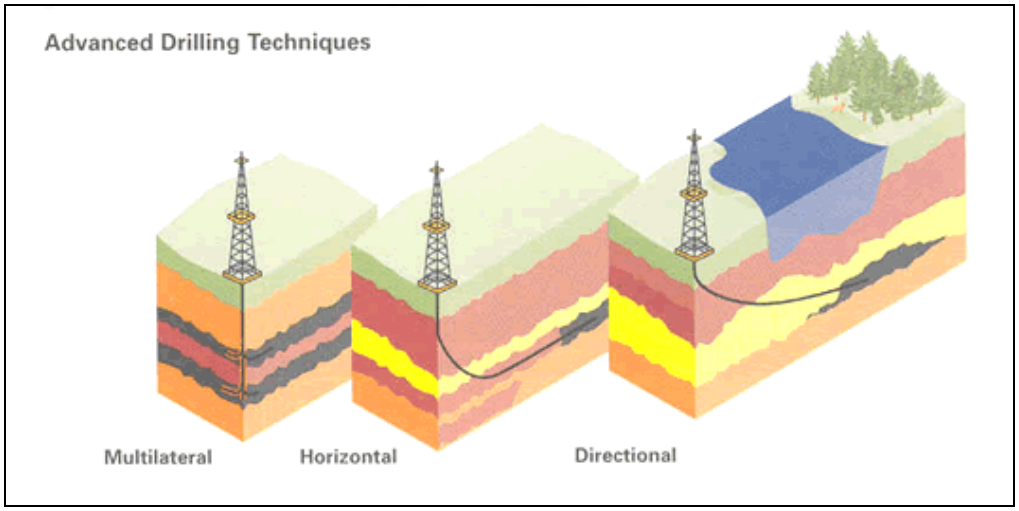

Figure 6 – Examples of directionally drilled wells. (Source: DOE 1999, "Environmental Benefits of Advanced Oil and Gas Production Technology," DOE-FE-0385, U.S. Department of Energy, Office of Fossil Energy, Washington, D.C. Available at http://www.osti.gov/bridge/product.biblio.jsp?osti_id=771125)

Figure 7 shows a drilling rig in the process of drilling a well. Figure 8 shows a blue drilling motor on the pipe rack. Unlike the rest of the straight drill pipe in the background, the drilling motor has a slight curvature. It is placed on the leading end of the rotating drill string and gradually bends the well bore until the desired angle is reached.

Many of the horizontal sections of SEECO's wells are drilled using water-based muds (WBMs). When WBMs are used for drilling, the drill cuttings are placed in the reserve pit. At the end of the drilling job, the cuttings are stabilized with fly ash and then are buried in place after all liquids have been removed. Figure 9 shows a reserve pit that has been reclaimed by burial at the end of the drilling job. The used WBMs are disposed of using land application.

Figure 7 – Drilling rig.

In some of the wells toward the eastern side of SEECO's leases in the Fayetteville Shale, the formations are more difficult to drill. There, SEECO uses oil-based muds (OBMs) to drill the horizontal sections. Because OBMs pose more environmental risk than WBMs, any wells drilled with OBMs use a closed system of tanks rather than putting muds and cuttings into a reserve pit. At the end of drilling a well with OBMs, the OBMs are recycled, and the cuttings are hauled offsite for disposal, typically at a municipal landfill, with permission from the landfill operator.

Preparing the Well for Production: A newly drilled well must be properly completed to allow gas to enter the well and move to the surface. In a well that has casing along the gas-producing section, holes or perforations ("perfs") are made in the casing using small explosive charges or guns. The perfs allow gas to enter the well.

Figure 8 – Downhole drilling motor.

Figure 9 – Reclaimed reserve pit.

Because shale gas is held within a nonporous medium, it is necessary to fracture the shale so that gas has a conduit or pathway to move from the shale to a production well. The fracturing process (a “frac job”) injects water, sand, and other ingredients at very high pressure into the well. The high pressure creates small fractures in the rock that extend out as far as 1,000 ft laterally away from the well. The vertical extent varies but is related to the thickness of the shale layer. After the fractures are created, the pressure is reduced. Water can be removed from the well (“flow-back water”), but the sand grains remain in the rock fractures, effectively “propping” the fractures open and allowing the gas to move. Fracturing is a critical step in producing the Fayetteville Shale wells.

Previously, SEECO used nitrogen foam as its “fraccing fluid.” It found that wells fracced in that way did not produce the fracture system the company hoped to achieve. SEECO now uses “slick water” — water with some surfactant additives to help the flow-back water return from the well at the end of the frac job.

SEECO conducts its frac jobs in stages. The length of the horizontal section of the well is divided into several sections by plugs. The outermost section is fracced first. First water is injected at increasingly higher pressure until a pressure chart shows that the bottom-hole pressure makes a sudden drop, indicating that the rock has fractured. At this point, sand is added to the injected water and the pressure is maintained until a desired dimension of fraccing is completed.

The plug separating the last from the next-to-last section is sealed, and the frac job is continued for that section. The entire frac job may take a day and uses 50,000 to 80,000 bbl (2.1 to 3 million gallons) of water and 1 to 1.5 million lb of sand. Operators try to avoid hauling

such a large volume of water across unimproved county roads. When local water supplies are available within a mile or two, SEECO will pump water for the frac job. SEECO is building a series of dams near its wells that can capture stormwater for future use as frac fluid. Figure 10 shows a temporary pipeline built to convey water from a pond to the well site.

Even without numerous tank trucks carrying water, the pad area at a well being fracced is crowded with heavy equipment. The service companies conducting the frac job will bring multiple engines and pumps, monitoring vans, frac tanks for making the frac fluid mixture and for capturing flow-back water, sand hauling trucks, and other support equipment. Figures 11 through 16 show a well in the midst of a frac job.

Immediately following completion of the frac job, the water used as part of the frac fluid begins to come back out of the well at a rate of 100 to 150 bbl per hour. It declines over time. This flow-back water is collected in 500-bbl frac tanks and is either reused or disposed of.

Figure 10 – Water pipeline conveying water for a frac job.

Figure 11 – Trucks lined up at the site of a frac job.

Figure 12 – One of several sand-hauling trucks in the center.

Figure 13 – A row of frac tanks.

Figure 14 – Sand storage tanks.

Figure 15 – The well being fracced is in the middle, with the pipe conveying the injectate. The two trucks beside the well are pumping units.

Figure 16 - The well being fracced is behind the white crane. The other wellhead near the middle of the picture was fracced on the previous day. In this case, two wells were constructed at the same well pad.

When the frac job is finished, SEECO brings in a coiled tubing rig to drill out the plugs that separated the sections of the horizontal leg of the well. Then a workover rig is used to install production tubing.

Water Management: Water is generated in three ways — ground water, flow-back water, and produced water. First, as the well is drilled with air drilling rigs, the borehole passes through shallow water-bearing formations. A substantial amount of water collects in the wellbore. SEECO is working with the Arkansas Department of Environmental Quality (ADEQ) to capture this water and treat it with an aluminum-based flocculant. If the chlorides concentration is less than 1,500 ppm, ADEQ allows the water to be applied to roads for dust control.

As mentioned in the previous section, a large volume of water is used to make up the frac fluid. Much of the water flows back out of the well immediately following the frac job. A significant volume comes out of the well at a slower rate over an extended period of time. Mr. Sheffer noted that the Fayetteville Shale generates very little produced water (i.e., water naturally in the shale rock along with the gas). The combined water flowing out of the well when the well is producing gas is a blend of flow-back water and produced water. If this production-phase water has a chloride concentration less than 5,000 ppm, it can be sent to a land application site. If the chloride concentration exceeds 5,000 ppm, the water must be transported to distant commercial disposal wells. The cost of disposing of the high-chloride water, including transportation can exceed $6/bbl, a very high cost. SEECO has recently drilled some of its own water disposal wells that are closer to its active sites. Active well sites generally have water storage tanks onsite. Figure 17 shows a water storage tank.

Figure 17 – Water storage tank at well site.

Well Production, Maintenance, and Closure: Gas initially flows to the surface by reservoir pressure. If necessary, later in the life of a well, SEECO plans to install plunger lift systems to produce the natural gas.

SEECO estimates that the life of these wells is 20 to 30 years. If production declines in a few years, SEECO would consider additional frac jobs to restimulate the well. When the well reaches the end of its productive life, SEECO plans to plug and abandon the well in accordance with the prevailing state requirements at that time.

Sending Gas to Market: Natural gas is produced at the wellhead (Figure 18). It moves to a metering station at the well site (Figure 19) and then is transferred to SEECO's sister company that handles gas sales.

SEECO has constructed a series of underground gathering lines at each well site that connect to larger gas pipelines running along some of the county roads. Figures 20 and 21 show workers connecting sections of pipe in a trench near a site where active well drilling was occurring that day.

Figure 18 – Wellhead.

Figure 19 – Gas metering station at a producing well site.

Figure 20 – Worker connecting pipeline sections. Pipeline corridor can be seen in the background.

Figure 21 – Workers splicing plastic pipeline and connecting a junction line in the field.

Production Information

Within a few days following the field visit, the *Oil & Gas Journal* published a short article[1] giving some production statistics for Southwestern Energy Co., SEECO's parent company. Some of those statistics are provided in this section.

The company has run 145 mi^2 of 3D seismic through June 30 in the Fayetteville Shale play, and expects to reach 400 mi^2 of 3D seismic by the end of 2007. Southwestern averaged a net production of 105 MMcfd (million cubic feet per day) in the Fayetteville Shale during the first half of 2007. As of June 30, 2007, Southwestern has drilled and completed 303 producing wells; 246 of them are horizontal wells, and 219 were fractured using slick water fluid.

During the April–June 2007 quarter, Southwestern drilled and completed 62 wells in the Fayetteville Shale play. The average cost for these wells was $2.9 million. The horizontal portion of the wells averaged 2,550 ft, but 10 of the wells had horizontal reaches greater than 3,000 ft. The average drilling time took 18 days. The last 10 wells completed with slick water frac jobs averaged initial production rates of 2.6 MMcfd.

[1] "3D Seismic Guides Arkoma Basin Fayetteville Play," *Oil & Gas Journal*, August 13, 2007, p. 40.

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Appendix C:

Trip Report for Field Visit to Fayetteville Shale Gas Wells (Chesapeake Energy)

Trip Report for Field Visit to Fayetteville Shale Gas Wells (Chesapeake Energy)

Greg Thoma, Jackson Cothren, Peter Smith, and Lyda Zambrano

Introduction

This report describes a visit to several gas well sites in the Fayetteville Shale on August 2, 2007. We met with Jace Marshall, the field Health and Safety Officer for Chesapeake Energy, Inc. (a large gas producer in Arkansas). We talked in his Albion, AR office for an hour and a half about the processes and technologies used by Chesapeake. Then we drove into the field to to see Chesapeake's operations.

Purpose of the Field Visit

In 2006, the U.S. Department of Energy's National Energy Technology Laboratory (NETL) made several funding awards under a program called Low Impact Natural Gas and Oil (LINGO). One of the projects receiving an award is "Probabilistic Risk-Based Decision Support for Oil and Gas Exploration and Production Facilities in Sensitive Ecosystems". The University of Arkansas at Fayetteville has the lead on the project, and Argonne National Laboratory is a partner.

The goal of the project is to develop a web-based decision support tool that will be used by mid-and small-sized oil and gas companies as well as environmental regulators and other stakeholders to proactively minimize adverse ecosystem impacts associated with the recovery of gas reserves in sensitive areas. The project focuses on a large new natural gas field called the Fayetteville Shale Play.

One of the project tasks is an evaluation of existing natural gas exploration and production technologies. This visit to the field provided an opportunity to learn the current technologies employed by Chesapeake Energy, Incorporated.

Fayetteville Shale

Unlike more traditional oil and gas fields that hold hydrocarbons in porous rock formations, shale holds gas in a fine-grained rock matrix. Until recent years, most shale formations were not considered profitable areas for gas production. With new technology and elevated natural gas prices, companies have made the Barnett Shale play in north Texas one of the hottest production fields in the country. Encouraged by the success in the Barnett Shale, operators looked at other large shale formations. The Fayetteville Shale play spans much of the northern and central portions of Arkansas. The Fayetteville Shale ranges in thickness from 50 to 325 feet and ranges in depth from 1,500 to 6,500 feet. The Arkansas Oil and Gas Board shows the locations of all the gas wells in the Fayetteville Shale play on its website at http://www.geostor.arkansas.gov/apps/aogc/index.htm.

The Area Visited During the Field Visit

Albion, Arkansas is located approximately 20 miles north of Searcy, in White County. A majority of Chesapeake's current activity is in western White County. We travelled primarily on county roads, most of them paved. Access roads to drill pads are clearly new construction, but for the Chesapeake sites we visited, most of the access roads were less than ½ mile in length.

How Does Chesapeake Produce Natural Gas?

This section of this report parallels that of the SEECO report. The basic steps involved in the production of natural gas are essentially the same for both of the major companies involved in

the Fayetteville Shale Play. In this section only the significant differences in the protocols followed by the two companies will be presented.

Leasing: The first step towards producing natural gas involves gaining access to the property under which the prospective natural gas resources are located and on which surface facilities will be located. The process is fundamentally the same for all oil and gas developers.

Seismic Surveys: While the subcontractors used for seismic surveys on different, the seismic technology data acquisition is fundamentally the same. As with the SEECO, Chesapeake also has an in-house geophysical analysis group.

Well Drilling: Wells in the Fayetteville Shale Play typically have a vertical section which reaches to near the top of the Fayetteville shale formation followed by a horizontal lateral that may be up to 4000 feet in length through the active producing zone. The drilling and casing procedures are very similar to those described in the report on SEECO's activities. Based on our conversations with SEECO and Chesapeake representatives, it appears that one area of potentially significant difference in operation is associated with the type of drilling muds used by each of the two companies. In our conversations with the SEECO, it was indicated that currently the majority of their wells are drilled using water based muds, while Chesapeake's representatives indicated that all of their wells were drilled using oil-based muds. One operational difference that results from the use of oil-based muds that is the requirement for a closed loop cuttings handling system (Figure A22) . Each of the Chesapeake sites that we visited included a closed loop system which separates the cuttings from the drilling mud, allowing the drilling mud to be recycled downhole, and the cuttings to be a dried and stored on site.

One other difference between the two operators that was observed during field trips is that the on site pit used for collection of shallow aquifer water and surface runoff was not lined at Chesapeake sites but was lined at SEECO sites (Figure A23).

Figure 1. Dried cuttings after separation from oil based mud. Cuttings are stored onsite until ultimately hauled to a landfill for disposal.

Preparing the Well for Production: As with seismic exploration, both SEECO and Chesapeake use subcontractors for well fracturing jobs. While there are minor differences in the operation of these jobs, description provided from the SEECO trip report accurately describes Chesapeake's "fraccing" (Figure 2). Approximately 75,000 barrels of water or nearly three million gallons is required to fracture the shale formation for a single well. The operators are working with local communities in residents in the Fayetteville Shale Play area so the sufficient water will be available to complete the frac jobs necessary. Chesapeake has constructed a large reservoir near the Little Red River and has plans to withdraw approximately 1500 acre feet of water on an annual basis from the river during high flow. They plan to construct distribution pipelines from this reservoir to distribution points throughout White

County where will be available for well fracturing. SEECO, on the other hand, is constructing a large number of small, 1 to 5 acre reservoirs from which they will haul water to fracture jobs.

Figure 2. Stormwater collection pit. Unlined pits are not used for collection of water generated during the drilling process.

Water Management: Water is generated in three ways – ground water, flow-back water, and produced water. All of this water must currently be disposed in licensed disposal wells. Chesapeake typically attempts to re-use this water for a subsequent fracture job; however, as the salts and other contaminants build up, this becomes more difficult. Typically, the flow-back frac water is reused 3-4, but up to as many as 8 times.

Well Production, Maintenance, and Closure: Current estimates are that the life of these wells is 20-30 years. If production declines in a few years, additional frac jobs to restimulate the well may be employed. At the end of its productive life, each well will be pluged and abanded in accordance with the state requirements at that time.

Sending Gas to Market: As with SEECO, Chesapeake monitors production at each well and meters the produced gas to a compressor station and ultimately feeds it to a large inter-state transmission line. The transmission pipelines are operated by different companies.

Gathering Lines: Chesapeake uses exclusively metal pipe for its gathering lines, in contract to SEECO which has chosen to use primarily polymeric pipe.

Appendix D

Tabulated Summary of Potential Environmental Concerns Associated with Sensitive Species in the Fayetteville Shale Play

In order to recommend a best management practice using the US Fish and Wildlife BMP recommendation document, several sources of information must be available. The table below identifies which GIS (or other) layers (and their associated spatial and temporal constraints) are required to make a decision concerning a given BMP.

Table D1. Summary of sensitive species potentially found in the Fayetteville Shale Play, including development constraints necessary for protection.

Target	Threat	Dataset	Owner	Spatial Constraint	Temporal Constraint
1.1 Bald Eagle					
1.11	Clearing, external construction and landscaping	Locations of Bald Eagle Nest(s)	FWS		must be done outside Dec 15-Jun 30 nesting season
1.12	Road construction during nesting season	Locations of Bald Eagle Nest(s)	FWS	within 660 feet of a nest	must be done outside Dec 15-Jun 30 nesting season
1.13	Clear cutting	Locations of Bald Eagle Nest(s)	FWS	within 330 feet of a nest	avoided at ALL times
1.13c	Use of Explosives	Locations of Bald Eagle Communal Roost(s)	FWS	within 0.5 miles of communal roosts (or within 1 miles in open areas) when eagles are congregating	
1.2 Ivory-billed Woodpecker					
1.22	Surface occupancy	Locations of IBW active or inactive nest or roost activities	TNC	.5 mile radius buffer (primary zone) around active or inactive nest or roost cavities	

Target	Threat	Dataset	Owner	Spatial Constraint	Temporal Constraint
1.23	Disturbances in secondary zone	Delineation of IBW 1) Primary Zone and 2) Secondary Zone	TNC	within .75 mile of primary zone around active or inactive nest or roost cavities	not permitted during nesting period Feb 1-May 31 in secondary zone
1.3 Red-cockaded Woodpecker					
1.31	Surface occupancy	Locations of RCW cluster(s)	ANHC	within .5 miles of cluster	
1.31	Vehicle use within cluster outside of existing, maintained road	Locations of RCW cluster(s)	ANHC	no vehicle use within RCW cluster	
1.4 Interior Least Tern					
1.41	Surface occupancy	Locations of ILT breeding areas		.5 mile of observations of breeding activity	
1.5 Karst Species and Groundwater					
1.51a Bats (Indiana, Gray, & Ozark Big-eared)	Drilling or blasting	Locations of 1) known maternity or 2) hibernacula		1 mile radii around known maternity or hibernacula	should be phased and time delayed and coordinated with FWS and AGFC
1.51a	Tree removal	Locations of 1) known maternity or 2) hibernacula		within 5 mile radii around known maternity or hibernacula	Mar 15-Dec 1
1.51b	Ground disturbance	Locations of 1) known maternity or 2) hibernacula			should occur between Dec 2-Mar 15
1.51d	Surface occupancy	Locations of 1) known maternity or 2) hibernacula		apply .25 mile conservation zone	

Target	Threat	Dataset	Owner	Spatial Constraint	Temporal Constraint
1.51e	Disturbances in riparian areas of bat conservation zones	Locations of bat conservation zones		riparian buffer strips >= 250 feet either side of streams within 5 mile conservation zone	
1.51k	Removal or modification of old buildings, wells, cisterns, and other man-made structures	Locations of bat roost(s)			
1.57 Groundwater	Production within 1 mile of known human consumed groundwater or rare and endangered species	Locations of 1) known human consumed groundwater and 2) rare and endangered species		? Need clarification on this ?, dye tracing recommended?	
1.513	Directional Drilling	Locations of Cave Occurrence Zone(s)		directional drilling should occur at least 100 feet below the bottom of the cave occurrence zone	
1.518	Abandonment Cementing	Locations of Cave Bearing Zone(s)		well bore cemented from 100 feet below the bottom of the cave bearing zone to the surface	
1.6 Aquatic Species					
1.61	Discharges near rivers, streams, wetlands and springs	Locations of 1) rivers 2) streams 3) wetlands, and 4) springs locations		250 foot buffer surrounding: Rivers, Streams, Wetlands, and Springs	
1.61	Disturbance of natural vegetation	Locations of 1) rivers 2)		250 foot buffer surrounding:	

Target	Threat	Dataset	Owner	Spatial Constraint	Temporal Constraint
		streams 3) wetlands, and 4) springs locations		Rivers, Streams, Wetlands, and Springs	
1.63	Spanning creeks and floodplains	1) creek and floodplain delineations 2) locations of waters or wetlands supporting federally listed and sensitive species		minimum 250 foot set back from stream banks under creeks, rivers, and other waters or wetlands supporting federally listed and sensitive species	
1.64 bi	Sediment and erosion	Ordinary high watermark information of wetlands, streams, and rivers		filter fences placed minimum of 10 feet from ordinary high water mark	
1.7 Federally Listed Plants					
1.72	Use of pre-emergent herbicides	Locations of 1) federally listed species and 2) state species of concern		avoid use of pre-emergent herbicides	
1.73a	Use of pre-emergent herbicides	Locations of Virginia Sneezeweed		avoid use of pre-emergent herbicides	avoid use Spring "green up" until first frost
1.73b	Use of pre-emergent herbicides	Locations of Geocarpon minimum		avoid use of pre-emergent herbicides	Feb-Jun
1.73c	Use of pre-emergent herbicides	Locations of Missouri Bladderpod (Physaria (Lesquerella) filiformis)		avoid use of pre-emergent herbicides	Jul-Sep

Target	Threat	Dataset	Owner	Spatial Constraint	Temporal Constraint
1.73d	Use of pre-emergent herbicides	Locations of Pondberry (Lindera melissifolia)		avoid use of pre-emergent herbicides	Dec-Feb
1.73e	Use of pre-emergent herbicides	Locations of Running Buffalo Clover (Trifolium stoloniferum)		avoid use of pre-emergent herbicides	Aug-Feb
1.8 Migratory Birds					
	Reserve pits and ponds exhibiting sheen (contaminated water)	Locations areas frequented by migratory birds		reserve pits should be netted	10 days after well completion
3.0 Geophysical Activities					
3.9	Disturbance to cultural sites	Locations of cultural sites/resource s		avoid cultural sites	
4.0 Construction Activities					
4.20e	Erosion due to road construction	Locations of slope areas > 40 %		avoid road construction on side slopes > 40%	
5.0 Vehicle Maintenance, Petroleum, and Chemicals					
5.2	Petroleum products contaminating soils and water bodies	Locations of wetlands, streams, and Karst Features		staging areas for equipment/vehicl e maintenance and chemical storage should be established 250 feet or more away from wetlands, streams, or karst features	
5.6	Wash water (including mild detergent)	Locations of wetlands, streams, and Karst Features		wash water should be allowed to infiltrate into a permeable area 250 feet or more away from	

Target	Threat	Dataset	Owner	Spatial Constraint	Temporal Constraint
				wetlands, streams, or karst features	
10.0 Chemical Controls					
10.2	Aerial application of herbicides or other pesticides	Locations of listed species or habitat		no aerial application of herbicides, or other pesticides, sterilants, or adjuvants within 250 feet	
10.2	Ground application of herbicides or other pesticides	Locations of listed species or habitat		no ground application of herbicides, or other pesticides, sterilants, or adjuvants within 150 feet	
10.4	Storage and or changing of herbicides, fertilizers, vehicle maintenance fluids, petroleum products and drilling fluids	Locations of streams		no closer than 250 feet from streams	
10.5	Storage of discharge material, overburden, fuel and equipment	Locations of streams and cave watersheds		no closer than 250 feet from edge of streams and cave watersheds	
11.0 Gathering and Transmission Lines					
11.8	Directional Drilling	Locations of perennial streams		250 foot setback from perennial streams for all directional drilling operations	
11.9	Stream crossings	Locations of streams			conduct stream crossings during

Target	Threat	Dataset	Owner	Spatial Constraint	Temporal Constraint
					periods of low flow (Jul-Sep)
12.0 Storm Water					
12.2	Detention basins	Locations of streams		should not be constructed in a stream	
Appendix A Forest Wide (FW) Karst Standards for the Ozark-St. Francis National Forest					
FW18	Disturbance of mature forest cover	Location(s) of mature forest cover in Ozark-St. Francis National Forest		maintain within 100 feet slope distance from top of bluffs	
FW18	Disturbance of mature forest cover	Location(s) of mature forest cover in Ozark-St. Francis National Forest		200 feet slope distance from the base of bluffs	
FW44	Surface soil disturbance in KMZ (Karst Management Zone)	Locations of KMZs		surface disturbance measured should be < 5% soil disturbance over entire KMZ within project area	
FW54	Camping and campfires	Locations of cave entrances, mines, and rock shelters used by TES		camping and campfires prohibited	

However, because the system will take into account imprecision and uncertainty in the underlying geospatial data layers, it will provide enough information to filter for (or perhaps

rank order by) potential for environmental impact the full set of possible infrastructure locations and thus limit the number of required on-site surveys.

Table D2. Participating organizations and the data layers they are capable of providing.

US Geological Survey	National Elevation Dataset (NED will serve as the basis for all terrain based decisions such as slope, aspect and flow)
US Geological Survey and US Environmental Protection Agency	National Hydrology Dataset (1:24,000 scale)
Arkansas Geographic Information Office	Arkansas Road Centerlines
Arkansas Geographic Information Office	Public Land Survey System (Township, Range and Section corners)
Arkansas Geographic Information Office	2006 Orthophoto Image Base (0.33 – 1.0 meter GSD)
Arkansas Geographic Information Office	Arkansas political boundaries (county, city)
Arkansas Natural Heritage Commission	Threatened and Endangered Species (Red Flag version)
Arkansas Natural Resources Commission	Location of known wetlands
Arkansas Natural Resources Commission	Watershed boundaries
US Forest Service	Public forest boundaries
US Census Bureau	TIGER Road Features
Bureau of Land Management	Public land boundaries
Arkansas Oil and Natural Gas Commission	Existing drill pad and well locations (permit status and production history)
Arkansas Oil and Natural Gas Commission	Locations of major gas transmission lines
Arkansas Department of Environmental Quality	Locations of reserve pit locations
Arkansas Natural Resources Commission	2006 Land Cover
Natural Resources Conservation Service (US Department of Agriculture)	State Soils Geographic Data (STATSGO) and Soil Survey Geographic Data (SSURGO)
US Fish and Wildlife Service	Threatened and endangered species sensitive areas