Winter 2011 Oil & Natural Gas Program Newsletter

NETL

CONTENTS

CONTACTS

Roy Long

Technology Manager—Ultra-Deepwater, Strategic Center for Natural Gas & Oil

281-494-2520

roy.long@netl.doe.gov

Albert Yost

Technology Manager—Exploration & Production, Strategic Center for Natural Gas & Oil

304-285-4479

albert.yost@netl.doe.gov

U.S. DEPARTMENT OF ENERGY

Bakken – The Biggest Oil Resource in the United States?

The announcement of the acquisition of large acreage positions in the Bakken play has become a fairly regular event. Leasing activity in the Bakken has exploded over the last five years and bonus payments per acre have jumped. Total lease bonus payments exceeded $100 million in 2009 (Figure 1).

The heightened acquisition activity is driven by the Bakken's immense potential. In 2008, the United States Geological Survey (USGS) estimated that the U.S. portion of the Bakken formation contains between 3 and 4.3 billion barrels (a mean of 3.63 billion barrels) of undiscovered, recoverable oil, ranking it among the very largest U.S. oil plays.

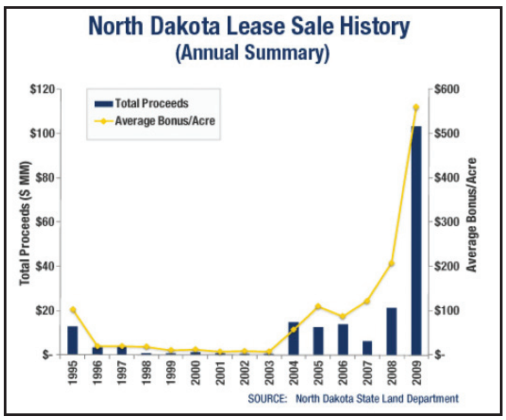

Figure 1: Lease payments in North Dakota's portion of the Bakken Play have grown dramatically. Source: North Dakota Oil & Gas Division/Rigzone.

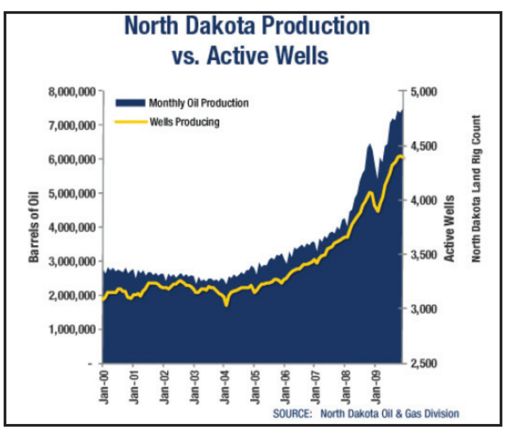

Figure 2: Bakken oil production from 2000 to 2009. Source: North Dakota Oil & Gas Division/Rigzone

The number of producing wells and volume of oil production has grown with the growth in leasing and drilling (Figure 2). Production has reached nearly 8 million barrels per month from roughly 4500 producing wells.

The Bakken Formation

The Bakken petroleum system is part of a larger depositional system laid down in the Williston Basin during the Phanerozoic period with sediments up to 16,000 feet thick. The Bakken system covers parts of North Dakota and Montana in addition to parts of Saskatchewan and Manitoba, Canada and includes the Bakken, Lower Lodgepole and Upper Three Forks Formations (Fig. 3).

The Bakken Formation is comprised of three distinct members, the upper and lower Bakken's organic rich shale layers, and the middle Bakken member, which is primarily sandstone and siltstone. The middle Bakken is the primary reservoir rock, together with the Lower Lodgepole and Upper Three Forks, although all the Bakken

National Energy Technology Laboratory

1450 Queen Avenue SW
Albany, OR 97321
541-967-5892

2175 University Avenue South
Suite 201
Fairbanks, AK 99709
907-452-2559

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304-285-4764

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-4687

13131 Dairy Ashford, Suite 225
Sugar Land, TX 77478
281-494-2516

Visit the NETL website at:
www.netl.doe.gov

Customer Service:
1-800-553-7681

E&P Focus is published by the National Energy Technology Laboratory to promote the exchange of information among those involved in natural gas and oil operations, research, and development.

This newsletter is available online at http://www.netl.doe.gov/E&P Focus

Commentary

When the Amerada Petroleum Corporation brought in the discovery well in the Williston Basin in early 1951 it had every reason to be optimistic. In less than two years, the millionth barrel of oil was produced in the basin. By the end of December 1952, production from the basin stood at 356,000 barrels per month. By any standards, things were going well. By the third anniversary of the initial well, in 1954, 15 oil fields had been discovered and were being developed. By that point, the Williston Basin was on its way to becoming a significant oil producing region in the U.S.

It is doubtful that many thought addition potential lay a bit deeper in the basin, in a series of shale deposits called the Bakken. In the 1950's shales were "marker" formations and potential reservoir seals. Over-pressured shales were a drilling nuisance. Permeability in shales was so poor that little, if any, thought was given to their production potential. There was no reason to believe that the new Williston play sat atop shale formations that might contain as much, if not more, oil than any existing U.S. field.

The potential of the Bakken formations was not raised until 1974 when two complementary papers (Dow, Wallace G., *Application of oil-correlation and source rock data to exploration in Williston basin,* and Williams, J.A., *Characterization of oil types in Williston basin*, American Association of Petroleum Geologists Bulletin, v. 58, p. 1253 – 1262 and p. 1243 – 1252, respectively) suggested that the Bakken was capable of generating 10 billion barrels of oil. A spate of subsequent papers through the mid 1990s brought the estimate as high as 500 billion barrels of oil potential. More recent estimates have put the size of the resource at 3-4.5 billion barrels of recoverable reserves.

In the last decade and a half, the potential of the Bakken has begun to be developed. As in shale gas, the progress of technology has been absolutely essential to successful development. And, as in shale gas, the National Energy Technology Laboratory has been in the forefront of technology development for oil-bearing shales, funding numerous projects to improve recovery, decrease footprints, and enhance safe, and environmentally responsible development of this important resource. A few of our efforts are examined in this issue. For more information on our Bakken-focused R&D, contact us at www.netl.doe.gov or access our Knowledge Management Database at www.netl.doe.gov/kmd. As always, your comments are welcome.

John R. Duda
Director, NETL Strategic Center for Natural Gas and Oil

Formation members have reservoir potential. The upper and lower Bakken Formation members are also source rocks. Laid down in the Devonian-Mississippian eras, the Bakken has a maximum thickness of approximately 150 feet.

Porosity and permeabilities are, generally, low over most of the Bakken. A 2001 USGS paper by Pitman, Price and LeFever estimates average porosity and permeability in the Bakken at 5% and 0.04 millidarcies, although values vary widely over the play. Porosity is enhanced, in many cases, by natural fracture systems in the Bakken.

The first Bakken wells were drilled in the early 1950's. Production from these vertical wells was satisfactory but not high. Production in the Bakken did not take off until the introduction of horizontal wells in the late 1980s that produced a defined production spike through 1991 (Fig. 4). Introduction of extended reach horizontals with giant, multi-stage frac jobs produced another, much more dramatic, upward trend beginning in 2002-2003. These massive frac jobs are applied over extended laterals of up to 10,000 feet. Frac jobs of 24 to 28 stages are not unusual.

Activity

There are a number of new and emerging fields in the Bakken play. Most important, and most productive, is the Elm Coulee Field, discovered in 2000 by LYCO Energy. The field, located in Richland County, MT, has produced in excess of 41 million barrels of oil and 24 BCF gas from over 400 horizontal wells. The field is being developed using horizontal drilling in the middle member of the Bakken. The wells generally are fracture stimulated with gelled water and sand (~5,000 barrels of gelled water and 400,000 pounds of sand per horizontal lateral). The area was targeted for vertical drilling in the late 1990s and horizontal drilling began in 2001.

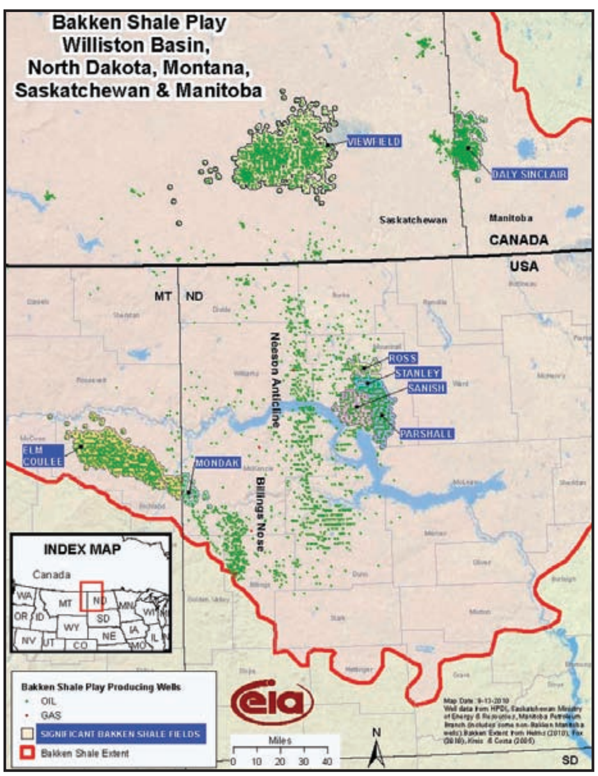

Figure 3: Map of the Bakken Shale play with significant fields identified. Source: Energy Information Administration, U.S. Department of Energy

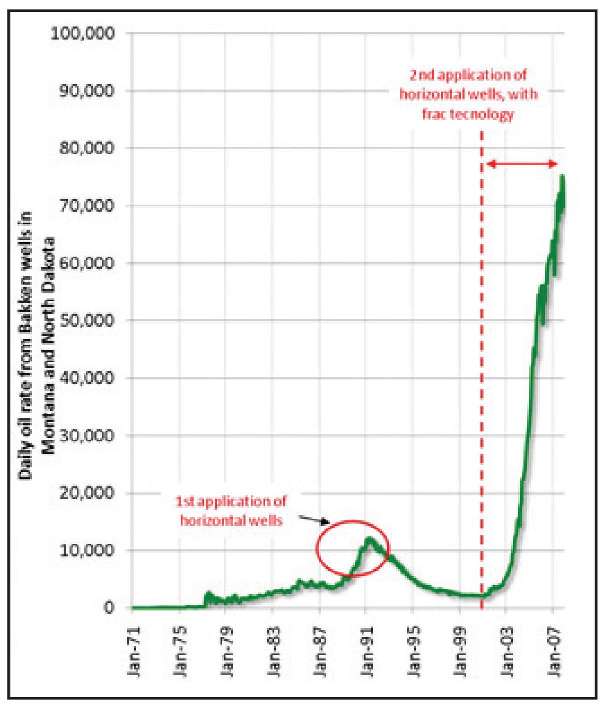

Figure 4: Bakken Montana and North Dakota daily production rates 1971-2007 illustrating the impact of horizontal wells and multi-stage fracturing. Source: www.theoildrum.com

The middle Bakken in this area is interpreted to be a dolomitized carbonate bar complex. The reservoir is developed over a large area (450 square miles) and has relatively low porosity (8-10%) and permeability (average of 0.05 md). Natural fracturing is thought to contribute to production. Initial production from wells ranges from 200 to 1900 BOPD. The field is being developed on 640 and 1280 acre spacing. Estimated recovery per well is 350 to 600 thousand barrels. Estimated ultimate recovery for the field is greater than 200 million barrels (Sarg, 2010).

The Parshall Field, discovered in 2006, is located on the east side of the Nessen Anticline and produces from the middle Bakken. Through April 2010, the field had produced approximately 32 million barrels of oil and 13 Bcf of gas from 228 wells. The field connects to the Sanish Field on the West and the Ross Field to the north (Sonnenberg, 2010).

Key Bakken Players

Activity levels have increased exponentially in the Bakken. The North Dakota rig count has exploded over the last 12 months, as indicated in the chart below, due to development of the play (Figure 5).

Those rigs are operating, primarily, for the top 20 Bakken players defined by acreage. Among them, these 20 operators hold nearly 5.5 million acres of prime Bakken acreage. The top three players control over 2 million acres in the Bakken (Figure 6).

Continental Resources is the number one driller and lease holder in Bakken as of November 2010, with 864,559 net acres. In 2009, Continental performed the first 24-hour continuous frac in the North Dakota portion of the play. In 2010, Continental developed the ECO-Pad® drilling concept, a system whereby the company drills multiple horizontal wells from a single pad with zero boundary-line setbacks. The ECO-Pad concept is expected to reduce drilling and completion costs per well by approximately 10 percent, with approximately 70 percent less surface footprint area than four conventional drilling pads and only one access road.

Whiting Oil and Gas has 14 rigs operating in the Bakken and approximately 480,000 net undeveloped acres in the Bakken/Three Forks. EOG Resources has 11 rigs operating and net acreage of 580,000 acres.

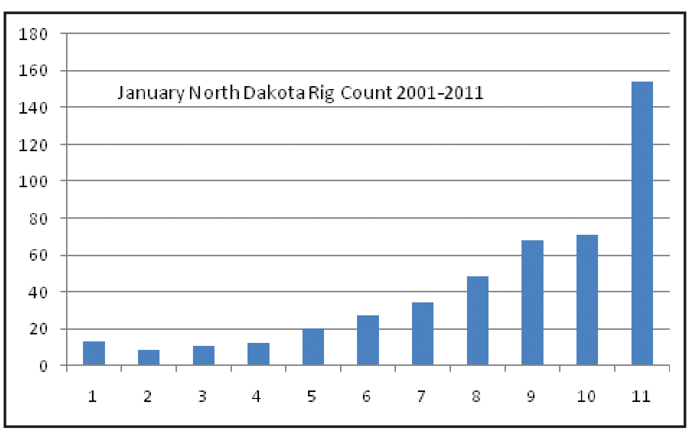

Figure 5: Historic and current North Dakota rig count illustrating the magnitude of the activity surge in the Bakken. Source: Baker Hughes Rig Count.

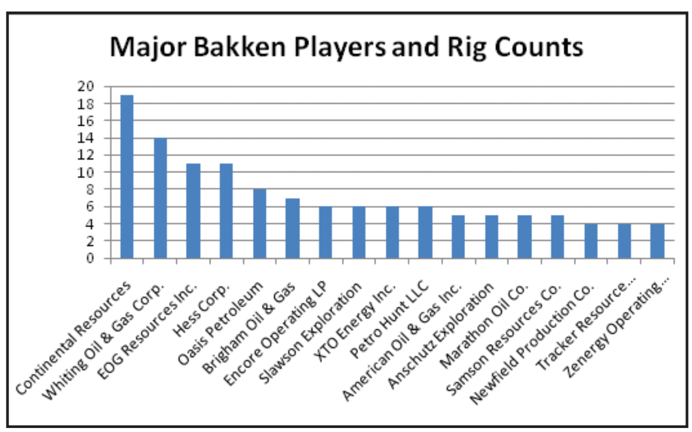

Figure 6: North Dakota rig count on January 7, 2011 indicates major players in the Bakken. Source: North Dakota Department of Mineral Resources

Keys to the Future of the Bakken

Although the Bakken resource is immense, exploiting its full potential will require development and/or further refinement of a number of technologies, including:

Microseismic Fracture Monitoring. MicroSeismic Inc. has buried seismic arrays across more than 150 square miles in Mountrail County for Whiting Oil and Gas. The array uses more than 1200 geophone channels to monitor, map and analyze hydraulic fracturing operations in Whiting's Bakken and Three Forks wells in the Sanish Field (Kulkarni, 2010). Further deployment of microseismic fracture monitoring will enable increased understanding of fracture propagation and extent in the Bakken system, resulting in better frac jobs and enhanced production.

Extended Reach and Rotary Steerable Drilling. Without extended laterals and massive, multi-stage hydraulic fracturing, development of the Bakken would be uneconomic. With laterals now extending beyond 10,000 feet, precise well placement control is crucial, as is the ability to deliver a smooth wellbore that enables single-trip fracturing and completion equipment installation.

Enhanced Multi-Stage Fracturing. Single-well fracture programs of 30 stages, or more, are now possible. Earlier this year, Brigham Exploration completed a 35 stage fracturing program on its Figaro 29-32 horizontal well (20,673 feet TD) that used 3.1 million pounds of proppant. Increasing the ability to pump larger and larger multi-stage fracs will improve economics in the Bakken play

Water Issues. Typical water use for hydraulic fracturing n the Bakken is 1.5 – 4.0 million gallons per well. Surface water in the Williston Basin is in short supply. Costs for acquisition of frac water, and for disposal of flow back and produced water, can range from $2 to $11.75 per barrel (Kulkarni, 2010). Clearly, further advances in cleaning and reuse of flowback and produced water are crucial to continuing operations in the Bakken play.

In each of these areas, NETL is funding or has funded R&D projects to assure that the technologies necessary to exploit the full potential of the Bakken System are available when and where they are needed.

References:

Pitman, Janet K., Price, Leigh C., and LeFever, Julie A., *Diagenesis and Fracture Development in the Bakken Formation, Williston Basin: Implications for Reservoir Quality in the Middle Member*, USGS Paper 1653, 2001.

Sarg, J. Frederick, *The Bakken – An Unconventional Petroleum and Reservoir System*, Project DE-NT0005672, Update, National Energy Technology Laboratory, October 2010.

Sonnenberg, Stephen A., "Focusing on the Bakken", *Bakken/Three Forks; The Playbook*, Hart Energy Publishing, July 2010, p. 5.

Kulkarni, Pramod, "High Oil Prices Spur Bakken Activity", *World Oil*, May 2010, p. D-55.

Key Factors Affecting Successful Oil Production in the Bakken Formation, North Dakota

The University of North Dakota's Energy & Environmental Research Center (EERC) in Grand Forks, North Dakota, with funding from the National Energy Technology Laboratory (NETL), has embarked on Phase 2 of a study that is evaluating key factors affecting successful oil production in the Bakken Formation in the Williston Basin. Phase 1 ended in May 2010 and Phase 2 will run through October 2011. The goal of the project is to quantitatively describe and understand the Bakken Formation by collecting and analyzing data on a wide range of parameters, including seismic and geochemical, that might have an impact on well productivity/oil recovery.

The EERC is conducting three major activities as part of this project: 1) comparison of well file data related to drilling, completion and stimulation field activities; 2) reprocessing of historical seismic surveys and examination of geomechanical properties; and 3) geochemical studies. The results of this study will provide a clearer understanding of how to efficiently maximize the exploitation of the vast Bakken formation oil and gas resources in the Williston Basin. A detailed comparison of the predictive utility of various collected data sets within different geological settings of the overall Bakken play will be compiled to provide operators and stakeholders with fresh insight regarding the roles that geologic structure and geomechanics play in the design and operation of a successful Bakken well.

Accomplishments – Phase 1

During Phase 1, a collaborative relationship with a field operator currently producing oil from the Bakken was established. This relationship provided the project with a wide variety of data on well drilling, completion, stimulation, and production for Bakken wells in western North Dakota. The North Dakota Department of Mineral Resources (NDDMR) Oil and Gas Division also provided field and production data. The data was categorized with regard to the relevant geological, drilling, and completion parameters to produce a system for determining the items that are most likely to contribute to successful wells in the Bakken. Analytical work on historical production and stimulation techniques in the area was also conducted.

Data was evaluated from two "type" areas of Bakken exploration and production within North Dakota so that the data could be compared, contrasted, and finally compiled into a geographic information system (GIS) database designed to support efficient interpretation of the data, enabling users to make comparisons between wells and/or areas of interest.

Much of the work focused on a static petrophysical model of the Dunn County, ND study area. This model describes the geological framework that makes up the middle member of the Bakken in that area and will provide the necessary background to evaluate completion and stimulation strategies to determine the correlation of the parameters to well "success."

In addition, The North Dakota Geological Survey (NDGS) completed the interpretation of a seismic survey conducted in the 1980s proximal to the area of interest. The results indicate that there appear to be significant structural features that may positively affect oil production in the Parshall area of North Dakota. The NDGS also selected samples from some of their Bakken core holdings to be used for geochemistry/mineralogy evaluations and made them available to EERC. The EERC used those samples to conduct a series of laboratory experiments to generate data on the mineralogical, geochemical, and geomechanical properties of the middle member of the Bakken Formation.

Conclusions – Phase 1

The preliminary conclusions derived from Phase 1 research activities include the following:

- Horizontal drilling of wells in the middle member of the Bakken, coupled with multistage fracturing, has outperformed all previously completed Bakken wells in North Dakota;
- Geologic influences appear to be dictating the hydrocarbon production rates for given areas within North Dakota that have similar completion practices;
- Production in Mountrail County greatly exceeds production in Dunn County and has significantly higher variability, with the higher production appearing to be linked to greater total organic carbon (TOC) and shale thicknesses which, in turn, have the potential to create greater pore pressure-related fracturing;
- The presence of structural elements, although different in both Dunn and Mountrail Counties, is consistent with areas of higher production. The major contribution of these structural elements may not be their ability to serve as traps but rather their influence on the creation of both natural and operationally induced fracture systems;
- Higher production within Dunn County is associated with the Heart River Fault, which coincides with an area of high original TOC content;
- Multilateral wells do not appear to gain significant production advantage over single lateral wells, despite lower per-foot drilling costs;
- Lithology could potentially play a role in oil mobility, an improved understanding of which may serve to guide the design of stimulation practices and provide insight regarding future exploration efforts;
- Multistage fracture completions appear to be outperforming lesser-stage completions when compared in proximity. It appears that, at least in some areas, multistage hydraulic fracturing should improve the likelihood of further oil production;
- Well azimuth, although relevant to the direction of principal stress, does not appear to be a factor regarding oil production; and
- Longer lateral wells appear to produce more oil when compared to shorter lateral wells in proximity.

More information on the results of this research may be found in the final report, which presents and discusses the activities conducted over the course of the research program http://www.netl.doe.gov/technologies/oil-gas/publications/EPreports/NT43291_FinalRpt.pdf .

Phase 2 Activities

The results to date have provided operators with a better understanding of the natural fracture network system of the Bakken

Formation, which is critical to improving production performance. However, a more detailed geologic study is required to further support the preliminary conclusions. EERC is conducting four major activities in Phase 2 of this project:

- Further development of the Bakken Decision Support System (BDSS) into a web-based GIS analytical tool that includes a database of well file information;
- Development of geomechanical data sets to examine how macro-scale stress and strain forces can affect the geomechanical properties of Bakken rocks and capitalize on the analytical methods developed under Phase 1;
- Continued geochemical evaluations of Bakken samples to evaluate potential relationships between geochemical and petrological properties of the Bakken and oil productivity; and
- Establishment of an industry advisory board for the project to meet with the EERC research team and provide guidance regarding the overall direction of the proposed research.

Anticipated Benefits

The activities will be coordinated with complementary, but separate, ongoing research efforts being conducted by the North Dakota Geological Survey and a consortium of petroleum production and service companies. The web-based Bakken Decision Support System (BDSS) will provide an interactive database that will allow users to compare and analyze all publically available data. A detailed comparison of the predictive utility of various collected data sets within different geological settings of the overall Bakken play will provide fresh insight regarding the roles that geologic structure and geomechanics play in the design and operation of a successful Bakken well in North Dakota. This, in turn, will further better well construction designs and enhance Bakken production.

Current Status

Data on production, drilling, completion, and stimulation activities from hundreds of additional wells have been added to the BDSS. Efforts to finalize the BDDS for a public launch are underway. EERC has begun formalizing an Industry Advisory Board and anticipates holding the first meeting of that board in the second quarter of the fiscal year. In addition, EERC is collaborating with the North Dakota Geological Survey and oil companies to obtain Bakken core for the next round of geomechanical and geochemical laboratory experiments.

For further information about this NETL funded project, contact John Terneus at NETL (John.Terneus@netl.doe.gov or 304-285-4254) or James Sorensen at Energy & Environmental Research Center (jsorensen@undeerc.org or 701-777-5181).

The Bakken—An Unconventional Petroleum and Reservoir System

A study led by the Departments of Geology, Geophysics, and Petroleum Engineering at the Colorado School of Mines (CSM), with funding from NETL, aims to characterize the unconventional petroleum and reservoir system of the Bakken play. Additional investigators in the project include Fidelity Exploration Company, Samson Resources Company, The Discovery Group and the Idaho National Laboratory (INL). The project (scheduled for completion in September 2011), will accurately assess the hydrocarbon potential for the Bakken stratigraphic interval on a sub-regional basis; construct an integrated exploration model for the Bakken; and build a fully integrated, three-dimensional reservoir geo-model for the Middle Bakken reservoirs in the Elm Coulee area.

The successful conclusion of this study will aid in the development of an initial alpha version of a predictive exploration model that could be used for future identification of high potential fairways and traps for the Bakken hydrocarbon system. The initial model will be based on the integration of a sub-regional stratigraphic and reservoir characterization, rock physics calibrated seismic attribute analyses, and acoustic impedance developed for different levels of organic richness and maturity. The model will also include a secondary permeability potential that will be derived from a fracture analysis. Finally, validation of, and revisions to, the model will be conducted to compare predictive attributes to known seismic, log, and core data throughout the Williston Basin.

Since the project kick off in September 2008, a number of key goals have been reached. Several of the important successes include:

- CSM has completed construction of a regional stratigraphic framework for the Bakken, and the over- and underlying Lodgpole and Three Forks formations, both of which are part of the Bakken Petroleum System. This has involved detailed description of cores stored at the USGS in Denver, at the North Dakota Geologic Survey, and at the core repository at CSM. The framework includes compilation of subsurface data and stratigraphic interpretation using well data and 3-D seismic contributed by industry participants. A major conclusion gained from this activity has been the recognition that the Parshall and Elm Coulee fields have a significant lateral trap for hydrocarbons that is a combination of stratigraphic pinch-outs, lithofacies changes, and the boundary of hydrocarbon maturity. Industry can make use of this knowledge to identify new exploration opportunities in the Bakken oil play trend. High resolution scanning electron microscope (SEM) analysis using the QEMSCAN® tool has shown that the Bakken units have a diverse mineralogy including illite, quartz, pyrite, calcite, and dolomite, all of which may affect fracability and reservoir performance. The high silica content and laminated structure of the organic-rich shales increases their fracability.
- Rock physics analysis has been performed on outcrop and core samples to calibrate seismic response of the reservoirs. The analysis used compressional and shear velocities at *in situ* conditions on core samples and compared these measurements to log data. These measurements are being used to construct predictive models to assess the effects of organic content, fluids, mineralogy, stress, etc. A2D Technologies is contributing a digital log database

that will provide critical sonic and density logs to tie geology to seismic response, which will help determine thin-bed petrophysical characteristics of the Bakken shale, Middle Bakken sandstone, and limestone reservoirs. Forty-seven wells across the basin have been used to define relationships between maturity-dependent rock properties. The goal is to develop a quantitative relationship between impedance and kerogen content that can be used to build predictive rock physics models. Total organic carbon linked to porosity, T_{max}, and normalized S_2 have the best potential for predicting impedance in organic-rich shale (ORS). This information will also assist in determining the natural fracture characteristics in the Bakken interval. Industry will be able to use this information to optimize hydraulic fracturing for production of oil.

- Fracture data have been collected from the Little Rocky Mountains and Big Snowy Mountains in Montana and from the Beartooth Mountains in Wyoming and will be used to construct a 3-D digital model of the sub-regional fracture system. Initial results show that there are differences in mechanical stratigraphy between the Middle Bakken sandstones, siltstones, and dolomites, and the Bakken shales. This data will be compared to fracture and small fault trends derived from seismic data. The results may be helpful to industry to determine the best intervals for hydraulic fracturing in the Bakken oil fields.
- Complementary to this project, and as part of technology transfer, the research team has organized the CSM Bakken Consortium. Consortium members include MJ Systems, IHS, Marathon, Total, Inerplus, Red Willow, Whiting Petroleum, EOG Resources, Hendricks and Associates, Fidelity Exploration and Production Co., Samson, The Discovery Group, XTO, Questar, Savant, Mike Johnson & Associates, and most recently, Statoil, Husky Oil Canada, and Chesapeake Energy. Samson, Fidelity, and The Discovery Group are original industry partners in this NETL project. Consortium membership will provide funding and data to the overall project.

Current Status

Nine Bakken samples have been returned from Idaho National Laboratory, where wet and dry pyrolysis experiments were performed on each sample. Determination of impedance values using the Scanning Acoustic Microscope at CSM is currently underway. These data will be added to the initial nano-indentation analysis to aid in mapping maturity. Based on the initial nano-indentation work, the impedance of ORS is directly related to maturity. During 2011, seismic and well data will be used to attempt to map Bakken impedance values in a test area of the basin that will be, by inference, a map of maturity levels. These efforts will lead to the development of an impedance-related maturity model for the organic-rich shale of the Bakken.

For further information on this project, please contact Skip Pratt at NETL (skip.pratt@netl.doe.gov or 304-285-4396) or J. Fredrick Sarg at the Department of Geology & Geological Engineering, Colorado School of Mines (jsarg@mines.edu or 303-273-3729)

Research Addresses Crude Souring in the Bakken

With rapidly increasing production in the Bakken, sporadic souring of this typically sweet crude oil has been observed in the field. The University of North Dakota's Energy and Environmental Research Center (EERC), with funding from NETL, is undertaking a study of the root causes of this phenomenon.

Current understanding suggests three general causes of souring exist, namely: 1) mechanical (fracturing and fluid intrusion from another formation), 2) thermochemical (e.g., mineral dissolution), and 3) biogenic (sulfur-reducing bacteria activity), or combinations thereof. In all cases, the root causes of excessive H_2S production in previously non-sour environments are primarily anthropogenic and originate through the disruption of an ancient equilibrium, where the system is forced to "seek" a new thermodynamically stable point.

Research performed to date has focused on mechanical and thermochemical origins in an attempt to diagnose the causes of isolated instances of Bakken souring. A series of laboratory experiments and numerical modeling exercises is being conducted to examine the extent to which geochemical mechanisms can account for the generation of H_2S within the Bakken. Specific activities are reviewed below.

Information Acquisition

A comprehensive literature review on souring of petroleum reservoirs, Bakken geology, and publicly available data has been performed. Discussions with industry sources are ongoing in an effort to obtain additional datasets that clearly illustrate the occurrence and facilitate its diagnosis.

Numerical Modeling and Simulations

Preliminary numerical geochemical modeling of "typical" fracturing procedures in Bakken wells is being conducted. These exercises are guiding complementary laboratory work. Figures 1–4 are examples of the modeling being conducted.

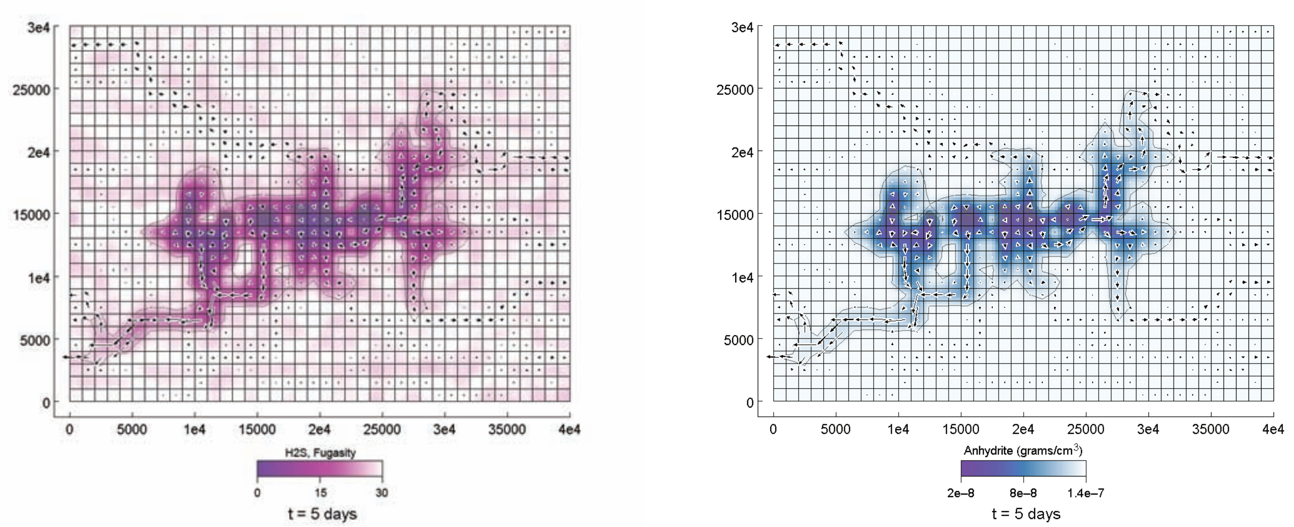

Figure 1: Map view of a "generic" Bakken well path that has undergone a multistage fracture treatment. The images illustrate one possible scenario of H_2S generation due to anhydrite reaction with hydrocarbons as a result of the fracturing procedure.

Laboratory Experiments and Numerical Modeling

A series of laboratory experiments have been designed in which typical Bakken reservoir rocks are selected, subjected to mechanical strength tests, and analyzed with respect to fracture strength and patterns. Results of these tests will be used to further calibrate numerical simulations that have been developed.

Anticipated Benefits

Furthering our understanding of Bakken crude oil production practices is critical to the oil and gas industry, and the states and provinces intersected by its geographical extent. Furthering our understanding of those mechanisms that can cause souring of this resource may facilitate the selection of completion and production practices that minimize and/or mitigate Bakken souring.

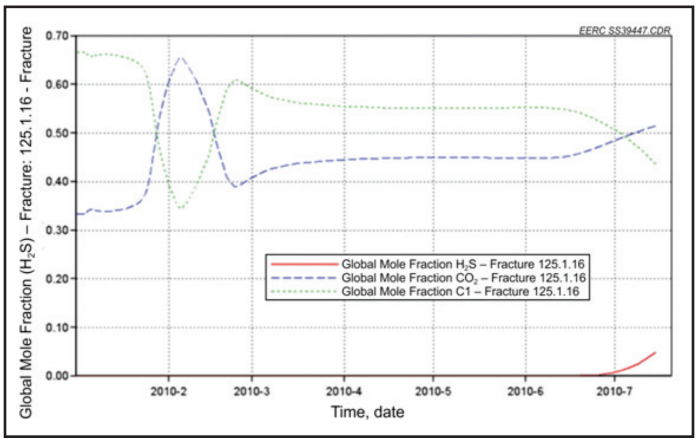

Figure 2: Modeling of the H_2S generation as a result of the fracture intrusion in the neighboring formation.

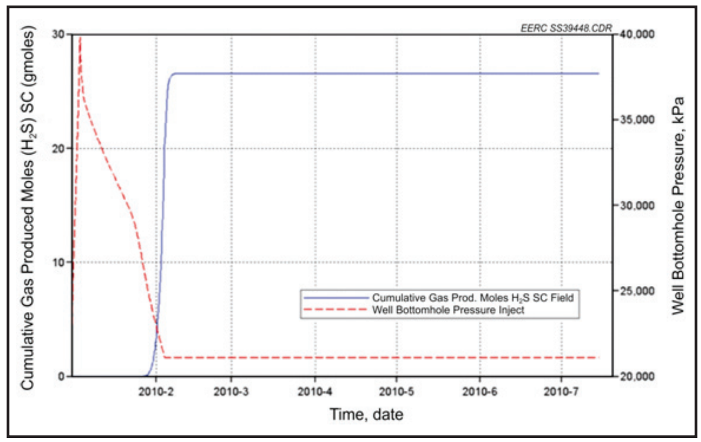

Figure 3: H_2S generation as a result of the fracture intrusion in the neighboring formation: pressure dependence.

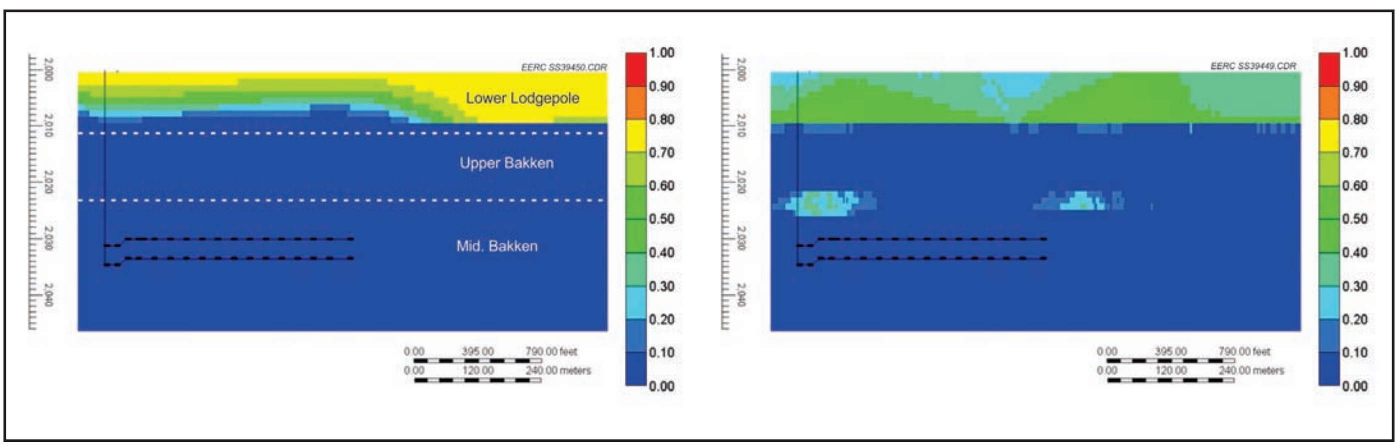

Figure 4: Geomechanical modeling scenario. Predictive simulation of H_2S migration into the reservoir from the overlying formation as a result of fracturing and reservoir pressure drop due to oil production: H_2S spatial distribution 3 days after fracturing (on the top) and 7 months after fracturing (on the bottom).

Geomechanical Study of the Bakken Formation Will Improve Oil Recovery

The goal of this project being undertaken by the University of North Dakota (UND), with funding from the National Energy Technology Laboratory, is to determine the *in situ* stress and geomechanical properties of the Bakken Formation in North Dakota, and to use these results to increase the success rate of horizontal drilling and hydraulic fracturing in order to improve the ultimate recovery of this vast oil resource. The project began in October 2008 and is scheduled for completion in September 2011.

Background

Compared to the success producing crude oil from the Bakken Formation in eastern Montana, the horizontal drilling and hydraulic fracture stimulation technology applied in western North Dakota has been a relative failure. The biggest problems are: (1) horizontal wells have not hit the natural fractures and, (2) hydraulically generated fractures have not developed in the designed linear orientation and symmetric shape, but in many cases, skew into complicated shapes.

The geological heterogeneity and inadequate knowledge of the *in situ* stresses and other geomechanical parameters of the Bakken Formation resulted in more failures than successes for horizontal well completions in North Dakota. Based on past research efforts, the following can be concluded:

- Horizontal well drilling with hydraulic fracturing is a required completion technology for recovering crude oil from the Bakken Formation;
- Well orientation is the essential factor for the success of hydraulic fracturing and wellbore stability during drilling and production;
- Hydraulic fracture geometry and orientation (longitudinal, transverse, or oblique) is fully controlled by the local *in situ* stress field and geomechanical properties of the Bakken Formation. More often than not in past completions, a longitudinal fracture in design became a transverse or skewed fracture in reality, which eventually killed well productivity and the investment;
- Changes in *in situ* stress field and geomechanical properties extend for several thousand feet along the axis of horizontal wells being drilled in the Bakken Formation;
- Knowing the *in situ* stresses and the fundamental geomechanic properties of the rock is key to designing a successful horizontal well and hydraulic fracture stimulation.

Potential Impacts

The results of this study will be used to produce an application guide that can be used for horizontal drilling and/or hydraulic fracturing operations in the Bakken Formation. New technology for *in situ* stress determination using the Kaiser Effect will be developed and tested to help the petroleum industry improve horizontal drilling and hydraulic fracturing in the Bakken Formation. With a better knowledge of *in situ* stresses and related geomechanical parameters, the success rate for drilling and hydraulic fracturing should be greatly improved.

Accomplishments

The project is progressing with the tasks as defined in the Project Management Plan; well screening and data collection is ongoing. Fundamental data from 65 wells in five assessment units have been collected (Figure 1) and well logs of these 65 wells have been digitized.

Two (one oil- and one air-based) shale sampling systems have been completed and tested using a reference shale (Pierre Shale). Shale sample preparation skills have improved through trial-and-error. New efforts are being made to improve the success rate of sampling from shales, especially the Bakken shale (Figures 2 and 3).

UND has been developing a methodology and preparing equipment for laboratory testing of *in situ* stresses and other geomechanical properties which include the following:

- UND acquired an advanced geomechanical testing system (AutoLab 1500-C) from New England Research. The machine has since been delivered and installed. The AutoLab 1500 System has been in self-training testing status. By now more than 80% of the fundamental functions have been tested with satisfactory results.
- UND developed an alternative triaxial geomechanical testing system and method. This system can be used to test small rock samples and will be useful for testing Bakken shale and other similar non-standard size rock samples. Several specimens of reference shale (Pierre shale) are being tested using the alternative system and method. New standard specimens of lead and plastic rods have been tested to improve calibration, because their stiffness is similar to that of shale.
- UND is currently developing a two-channel acoustic emission system for detecting the Kaiser Effect for *in situ* stress measurement. Improvement and testing of the in-house developed Kaiser *in situ* Stress system is ongoing.
- In addition, UND has screened more than 4000 Bakken wells in 300 oil reservoirs in the Williston Basin, North Dakota. Some useful geomechanical properties have been collected and compiled from 7 wells.

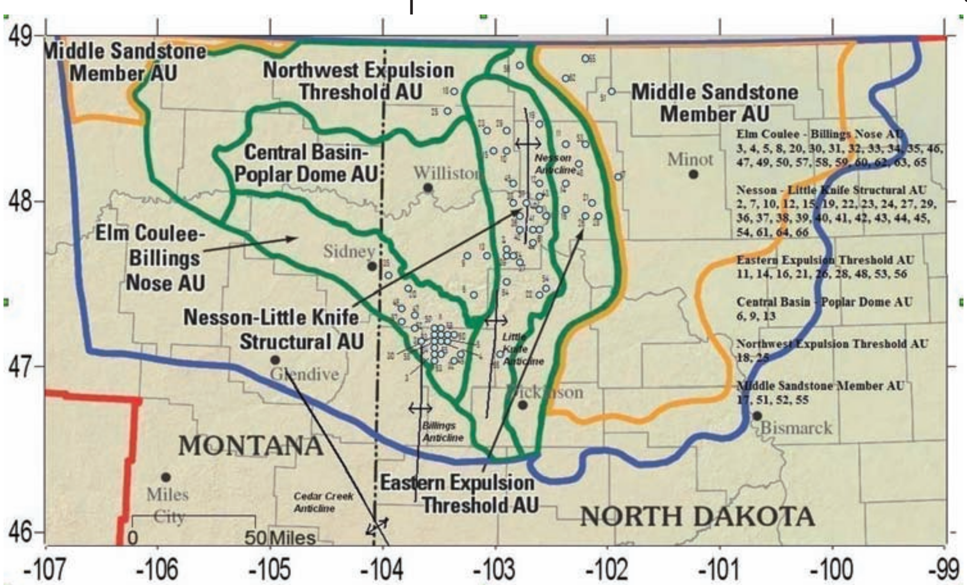

Figure 1: Distribution of 65 cored Bakken wells in North Dakota by assessment unit (assessment unit map is modified from United States Geological Survey [2008])

Technology transfer activities have begun with the creation of an initial version of a web-based database. The database can be found at http://www.petrodata.und.edu. Continuing effort will focus on improving its functions, and filling it with new data. This database will allow all interested parties to share the research results.

Currently, UND is converting the manually measured, piecemeal, irregularly distributed Rock Quality Designation (RQD) data into continuous log format. Figure 4 shows the converted RQD log for three wells aligned with gamma ray logs. Based on the completed digitized logs, a 3-dimensional (3-D) Bakken Formation porosity model has been completed and is shown in Figure 5. With the addition of other data, additional 3-D models for such properties as RQD, permeability, *in situ* stress can be developed. The development of the standard well log-based 3-D models allow an understanding of the distribution of some conventional petroleum properties, such as porosity, permeability, saturation, thus the potential target for oil drilling. The self-defined 3D model allows us to understand the distribution of some unconventional properties, such as RQD, Young's modulus, rock strengths. The 3D distribution of these geomechanical properties offer us new perspective to correlate them with well performance (drilling, completing, fracturing, and production).

For further information on this project contact John Terneus at NETL ((John.Terneus@netl.doe.gov or 304-285-4254) or Dr. Zhengwen Zeng at the University of North Dakota (zeng@und.edu or 701-777-3027).

Figure 2. Oil-based core sampling system — core barrel (left); saws for end cutting (right)

Figure 3. Air-based core sampling system — core barrel (left); end surface grinder (middle); end surface grinder in use (right).

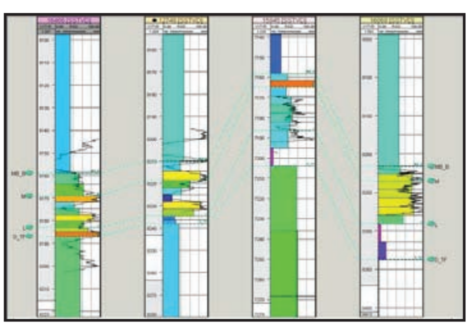

Figure 4. Converted RQD logs align with gamma ray logs of three wells.

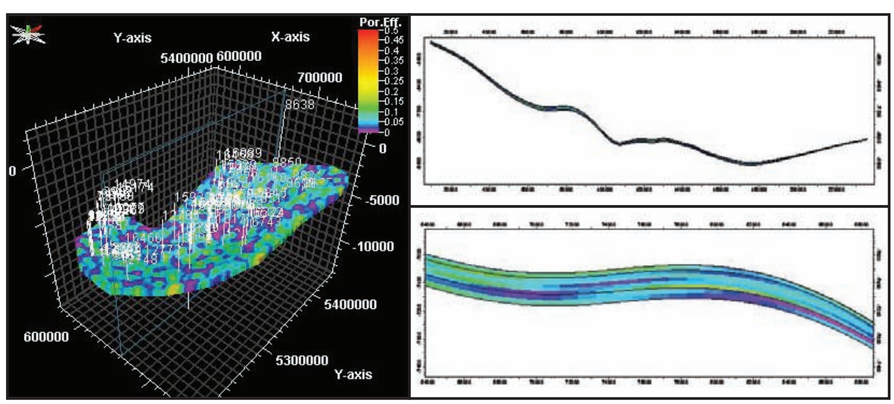

Figure 5. Three-dimensional Bakken Formation porosity model (left), north-south cross-section (middle) and enlarged cross-section (right).

Bakken Requires Outlet for Increased Production

Oil output from the Bakken has increased dramatically over the past five years (see lead article, page 1, Figure 2). Expected further expansion of oil production in the Bakken would benefit from increased in-state refinery capacity, which could in turn create significant financial benefits for North Dakota. However, as refiners have considered construction of new refining capacity, it has remained unclear whether or not the additional capacity would generate enough revenue to be considered commercial. To assess that issue, the North Dakota Association of Rural Electric Cooperatives (NDAREC), with funding from the National Energy Technology Laboratory, is undertaking a study to determine the feasibility of constructing new refining capacity in the state. An initial report by the Corval Group (partnered with Purvin & Gertz and Mustang Engineering), commissioned by NDAREC, has been released. The results of the study, discussed below, indicate that additional refinery capacity, while feasible, may require financial stimuli.

Analytical Results

The Bakken oil play is located in Petroleum Area Defense District II (PADD II). The study concluded that demand for gasoline in PADDII will begin to decline by 2015, reflecting mandated vehicle efficiency improvements and growth in ethanol production. Demand for diesel in PADD II, on the other hand, is projected to rise in line with underlying economic growth. These projections are consistent with Energy Information Administration and Department of Energy projections.

The study team looked at three specific refinery capacity addition options: 20,000, 50,000 and 100,000 barrels per day (BPD). None of the specified refining capacity additions achieved adequate capital recovery to support traditional project financing options. North Dakota's demand for light refined products represents only a small fraction of the overall PADD II total and as a conventional gasoline market with some ethanol blending the North Dakota market balances on net transfers out of the state. The diesel market, on the other hand, relies on increasing net transfers into the state. Consumption of gasoline relative to diesel is lower than both the overall U.S. and PADD II markets because of high diesel consumption in the agriculture sector.

In a second phase of the analysis the team compared a 20,000 BPD capacity increase case with a 34,000 BPD alternate naphtha refinery case, eliminating the production of gasoline. This configuration would maximize diesel production based on market demand and recognize an existing market for naphtha in Alberta, Canada. Growth in Canadian bitumen production has created a demand for naphtha for use as a diluent for pipelining heavy crude. While the Enbridge Southern Lights pipeline project could allow for diluents to be shipped from Chicago to Edmonton, Canada, the tariffs for uncommitted shippers are not economical. Rail transport, however, does offer a suitable option and would be the most expedient option for exporting naphtha diluent to Canada.

The 20,000 BPD configuration provided a 92% yield of gasoline, jet and diesel. This configuration, which is much more complex than the naphtha configuration, has estimated capital costs of $650 million. The 34,000 BPD naphtha configuration provides 15,000 BPD of naphtha with 17,600 barrels available for jet and diesel yield. Capital costs are estimated at $700 million.

A 34,000 BPD diesel and naphtha refinery produces a higher return on investment than the 20,000 BPD refinery producing gasoline and diesel. Overall, total operating costs per barrel for the 34,000 BPD case are more favorable than the 20,000 BPD case. The fixed and variable costs are similar for each case but the high labor costs for the 20,000 BPD are the primary difference in the operating cost per barrel. The 34,000 BPD naphtha refining product provides a nominal 9.2 percent IRR.

Benefits to North Dakota

New refinery capacity would provide employment to an estimated 75 operations personnel with an average salary of $80,000, an estimated 80 maintenance positions with an average salary of $75,000, and an estimated 55 professional and administrative jobs with an average salary of $85,000. The personal income from these jobs is estimated to be about $16.6 million per year. Increased economic activity required to provide goods and services would result from the spending of this new personal income. In addition, 16,000 BPD of diesel fuel supply into the local market would potentially reduce supply disruptions and citizens of the state would realize benefits due to the lower cost diesel fuel.

During construction of the refinery an estimated $220-250 million could be paid for labor and some local fabrication work. Furthermore, increased crude netback prices for a period of 3-5 years might positively affect severance taxes and royalty payments.

A number of opportunities to improve project viability were identified by the study, including:

- Expanding an existing refinery instead of building a “grass roots” facility,
- Exploring the potential for obtaining, relocating and installing existing process equipment,
- Optimizing the return of a grassroots refinery through the site selection process to improve the contribution margin,
- Debt financing options that may provide opportunities to improve the internal rate of return.

Conclusions

The growth in Canadian heavy crude production has created a demand for diluents and the Canadian import of naphtha is the most expedient short-term option to meet the growing need for diluents. Naphtha from a new North Dakota refinery processing Bakken crude oil may find the diluents market an attractive alternative to the sale of gasoline in a locally oversupplied market.

The benefits to North Dakota are primarily in the areas of increased state revenues, new employment opportunities and increased North Dakota production of diesel fuel.

For further information on this project, please contact Bill Fincham at NETL (william.fincham@netl.doe.gov or 304 285 0985) or Dennis Hill at NDAREC (dhill@ndarec.com or 701-663-6501).

Access to DOE Database of Oil and Natural Gas Research Results Expanded

The results of nearly four decades of research supported by the U.S. Department of Energy (DOE) are now available through the OnePetro online document repository.

DOE's Knowledge Management Database (KMD) provides access to content from dozens of CDs and DVDs related to oil and natural gas research that the Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL) has published over the years. It also provides links to reports, data sets, and project summaries from ongoing research supported by FE's Oil and Natural Gas Program.

OnePetro

The OnePetro website now contains NETL's Oil & Gas Knowledge Management Database

Now, the 9,000 DOE documents in the KMD are searchable on the OnePetro website, together with documents from the Society of Petroleum Engineers (SPE) and 10 additional professional societies.

The KMD debuted at the SPE Annual Technical Conference and Exhibition in October 2009. Following its full roll-out at the Offshore Technology Conference in May 2010, NETL and SPE worked together to make the KMD available through OnePetro. Containing more than 100,000 documents relating to upstream technology, OnePetro is the primary technical resource for the global upstream industry.

Results of a keyword search on OnePetro will now include all related NETL documents. The repository may also be searched for NETL documents only by entering "NETL" in the search box. All NETL documents are open access.

This collaboration is expected to provide the oil and natural gas industry, petroleum engineering students, academic researchers, and the wider research and development (R&D) community with unprecedented access to DOE oil and gas R&D publications — ultimately improving the recovery of the Nation's oil and natural gas while enhancing environmental protection.

The KMD is still available at the NETL website.

More Info: www.onepetro.org and www.netl.doe.gov/kmd

Innovative Telemetry System Will Help Tap Hard-to-Reach Natural Gas Resources

The commercialization of an innovative telemetry communications system developed through a U.S. Department of Energy research program will help U.S. producers tap previously hard-to-reach natural gas resources deep underground, resulting in access to additional supplies that will help enhance national energy security.

The patented, proprietary Sharewell L.P. EM-MWD electromagnetic (EM) telemetry system was initially developed by the Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL) and E-Spectrum Technologies of San Antonio, TX, under a four-year, cost-shared agreement. It was part of FE's Deep Trek initiative to foster new technologies to facilitate deep exploration of natural gas resources.

Using novel new technologies normally associated with interplanetary deep space navigation and missile guidance systems, the technology is designed to transmit data to and from downhole equipment in real time, enable surface processing of downhole sensor data, and control downhole tools directly from the surface. The technology allows the system to successfully operate at greater depths than other EM systems and to propagate signals through formations that typically weaken electromagnetic waves.

Rights to the EM technology were purchased in September by Sharewell of Houston, Texas, which plans to utilize the technology as part of its measurement-while-drilling (MWD) systems.

DOE's Deep Trek Program was established in 2002 to develop "smart" systems to address the needs of U.S. producers drilling to depths of 15,000 feet and deeper, where more than 125 trillion cubic feet (Tcf) of untapped natural gas is estimated to be in place. For comparative purposes, DOE's Energy Information Administration estimates technically recoverable U.S. natural gas resources at 2,119 Tcf, with proved reserves of 238 Tcf.

Natural gas is an important energy source for the U.S. economy, providing nearly one-quarter of total energy consumption in 2009. It is expected to remain a significant energy option for meeting increased energy consumption in the years ahead, and domestic supplies beyond traditional resources will be required to meet demand. Technology innovations through FE's Oil and Natural Gas R&D Program will be important in helping locate and develop these and other diverse natural gas resources in an environmentally responsible manner.

Upcoming Meetings and Presentations

February 10, Ultra-Deepwater Subsea Facilities TAC Quarterly Meeting, Houston, TX. www.rpsea.org/en/cev/282

February 10, Ultra-Deepwater Met-Ocean TAC Quarterly Meeting, Houston, TX. www.rpsea.org/en/cev/314

February 16, Ultra-Deepwater Flow Assurance TAC Quarterly Meeting, Houston, TX. www.rpsea.org/en/cev/283

February 17, Ultra-Deepwater Systems Engineering TAC Quarterly Meeting, Houston, TX. www.rpsea.org/en/cev/280

February 17, Ultra-Deepwater Environmental, Safety and Regulatory TAC Quarterly Meeting, Houston, TX. www.rpsea.org/en/cev/316

February 22, Subsea Tieback Forum & Exhibition, San Antonio, TX. www.subseatiebackforum.com/index.html

March 1 – 3, Horizontal Well Completions in North American Shales, Scottsdale, AZ. www.spe.org/events

March 27 – 29, SPE Production and Operations Symposium, Oklahoma City, OK. www.spe.org/events

April 10 – 13, AAPG 2011 Annual Convention & Exhibition, Houston, TX. www.aapg.org/houston2011/

April 11 – 12, From Shale Gas to "Liquid Rich": Learnings and Best Practices, Palos Verdies, CA. www.spe.org.events

April 18 – 20, Developing Unconventional Gas 2011, Ft. Worth, TX. www.dugconference.com

April 27 – 28, Reducing Environmental Footprint in Shale Gas Development, Pittsburgh, PA. www.spe.org/events

May 2 – 5, 2011 Offshore Technology Conference, Houston, TX. www.otcnet.org/**2011**/

May 23- 25, Success in the Marcellus and Utica Shales, Baltimore, MD. www.aapg.org/gtw/MarcellusUticaShale/index.cfm