PROGRAM facts

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OFFICE OF FOSSIL ENERGY
NATIONAL ENERGY TECHNOLOGY LABORATORY

Strategic Center for Natural Gas & Oil

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NETL R&D TACKLES TECHNOLOGICAL CHALLENGES OF THE WILLISTON BASIN'S BAKKEN FORMATION

Recent development of the Bakken Formation in the Williston Basin of western North Dakota and eastern Montana is a good example of persistent analysis of geologic data and adaptation of new completion technologies overcoming the challenges posed by unconventional reservoirs. However, as with most unconventional plays, as Bakken development continues, questions regarding exactly *how* to refine newly applied technologies to optimize recovery and economics become more specific.

The National Energy Technology Laboratory (NETL) is involved in five initiatives to enhance industry's understanding of the Bakken in order to improve oil recovery from this important domestic resource. Research activities will involve significant collaboration among researchers to maximize results from all efforts. The initiatives include: (1) an industry consortium gathering information on how hydraulic fracturing stimulations perform in the Bakken ; (2) an evaluation of key factors affecting production to determine relationships among Bakken rock properties, well completion methods, and well performance; (3) a geo-mechanical study to measure *in-situ* stresses and geo-mechanical properties of the Bakken to better design hydraulic fracture treatments; (4) an initial assessment of the hydrocarbon potential of the Bakken and development of an integrated exploration model; and (5) an effort to determine the controlling mechanisms affecting oil distribution and production and to identify methods for increasing oil flow through monitoring well conditions and (potentially) injecting carbon dioxide (CO_2).

Collectively, these initiatives will accelerate the safe and efficient development of this significant resource. The goal of this research is the collection and public dissemination of basic scientific data that can be utilized by industry to more rapidly develop and bring on stream domestic oil resources.

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Introduction

About 105 million barrels of oil were produced from the Bakken through 2007. The Elm Coulee oil field in Montana, discovered in 2000, has produced about 65 million barrels of that total. Currently, there are between 900 and 1000 wells producing in the Bakken, split almost equally between North Dakota and Montana.[1] Production in 2006 amounted to approximately 19 million barrels in Montana and 2.25 million barrels in North Dakota, although 2007 production in North Dakota jumped more than three-fold.[2] The most active operators in the United States portion of the Bakken Play so far includes Continental Resources Inc.; XTO Energy; Lyco Energy Corp.; EOG Resources Inc.; ConocoPhillips; Marathon Oil Corp.; Petro-Hunt Corp.; Whiting Petroleum Corp.; and Hess Corporation.[3] Collaborative ventures currently underway have teamed a number of these companies with regional academic institutions, state agencies, and the Department of Energy (DOE), to develop a better understanding of the reservoir and optimize development.

Geology

Throughout most of the Williston Basin, the Upper Devonian/Lower Mississippian Bakken Formation has three members: the Upper Member, a 23-foot thick black marine shale; the Middle Member, an 85-foot thick interbedded layer of limestone, siltstone, dolomite, and sandstone; and the Lower Member, a 50-foot thick black marine shale.[4] The formation depth ranges from 11,000 feet at the center of the basin to just over 3000 feet along its northern limit. The shale members are notable for their high organic carbon content, but early Bakken production efforts focused on the shales had very limited success. Current efforts are now focused on the Middle Member, which has more porosity and permeability than the adjacent shales. The thermally mature areas of the Bakken are overpressured, often oil-wet, with 41°API gravity crude oil in natural fractures capable of producing at high production rates.[5]

Resource

The hydrocarbon resources of the Bakken are defined as “continuous-type” resources, where the oil and gas have not accumulated into discrete reservoirs of limited areal extent. Other examples of continuous oil or natural gas resources are low-permeability (tight) formations (e.g., the Austin Chalk of Texas and Louisiana and tight gas sands of the Rocky Mountain basins), shales, and coalbeds.

A number of values have been estimated for the volume of oil generated by the Bakken.[6] These ranged from 413 billion barrels (BBbls)—an average range from 271 to 503—in an unpublished paper by Dr. Leigh Price, to 10 BBbls in landmark papers by Dow and Williams in 1974. New estimates of the amount of hydrocarbons generated by the Bakken were presented by Meissner and Banks in 2000 and by Flannery and Kraus in 2006. The first paper tested a newly developed computer model with existing Bakken data to estimate generated oil of 32 BBbls. The second paper used a more sophisticated computer program with extensive data input supplied by the North Dakota Geological Survey and Oil and Gas Division. Early numbers resulting from this information placed the value at 200 BBbls, which was later revised to 300 BBbls when the paper was presented in 2006. This research indicated that while the volume of oil was significant, additional work was still required to refine estimates and develop more reliable models.

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[1] North Dakota Department of mineral Resources (https://www.dmr.nd.gov/oilgas/) and Montana Board of Oil and Gas (http://bogc.dnrc.mt.gov/annualreviews.asp).

[2] *Ibid*.

[3] Petzet, A., 2008, “Williston’s Bakken Given 3-4 Billion Recoverable,” *Oil and Gas Journal*, April 21, 2008.

[4] EIA, 2006, “Technology-Based Oil and Natural Gas Plays: Shale Shock! Could There Be Billions in the Bakken?”, November 2006.

[5] *Ibid*.

[6] LeFever, J., and L. Helms, 2006, Bakken Formation Reserve Estimates, at https://www.dmr.nd.gov/ndgs/Bakken/newpostings/07272006_BakkenReserveEstimates.pdf.

Recovery

How much of the generated oil is technically and economically recoverable remains to be determined and will be based upon an evolving understanding of the best methods for producing the resource. Estimates of 50 percent, 18 percent, and from 3 to10 percent have been published. Obviously, the range of potential reserves is large, depending on the choice of estimates of both generated volume and recovery. One of the two largest operators in the Elm Coulee Field estimated that the in-place resources of the field area are 5 million barrels per square mile. With an assumed 10-percent average recovery factor, primary oil recovery could be 270 million barrels from the Elm Coulee Field alone.[7]

In April 2008, the U.S. Geological Survey (USGS) completed an assessment of the undiscovered, technically recoverable oil and associated gas resources of the Bakken in the U.S. portion of the Williston Basin.[8] In this assessment, the USGS defined a petroleum system made up of seven assessment units. It also made quantitative estimates of the undiscovered, technically recoverable oil and associated gas resources within six of these assessment units for the Bakken in Montana and North Dakota (see Figure 1). Mean undiscovered volumes of technically recoverable resources were estimated to be 3.65 billion barrels of oil, 1.85 trillion cubic feet of associated and/or dissolved natural gas, and 148 million barrels of natural gas liquids. The next largest continuous oil accumulation in the United States is the Austin Chalk, with an undiscovered estimate of 1.0 billion barrels of technically recoverable oil.

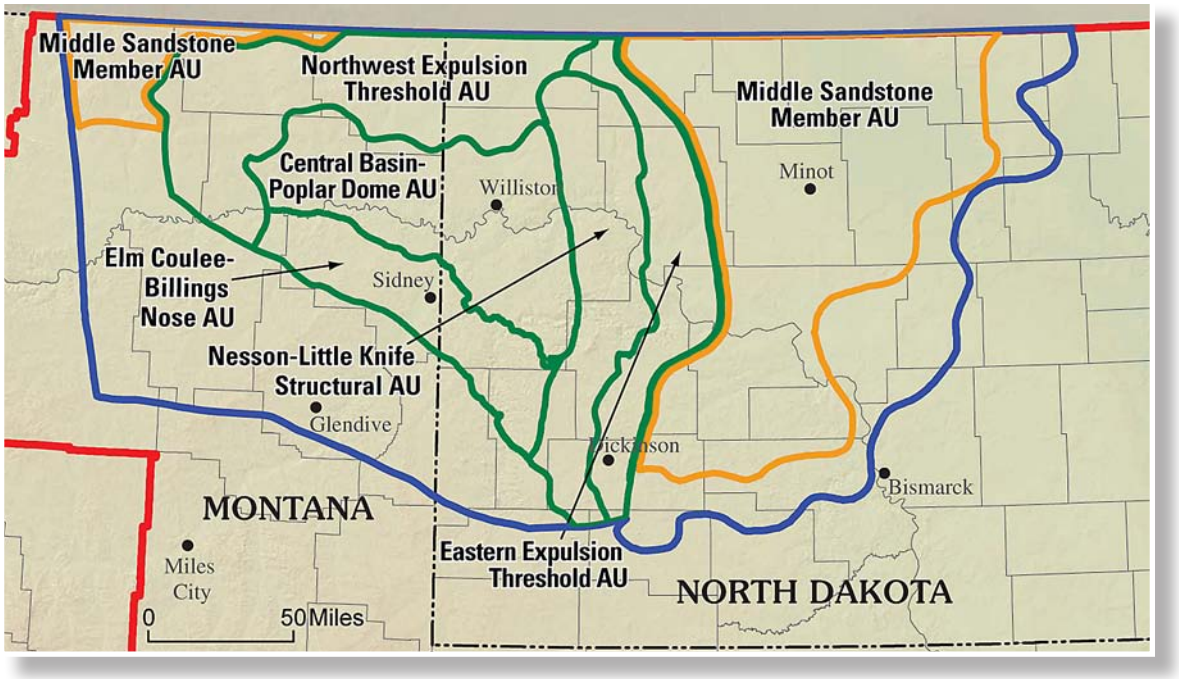

Figure 1.

Map showing the boundary of the Bakken-Lodgepole Total Petroleum System (TPS) (in blue), and the five continuous units (in green) and one conventional unit (in orange) defined for the assessment of undiscovered oil resources in the Upper Devonian–Lower Mississippian Bakken Formation in the U.S. portion of the system. The outermost green line defines the area of oil generation for the upper shale member of the formation (from USGS Fact Sheet 2008–3021, April 2008).

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[7] EIA, 2006, *op cit.*

[8] Pollastro, R. M., *et al*., 2008, Assessment of undiscovered oil resources in the Devonian-Mississippian Bakken Formation, Williston Basin Province, Montana and North Dakota, 2008: U.S. Geological Survey Fact Sheet 2008–3021, April 2008.

Challenges

The success of the Bakken development to date has been based primarily on a combination of horizontal drilling and hydraulic fracturing technology. Nevertheless, recovery factors are still very low. Some of the key questions facing operators include:

- How does one characterize the reservoir geology at the field or prospect level?
- What is the true nature of reservoir matrix and fracture permeability?
- What is the optimal completion design alternative among those employed to date?
- What is the optimal horizontal wellbore length?
- What is the optimal well spacing?
- Are there novel techniques that can be applied to increase recovery?

NETL Research Initiatives

NETL is involved in five initiatives to enhance industry's understanding of the Bakken and help operators answer some of these questions:

- An industry consortium to gather information on how hydraulic fracturing stimulations perform in the Bakken.
- An evaluation of key factors affecting production to determine relationships among Bakken rock properties, well completion methods, and well performance.
- A geo-mechanical study to measure *in-situ* stresses and geo-mechanical properties of the Bakken to better design hydraulic fracture treatments.
- An initial assessment of the hydrocarbon potential of the Bakken and development of an integrated exploration model.
- An effort to determine the controlling mechanisms affecting oil distribution and production and to identify methods for increasing oil flow through monitoring well conditions and (potentially) injecting CO_2.

Research activities will involve significant collaboration among researchers to maximize results from all efforts.

Industry Consortium – NETL is participating in an ongoing field study to gather a comprehensive suite of geophysical data from surface and subsurface sensors, during and after fracture stimulation of a pair of horizontal wellbores in the Bakken. This experiment, led by XTO Energy, includes a surface geophone array, three 1000–1500 foot deep wells with permanently emplaced subsurface geophones dedicated to continuous monitoring (funded by NETL/DOE), a series of 18 shallow holes with emplaced geophones, and 3 horizontal wellbores, one of which includes emplaced geophones for monitoring (see Figure 2). The fracturing carried out in two of the horizontal wells was monitored by this extensive array of sensors in an effort to understand exactly how hydraulic fractures are created in the Bakken. Downward-looking vertical seismic profiling will be used in a passive seismic acquisition mode to continually monitor the formation for years after production is initiated. NETL is also funding Lawrence Berkeley National Laboratory to interpret the wealth of seismic data generated and develop geologic models that can be used to guide future stimulations. The results of this field study are expected to be made public in January 2009.

Evaluation of Key Factors Affecting Production – NETL has recently initiated an effort with the University of North Dakota's Energy and Environmental Research Center (UNDEERC) to fund a Williston Basin Bakken Play Assessment. This detailed analysis will incorporate data from state agencies on wells, stimulations, locations, completion designs, and productivity, to provide critical insights on optimal development strategies.

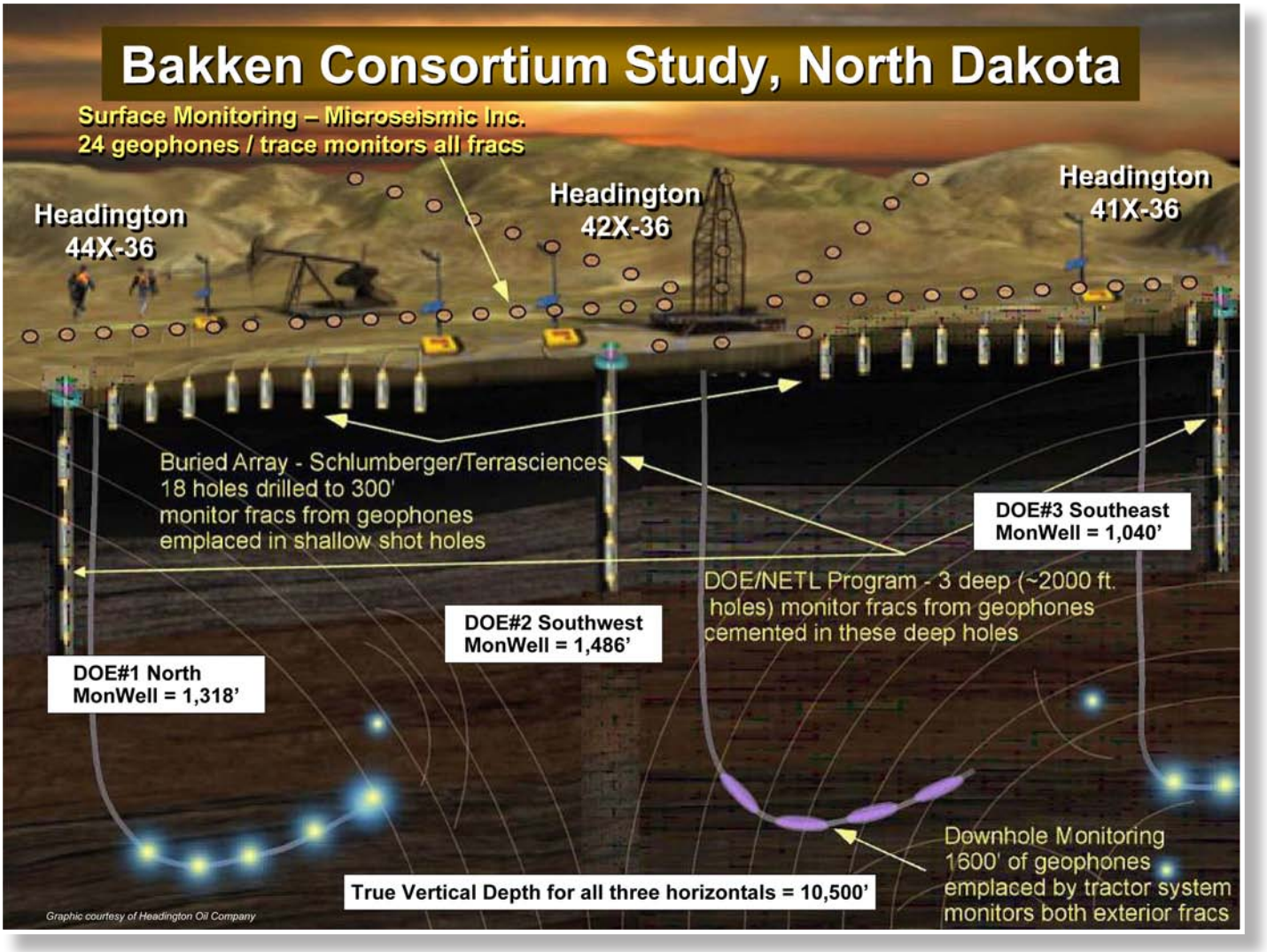

Figure 2.

Artist's depiction of an ongoing field study to gather geophysical data from surface and subsurface sensors, during and after fracture stimulation of a pair of horizontal wellbores in the Bakken (courtesy of XTO energy).

The investigation to be undertaken entails three activities: analysis of well file data, seismic and geo-mechanical studies, and geochemical studies. The first activity will involve use of the Risk-Based Data Management System (RBDMS) to enter, process, and archive well data. The RBDMS and other databases and records will be used to analyze a wide range of parameters that impact well productivity and oil recovery from the Bakken. Currently, many key parameters of interest are not gathered (e.g., proximity to structure, number and azimuth of induced fractures, nature and distribution of sand, etc.). Obtaining these data will necessitate manual evaluation of well files and significant personal interaction with companies currently operating in the Bakken. Data collected from operators, as well as those data resident in the existing databases, will be analyzed in terms of well performance and/or oil recovery. UNDEERC will evaluate data from an area in Mountrail County near Parshall, ND—which has seen many sustainable, highly productive new Bakken wells—and compare this data with similar data collected from another area of the state (to be determined) in which success rates and production have been less prolific.

A second activity of this project involves the analysis of existing sets of seismic data (from within the Parshall area), together with geo-mechanical properties of Bakken reservoir and seal rock samples, to develop a better understanding of how the macroscale stress and strain forces associated with geologic structure in central North Dakota may influence the geo-mechanical properties of Bakken reservoir rock and seal rock on the microscopic scale. These seismic and geo-mechanical data, combined with the knowledge and data gained in the first activity, will be used to develop a comprehensive petrophysical model of a Bakken reservoir system.

The third activity involves the testing of a hypothesis regarding the source of fractures in the Bakken. It is generally understood that the thermal conversion of kerogen to oil results in increased pressure in the source rock (in this case, the organic-rich shales of the Bakken), which in turn can lead to the creation of expulsion fractures in the source rock, and possibly, even the overlying seal (Pitman et al., 2001). The objectives of this activity are to determine if there is a relationship between opal-to-chert and smectite-to-illite ratios in Bakken samples and the productivity of a well. To achieve this objective, approximately 400 Bakken samples will be characterized for the occurrence of opal, chert, smectite, and illite using x-ray diffraction (XRD) analytical techniques. The geographical distribution of the analytical results will be compared with the results generated in the first two activities, and conclusions will be drawn regarding the potential influence of water expulsion from hydrated minerals on Bakken productivity.

Geo-Mechanical Study – The University of North Dakota will receive funding from NETL to determine *in-situ* stresses and geo-mechanical properties of the Bakken in the North Dakota Williston Basin, in an effort to increase the success rate of horizontal drilling and hydraulic fracturing.

The geological heterogeneity and special features of the Bakken make it difficult to drill and complete wells successfully without knowing the *in-situ* stress regime and geo-mechanical properties of the rocks. However, these parameters that allow the prediction of natural and hydraulic fractures in the Bakken are not well known. Some areas have experienced drilling success rates of less than 10 percent as a result of wellbore instability and unsuccessful fracturing, which is partly due to lack of data. This project will measure *in-situ* stresses and related geo-mechanical properties using field and well data, core samples, and lab experiments. The generated database of geo-mechanical properties of the Bakken will enable operators to optimize well placement and completion strategies.

Integrated Exploration Model – Another project funded by NETL with the Colorado School of Mines will conduct an assessment of the hydrocarbon potential of the Bakken shale in the Williston Basin and develop an integrated geologic model. A fully integrated analysis of the Bakken has not been done, nor has seismic attribute analyses or large-scale SEM compositional and textural analyses been attempted for this hydrocarbon system.

The proposed research will develop a new predictive stratigraphic framework and geologic model for the Bakken to improve play and prospect assessment and allow accurate estimates of reserves. An improved understanding of Bakken producibility is expected to reduce drilling risk and provide more accurate resource estimates, so operators can significantly improve recovery by optimizing drilling and completion strategies.

Oil Distribution and Production Mechanism – Lastly, NETL's Office of Research and Development (ORD) is conducting on-site research to develop specific reservoir data for the Bakken shale; determine the controlling mechanisms affecting oil distribution and production; and identify methods for increasing oil flow through the monitoring of well conditions and the potential injection of CO_2 or other fluids to enhance production. This effort will utilize reservoir modeling capabilities at NETL and is being carried out as part of the complementary R&D program NETL is pursuing under Title IX, Subtitle J, Section 999 of the Energy Policy Act of 2005.

Over the past several years, NETL-ORD has developed valuable experience in fractured-reservoir technologies, both for oil recovery and for carbon sequestration. A medical-grade x-ray CT scanner is available for imaging core samples that contain fluids, as well as changes in the samples as one fluid is swept by another. In addition, ORD has developed a naturally-fractured reservoir simulator, NFFLOW, which is able to model the migration of fluids within a fractured formation and the surrounding rock matrix.

As part of this project, NETL-ORD will acquire core and formation fluid samples from the Bakken , and use the CT scanner to image the nature of the fractures within the shale and other reservoir rock, the composition of the shale, and the amount of oil locked up within the shale matrix. The core will then be exposed to floods of CO_2, water, and/or other fluids to test their ability to sweep the shale of its oil.

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Additional Information Resources

USGS Resource Assessment Factsheet: http://pubs.usgs.gov/fs/2008/3021

EIA Report on the Bakken Formation as a Technology-Based Shale Play http://www.eia.doe.gov/pub/oil_gas/natural_gas/feature_articles/2006/ngshock/ngshock.pdf

North Dakota Industrial Commission, Department of Mineral Resources, Oil and Gas Division https://www.dmr.nd.gov/oilgas

Montana Dept. of Natural Resources and Conservation, Board of Oil and Gas http://bogc.dnrc.mt.gov/annualreviews.asp

University of North Dakota Energy and Environmental Research Center http://www.undeerc.org/price/