October 15, 2018

Ms. Karlene Fine
Executive Director
North Dakota Industrial Commission
600 East Boulevard Avenue, Department 405
State Capitol, 14th Floor
Bismarck, ND 58505-0840

Dear Ms. Fine:

Subject: Annual Progress Report for the Period of October 1, 2017 – September 30, 2018,
Entitled “Bakken Production Optimization Program 2.0”; Contract No. G-040-080;
EERC Fund 22010

Attached please find the Energy & Environmental Research Center (EERC) Annual
Progress Report for the subject project. If you have any questions, please contact me by phone at
(701) 777-5355 or by e-mail at cgorecki@undeerc.org.

Sincerely,

Charles D. Gorecki
Director of Subsurface R&D

CDG/bjr

Attachment
BAKKEN PRODUCTION OPTIMIZATION PROGRAM 2.0

Annual Progress Report

(for the period October 1, 2017 – September 30, 2018)

Prepared for:

North Dakota Industrial Commission

Members of the Bakken Production Optimization Program Consortium (BPOP)

- ConocoPhillips
- Equinor
- Hess Corporation
- Liberty Resources LLC
- Marathon Oil Company
- Oasis Petroleum
- Petro-Hunt, LLC
- WPX Energy
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October 2018
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EXECUTIVE SUMMARY

The Bakken Production Optimization Program (BPOP) was established to facilitate Bakken Petroleum System oil recovery while simultaneously reducing the environmental footprint of oil and gas development. This program is administered by the Energy & Environmental Research Center (EERC) with funding from the North Dakota Industrial Commission (NDIC) Oil and Gas Research Program (OGRP) and the North Dakota petroleum industry. Through BPOP, the EERC is working closely with a consortium of industry partners and the State to address emerging opportunities and challenges related to Bakken development. As of September 30, 2018, nine member companies support BPOP. This annual progress report presents an update of activities from October 1, 2017, through September 30, 2018.

The major research focus areas of the program over the last year have included the following:

- Ongoing collaboration with Liberty Resources, LLC (Liberty) to evaluate rich gas enhanced oil recovery (EOR) in the Stomping Horse Oil Factory complex in Williams County.
- Various research efforts to address surface-related issues, including Bakken surface facilities modeling to identify areas to optimize performance, environmental support and produced fluids characterization to support ongoing BPOP activities and to gain a better understanding of geographic and temporal variations in produced oil, water and gas.
- Evaluation of produced brine treatment and storage options, including assessment of the long-term saltwater disposal (SWD) potential of the Inyan Kara Formation.
- Evaluation of components that can affect oil production, including assessment of recompletion/refracturing performance, evaluation of geologic and engineering factors that could affect oil production, and analysis of trends in fluid and gas production as a function of completion technique.
- Determination of the potential to use aromatic/aliphatic ratios in produced oil to determine the source of that oil (i.e., determine how much of the produced oil, if any, came from the shales as opposed to the Middle Bakken or Three Forks).

BPOP activities in support of the rich gas EOR pilot during the first two quarters of the year were focused on laboratory studies and the development of models of Liberty’s Stomping Horse reservoir and surface facilities. Laboratory experiments examined interactions between rich gas components, Bakken oil, and Bakken rocks, including minimum miscibility pressure (MMP) studies and rock extraction studies. The MMP studies showed that ethane and propane are effective at lowering MMP in Bakken crude oil. The extraction studies indicated that rich gas components can effectively mobilize oil from Bakken shale and non-shale matrix. The reservoir modeling exercises indicated that execution of a cyclic multiwell huff ‘n’ puff scheme for EOR can yield substantial incremental oil production. Surface facility modeling indicated rich gas EOR will not adversely affect existing infrastructure at Liberty’s Stomping Horse complex facilities. BPOP EOR pilot activities in the last two quarters were largely focused on field-based activities at the Leon–Gohrick drill spacing unit in the Stomping Horse complex. Multiple rounds of baseline fluid (oil, gas, water) samples from wells in the Stomping Horse complex were collected and analyzed.
over the course of 2018. Reservoir surveillance and monitoring equipment, including downhole memory gauges to record bottomhole pressure and temperature data, were also deployed. Liberty began initial injection using gas lift compressors into a Three Forks well in mid-July 2018. Subsequent injection into a neighboring Middle Bakken well was conducted in August 2018. Surface and subsurface monitoring data from those injection tests were collected and are in the process of being evaluated and interpreted.

The facility process modeling task continued with a focus on assessing weather-induced changes to crude oil vapor pressure. Modeling was completed for two member surface facilities that included an evaluation of design changes to ensure vapor pressure compliance during cold weather. A document summarizing the results of this work is expected to be ready for member distribution during the next quarter.

The Inyan Kara Formation (Dakota Group) modeling and simulation effort was completed and the final project report has been posted on the members-only Web site. The goal of the effort was to estimate local and regional pressure effects that have occurred in the Inyan Kara as a result of historic SWD and to evaluate areas that may be suitable or problematic for disposal through reservoir simulation of hypothetical future injection scenarios. Ongoing activities in this area are focused on the development of simplistic spreadsheet-based models to allow users to estimate the radius of influence of individual SWD wells.

Final topical reports for two efforts, the refracturing optimization and the reservoir performance modeling, underwent internal review and were sent out to select member representatives for review, after which these will be made available to all members. The goal of the refracturing optimization task was to analyze the production performance of Bakken wells that had been refractured and/or recompleted. The reservoir performance modeling effort employed multivariate statistical analysis techniques to evaluate the effects of different geologic and completion-related factors on well production performance.

The aromatic/aliphatic studies included laboratory experiments to determine aromatic/aliphatic ratios for oil samples extracted from Upper Bakken shale, Lower Bakken shale, Middle Bakken, and Three Forks rocks from several wells throughout North Dakota. This task also included collecting and analyzing oil samples from two proximal Marathon wells, including one well that has been producing oil from a horizontal well that has not been hydraulically fractured to establish baseline aromatic/aliphatic ratios. In late 2018, Marathon plans to hydraulically fracture the well and oil samples will be collected periodically and analyzed to determine changes in aromatic/aliphatic ratio that may indicate contribution of oil production from the shale and changes in that contribution over time.

Anticipated activities in the next year include ongoing collaboration with Liberty on the rich gas EOR pilot. The lessons learned from the 2018 summer injection tests will be used to design and conduct a larger-scale injection test using a larger compressor. The remainder of the activities for the next year will be determined by member input. A survey was provided to each BPOP member following the August 2018 meeting to better define our priority research areas for the next year. The results from the four members that responded to the survey were compiled, and using this input, individuals from all partner companies will be contacted to better define the details of each priority research area.
INTRODUCTION

The Bakken Production Optimization Program (BPOP) was established to facilitate Bakken Petroleum System oil recovery while simultaneously reducing the environmental footprint of oil and gas development. This program is administered by the Energy & Environmental Research Center (EERC) with funding from the North Dakota Industrial Commission (NDIC) Oil and Gas Research Program (OGRP) and the North Dakota petroleum industry. Through BPOP, the EERC is working closely with a consortium of industry partners and the State to address emerging opportunities and challenges related to the Bakken development.

The goals of BPOP are to do the following:

- Develop knowledge that will enhance overall production efficiency, recognizing that improved coordination among various design factors (reservoir management, well design, surface processing, gas management, waste management) can lead to significant improvements in resource recovery efficiency while reducing potential health, safety, and environment impacts.

- Conduct applied research in topic areas that positively impact the efficiency of production and reduce the environmental footprint of operations.

- Advise industry and state entities on scientific aspects of exploration and production activities, especially as they pertain to economic and environmental impacts.

- Facilitate collaboration on issues that may not otherwise receive collaborative attention from industry and/or the state of North Dakota.

The anticipated outcomes of BPOP are 1) increased well productivity and economic output of the Bakken petroleum system, 2) decreased environmental impacts of wellsite operations, and 3) reduced demand for infrastructure construction and maintenance. Specific results will include improved resource recovery efficiency, reduced land use impacts, increased royalties and tax revenue from harnessed associated gas and natural gas liquid streams, and increased revenue from added product streams captured earlier in the well life cycle.

ACCOMPLISHMENTS DURING REPORTING PERIOD

Enhanced Oil Recovery Task

The goal of the enhanced oil recovery (EOR) task is to develop knowledge that will support broad commercial implementation of EOR in the Bakken play. To achieve that goal, the EERC is conducting laboratory-, modeling-, and field-based investigative activities to examine the effectiveness of using rich gas for EOR. The centerpiece of this task is the rich gas EOR pilot being
conducted by Liberty Resources LLC (Liberty) at its Stomping Horse complex in Williams County, North Dakota. NDIC is providing $1,527,234 and the U.S. Department of Energy (DOE) has committed $2,000,000 to support EERC activities related to the Stomping Horse pilot. During the last quarter of the year, DOE committed an additional $1,000,000 toward laboratory-based investigations of the role that the organic-rich shales will play in rich gas-based Bakken EOR, especially with respect to gas utilization rates. The goals of the work to be conducted under the EOR task include the following:

- Determine the effectiveness of cyclic multiwell huff ‘n’ puff as an injection/production scheme that can maintain conformance of the working fluid within the reservoir.

- Determine the ability of various rich gas mixtures (methane, ethane, and propane) to mobilize oil in Bakken petroleum system reservoir rocks and shales.

- Determine changes in gas and fluid compositions over time in both the reservoir and surface infrastructure environments, and assess how those changes affect reservoir and process facility performance.

- Optimize future commercial-scale tight oil EOR design and operations via iterative modeling of surface infrastructure and reservoir performance using data generated by the field- and laboratory-based activities.

- Establish the effectiveness of selected monitoring techniques as a means of reservoir surveillance and injection conformance monitoring in the Bakken petroleum system.

- Determine the sorptive capacity of Bakken shales for rich gas components and the effects of sorption in the shales on gas utilization rates in samples representing areas of low, medium, and high thermal maturity.

During this reporting period, activities to accomplish the BPOP goals for the pilot project stated above were conducted. These activities were conducted in close collaboration with Liberty.

Laboratory-based examinations of rich gas interactions with obtained crude oils and core/cuttings were conducted to determine the ability of various rich gas mixtures to mobilize oil in the Bakken petroleum system. Laboratory studies were conducted to determine minimum miscibility pressure (MMP) values for different rich gas components (methane, ethane, propane; alone and in mixtures) and CO₂ (for comparative purposes) in crude oil from the Stomping Horse complex as well as a Middle Bakken crude oil. A modified rising capillary–vanishing interfacial tension technique was used for the MMP studies. The results of those studies indicate that ethane and propane can effectively lower MMP of Bakken crude oil. Substantial progress was made in preparing and utilizing stable ternary gas mixtures (methane/ethane/propane) for MMP studies of rich gas mixtures that will be conducted in the coming year.

Experiments to extract hydrocarbons from Middle Bakken and Lower Bakken shale core samples from four Liberty wells were performed using pure methane, ethane, and propane. Analysis of the hydrocarbon recovery rates with the different fluids from the samples was
conducted. The results of the extraction studies indicate that rich gas can effectively mobilize oil from Bakken shale and nonshale rocks, although some rich gas components are more effective than others. The progress in the ternary gas mixture has allowed for the performance of both “miscible” phase hydrocarbon composition determinations as well as Middle Bakken and Bakken shale rock extractions with typical methane/ethane/propane mixtures of produced gas to begin. The effect of exposing Bakken crude oil to these various hydrocarbon gases on the residual crude oil’s viscosity, API (American Petroleum Institute) gravity, and molecular weight distributions are also being determined.

Laboratory-based experiments to determine the effects of rich gas fluid composition and pressure on the mobilization of hydrocarbons from Bakken crude oil were conducted. Previous experiments have demonstrated that 1) true chemical miscibility (single phase) between injected fluids and crude oil have never been observed under any temperature and pressure conditions and 2) the hydrocarbon composition of both the rich gas-dominated upper phase in the test chamber and bulk crude-dominated lower phase is continually changing as reservoir conditions change. Experiments were conducted at pressures of 5000 and 3000 psi using methane, ethane, and propane and at 1500 psi using ethane and propane. The purpose of the experiments is to determine which hydrocarbons partition into the upper phase dominated by the working fluid comprising methane, ethane, and/or propane as the pressure increases and which molecular weight hydrocarbons revert to the lower phase as pressure drops.

Evaluations of the changes in gas and fluid compositions over time in both the reservoir and surface infrastructure environments are being conducted as well as examinations of how those changes affect reservoir and process facility performance. Additional crude oil and produced water samples were collected from several wells in the Stomping Horse complex to establish baseline compositions and determine the range of variability both spatially and temporally in the Stomping Horse area. Sample collection will continue periodically throughout the first 12 to 18 months of production to provide a temporal aspect to well fluid.

A systematic modeling and simulation effort is being executed to integrate laboratory and field data sets, acquired at the Stomping Horse location, into reservoir simulation models. Modeling and dynamic simulation activities are intended with a dual purpose: 1) provide technical support for informing practical decision-making processes regarding the pilot test and 2) gain understanding on how to improve hydrocarbon recovery by injection of rich gas in the Bakken Formation. Static geocellular modeling of the Bakken petroleum system and dynamic simulations of potential EOR schemes will be employed to predict EOR performance by means of rich gas injection. A geocellular model of the Stomping Horse drill spacing unit (DSU), the location in which the pilot test is being conducted, was created using data provided by Liberty. History-matching exercises, using detailed operational data provided by Liberty, will help to validate the geocellular model. After the model calibration step, dynamic reservoir simulations will be used for the prediction and evaluation of various potential pilot test schemes.

Two types of reservoir simulation models were built and calibrated. First of all, at early stages of the project (during the design phase), a mechanistic single-stage model allowed gaining an understanding of the key mechanisms affecting the performance of the gas injection EOR. Secondly, a DSU scale model was constructed to capture in more detail the geologic structure,
lithofacies distribution, and initial reservoir pressure and saturation spatial distribution. The models were used to predict incremental recovery factors considering the site-specific characteristics. Operational observations and laboratory measurements have been used to inform both the mechanistic and DSU models. Field data included petrophysical properties, reservoir pressure, temperature, fluid saturations, fluid composition, and primary production records. 3-D heterogeneous geologic models were built to investigate different injection strategies with the existing hydraulically fractured horizontal wells (i.e., without proposing drilling any new wells). Sensitivity studies were performed to quantify the effects of key parameters and injected fluids. Several hypothetical scenarios were examined in detail, including different injected fluid compositions, well schedules, and targeted injection/production rates.

The results obtained from reservoir modeling work showed that, overall, there is significant potential of increasing hydrocarbon recovery injecting rich gas into the Bakken Formation. Preliminary results on the evaluation of the EOR performance with the mechanistic model have shown that 1) injectivity does not seem to be a big concern and 2) higher injection pressures (and therefore higher injected fluid densities) seem to sustain hydrocarbon recovery. The simulation models and results have provided valuable information and supported planning the gas injection operations.

A variety of field-based activities were conducted to support the Liberty Resources rich gas EOR pilot at its Stomping Horse oil factory complex in Williams County. Fluid (oil, gas, water) samples from wells in the Stomping Horse complex were collected and analyzed throughout the first 6 months of 2018 to provide a set of baseline conditions against which analyses of future fluids produced during different stages of the pilot test can be compared. Reservoir surveillance and monitoring equipment, including downhole memory gauges to record bottomhole pressure and temperature data, were deployed in wells of the Leon–Gohrick DSU within the Stomping Horse complex. Liberty began initial injection, using gas lift compressors, into a Three Forks well in the Leon–Gohrick DSU in mid-July 2018. Subsequent injection into a neighboring Middle Bakken well was conducted in August. Another injection operation was conducted in the first Three Forks well in September. Surface and subsurface monitoring data from those injection tests were collected and are in the process of being evaluated and interpreted. The lessons learned from the summer injection tests will be used to design a larger-scale injection test that is anticipated to be initiated in the last quarter of 2018 using a larger compressor.

**Refracturing Optimization Task**

More than 90% of the estimated oil in place in unconventional reservoirs is not produced via primary production. While laboratory studies of EOR methods (e.g., gas injection) for unconventional reservoirs look promising, the results from pilot and field tests are inconclusive. Well refracturing (recompletion) provides an alternative to EOR methods and is one technique for improving oil recovery by counteracting the effects of suboptimal completions. Examples of suboptimal completions include undersized fracture treatments, widely spaced fracture intervals, inoperable completion failures, and damage mechanisms that cause a loss of connectivity to the reservoir. Refracturing is a recent development for the Bakken but is not a new technique, as refracturing was first implemented in the 1970s.
This study was conducted to 1) analyze the production performance of wells that have been refractured in the Bakken Formation of North Dakota, 2) investigate the economics of well refracturing and 3) evaluate the overall potential for Bakken-wide implementation of refracturing operations. Several metrics were used to evaluate refracturing performance, including changes in peak oil rate, uplift in oil production rate following refracturing, decrease in gas–oil ratio (GOR), and incremental estimated ultimate recoveries (EURs). The economic analysis focused on discounted net oil revenue, defined as the oil revenue after deducting royalties, state tax and refracturing costs, assuming an annual discount rate. The discounted net oil revenue was investigated using Monte Carlo simulation with different combinations of oil price, refracturing cost, and the low, middle, and high incremental annual oil production from the refracturing production analysis.

The results of this work were compiled into a final report that was provided to select BPOP members for review. Once the input from member review is incorporated into the report, it will be distributed to all BPOP members.

**Produced Fluid Characterization Task**

The fluid characterization task was established for the purpose of compiling physical and chemical property data pertaining to Bakken Formation fluids, including crude, produced water, and associated gas. The goal of this task was to develop and maintain a robust database of Bakken-related fluids data, and facilitate data and sample acquisition and analyses to support the many ongoing BPOP activities conducting basin-specific research of interest to industry and the state of North Dakota. The objectives of this task were to be accomplished by conducting a thorough review and compilation of relevant publicly available data, establishing industry partnerships to enable acquisition of nonpublic information, conducting sampling and analysis of fluids to support project needs, and performing a review of relevant information to identify specific data gaps and needs.

Key accomplishments for this year have included establishing partnerships with key industry partners to obtain access to fluids sample collection and acquisition of existing compositional data to support the ongoing research efforts of individual BPOP program tasks. Sampling and analysis activities have also continued, supporting an increased geographical distribution of data representation and providing a temporal evaluation of compositional changes throughout a well’s production life, as well as compositional differences in a stimulated versus a nonstimulated well. The EERC conducted the following activities this year:

- Coordinated with BPOP program leads to identify key information and data needed for ongoing and planned research efforts.
- Reviewed and refined collected data/information for inclusion in the previously developed database and to identify specific data gaps/needs.
- Created a “Bakken Fluids Characterization – Data Request and Sample Acquisition Information Sheet” for distribution to potential industry partners to help facilitate access to additional data/information and sample collection access.
Conducted a formal solicitation of produced fluids data from key industry partners as a database of information on produced water, crude oil, and associated gas is being built. These data will be integrated into the EERC-managed Bakken fluids database for support in understanding basinwide characteristics related to production and other reservoir/well statistics.

Developed partnerships with key industry to collect fluid samples.

Collected crude and produced water samples from three newly completed and producing Bakken and Three Forks wells. These samples have been collected from each well periodically since initial production throughout the first several months of production. Sampling will be repeated periodically throughout the first 12 to 18 months of production to provide data on compositional changes with time.

Obtained and reviewed significant fluid compositional data and associated well production information from an industry partner in a new area of the Bakken play.

Conducted crude, water, and gas sampling and analysis activities on several wells at two locations in the northern and southern portions of the Bakken play.

Supported the rich gas injection EOR demonstration through periodic sampling and analysis of fluids potentially impacted by injection activities. Data are currently being evaluated and will be assessed for potential inclusion in the current database.

Began sampling and analysis activities on a stimulated and nonstimulated well to compare compositional differences. Results may provide indications of fluid migration pathways and sources of produced water in stimulated Bakken wells.

Conducted monthly and quarterly sampling and analysis of four wells to temporal compositional changes.

**Reservoir Performance Modeling Task**

In the Bakken, there is a general trend of increasing initial oil production rates over time, which is related, at least in part, to advances in technology. However, some older wells outperform younger wells despite technology improvements, which suggests that geology or other factors have a greater impact on long-term oil production than the engineering practices of drilling and hydraulic fracturing.

A key unknown is the degree to which geologic- and engineering-related factors are correlated to oil production performance. Furthermore, among these geologic- and engineering-related factors, which ones are most significant in predicting long-term well performance? Do technological and engineering practices determine the long-term performance of a Bakken oil well? Alternatively, do geologic factors play a more significant role? This work explored these questions.
The database created for and used in this work includes 400 wells completed in the Bakken and Three Forks Formations and located across the Bakken petroleum system. Approximately 30 different factors (completion-related and geology-related) were analyzed for their effects on short-term (6-month) and long-term (60-month) production using a multivariate statistical approach.

The results of this work were compiled into a final report that was provided to select BPOP members for review. Once the input from member review is incorporated into the report, it will be distributed to all BPOP members.

**Water Injection Reservoir Assessment Task**

Because of industry’s current reliance on the Inyan Kara Formation as a saltwater disposal (SWD) target, an effort was conducted through BPOP to estimate local and regional pressure effects that have occurred as a result of historic SWD and to evaluate areas that may be suitable or problematic for disposal through reservoir simulation of hypothetical future injection scenarios. An additional goal was to evaluate the overall disposal potential of the Inyan Kara in the areas that are currently targeted for injection.

The modeling and simulation portion of this task was completed this past year and a report summarizing the approach, results, and conclusions was prepared and is available on the BPOP members-only Web site. The results and conclusions of this task were also presented to members during the August 2018 BPOP Annual Members Meeting. A copy of the presentation is also available on the Web site.

As a complementary activity for this task, the EERC has been working on the development of simplistic spreadsheet-based models that allow the user to estimate the radius of influence of individual SWD wells based on basic geologic characteristics (cumulative sand thickness, average porosity, and average permeability), injection rate, and period of performance. This activity will be completed in the next year.

**Brine Treatment and Storage Assessment**

The goal of the brine treatment and storage assessment task is to assess current and emerging brine treatment technologies of interest to BPOP members. One of the questions surrounding this topic is whether or not concentrating Bakken brine during the treatment process could result in precipitation of NORM (naturally occurring radioactive material). Geochemical modeling using PHREEQC was performed to evaluate the potential for scale and NORM precipitation in Bakken produced water concentrate streams. Several ranges of Bakken brine concentrates were evaluated. The results were compiled into a report that is undergoing internal review. Once internal review is complete, the report will be made available to BPOP members.

**Bakken Trend Analysis**

This task is focused on the evaluation of various trends related to Bakken fluids production and completion practices to better understand the potential future impacts of those trends on
surface-related infrastructure, freshwater demand, and SWD capacity. A data set of over 11,000 wells was used to evaluate trends in oil, gas, and water production based on general well completion practices, including single vs. multistage, proppant loading, and water use. The results of the trend analysis were presented to BPOP members during the August 2018 Annual Members Meeting. A copy of the presentation is available on the members-only Web site.

Additional work is planned in this area to assess the differences in oil, water, and gas production between parent and child wells and as a function of location, completion practice, completion year, lateral length, and other factors that could affect production. The scope of that effort will be determined once additional input on future activities is received from BPOP members.

**Facility Process Optimization Task**

The overall goal of this activity was to apply process simulation to the operation of Bakken surface facilities to improve performance, reduce emissions, and ultimately streamline operating costs. Production facilities are a key link in the overall Bakken production chain, and under this Task, models have been created with member input to examine in detail parameters that affect fugitive emissions and crude oil properties. Modeling results are then reduced to actionable suggestions for member producers to consider when evaluating their operations.

Within the past year, work focused on the issue of weather-induced changes to crude oil vapor pressure. Typically, vapor pressure targets are most difficult to meet during winter months when there is excessive heat loss from exposed process equipment. To evaluate solutions for this problem, the EERC created cold-weather models that were validated using site-specific data collected during the winter of 2017–2018 from two BPOP member sites. The analysis included predicting performance of the as-sampled facilities and evaluating design changes that could ensure vapor pressure compliance during cold weather.

Summary deliverables from this task consist of a technical brief and an accompanying slide presentation; these are under review by the BPOP members who provided data to the study. The documents will be made available to the general membership during the fourth quarter of 2018. Going forward, the tools developed under this task will be applied to member topics on an as-requested basis.

**Aromatic/Aliphatic Study Task**

Data reduction is continuing on the 40 Lower and Upper Bakken shale samples as well as the additional 33 rock core samples including several Middle Bakken, Three Forks, Pronghorn, and additional Upper and Lower Bakken shales that were extracted and analyzed for their aromatic/aliphatic ratios. These samples were selected to give complete profiles (including multiple depths of single lithofacies for some wells) of multiple wells including all relevant source and reservoir rocks. An update on the aromatic/aliphatic tracer studies was posted on the BPOP members-only Web site.
All temporal crude oil samples from three producing wells that were collected from September 2017 through August 2018 were analyzed for aromatic/aliphatic ratios to determine if the relative contributions of the shales compared to the Middle Bakken to the produced crude would shift over production time. To date, no significant change in those ratios have been observed in the produced crudes, indicating that no large change in the proposition of oil produced from the Middle Bakken and adjacent shales has yet occurred.

Several drill cutting samples from the Middle Bakken Formation from two Liberty Resources wells were analyzed for aromatic/aliphatic ratios. The cuttings were collected from the heel to the toe of the laterals and did show some significant variations from heel-to-toe cuttings. However, it is unknown whether the variations are a result of horizontal changes in the rock aromatic/aliphatic content over the length of the laterals or in distinct encountered facies over the length of the laterals. Additional attempts to remove diesel cutting fluids from drill cuttings in order to allow the rock drill cuttings to be used for aromatic/aliphatic analyses were not successful. The operator of these wells provided a sample of its diesel fluid, which was analyzed by gas chromatography–mass spectrometry (GC–MS) for the aromatic hydrocarbon composition and molecular weight distribution. Unfortunately, the diesel-based fluid has the same one- to three-ring aromatic hydrocarbons that are used for the aromatic/aliphatic tracer analyses. In turn, drill cuttings that include diesel-based drilling fluid cannot be used for aromatic/aliphatic tracer analyses.

An agreement was reached with the Canadian Geological Survey in which the EERC provided 40 Lower and Upper Bakken shale samples collected to represent both the geographic and the thermal maturity variations throughout the Bakken reservoir. In addition, a Lower Bakken shale extracted at three pressures (1500, 2500, and 5000 psi) using pure methane, ethane, and propane was provided. The Canadian Geological Survey conducted two sophisticated tests that describe thermal maturity behavior in tight shales better than conventional methods used for nonshale reservoirs. Extended slow-heating rock evaluation and vitrinite reflectance were performed on samples supplied by the EERC, and the data will be compared to the aromatic/aliphatic tracers measured by the EERC on the same sample suite. These investigations are expected to yield a better understanding of the shale thermal maturity across the basin as well as the relationship of the aromatic/aliphatic tracers to thermal maturity, oil sources and migration, and basin location and geology.

**Environmental Support Task**

EERC staff have been participating as subject-matter experts, providing input and presenting educational information at the Hydrocarbon Remediation Task Force meetings. The level of participation of EERC staff has varied from strictly an attendee to providing presentations to the group as a subject-matter expert. The purpose of the Hydrocarbon Remediation Task Force is to convene stakeholders to discuss hydrocarbon spill remediation and work toward general agreement of how hydrocarbon spills should be regulated by the North Dakota Department of Health. Additional stakeholders include North Dakota Petroleum Council members and staff, representatives of the Northwest Landowner’s Association, staff from the North Dakota Department of Mineral Resources, staff from the North Dakota Department of Agriculture, and staff from the Governor’s office.

EERC staff attended the second meeting of the Hydrocarbon Remediation Task Force on October 10, 2017, to discuss receptors and pathways in a risk-based corrective action system for crude oil remediation in the Williston Basin.

On January 26, 2018, EERC staff presented information as subject-matter experts to the Hydrocarbon Remediation Task Force related to hydrocarbon fate and transport and risk-based decision-making. EERC staff presented information to the Hydrocarbon Remediation Task Force on January 26, 2018, in Bismarck, North Dakota. Information presented at the January 26, 2018, Task Force meeting related to past research by the Total Petroleum Hydrocarbon Criteria Working Group and detailed the current Oklahoma Risk Based Corrective Action program for crude oil and condensates.

EERC staff attended the fourth and final education day of the Hydrocarbon Remediation Task Force on May 2, 2018, to hear presentations from Dr. Charles DeWolf regarding the risk-based corrective action program in Montana and Jon Tucker regarding the Alberta risk-based corrective action system.

As a result of preparing educational information for the Hydrocarbon Remediation Task Force, a body of technical work relevant to the previously published, “evergreen” North Dakota Remediation Resource Manual. Using this material as a starting point, EERC staff drafted additional hydrocarbon remediation content, incorporated it into the remediation manual, and facilitated the review of this text with a representative of Oasis Petroleum, the primary industry author in the original remediation manual text.

EERC staff continued the process of updating the North Dakota Remediation Resource Manual with additional hydrocarbon remediation text based on information presented on the North Dakota Department of Health education days. This included facilitating several conference calls with contributing authors from Oasis Petroleum to review draft text. The North Dakota Remediation Resource Manual is currently in final review and editing and will be republished prior to the end of 2018.

In addition to participating in the Hydrocarbon Remediation Task Force, EERC staff regularly attend the North Dakota/Montana Environmental Peer Group (EPG) meetings, which are held on a quarterly basis. The EPG meetings are a convening of environmental staff of oil and gas companies operating in the Williston Basin. The intent and value in EERC staff attending these
meetings included 1) introducing and enforcing EERC’s expertise to the industry when presenting to the group and 2) gathering valuable information from exchanges between industry peers.

**Program Management and Development**

A project kickoff meeting for the parallel DOE-sponsored EOR effort was held via WebEx on December 14, 2017.

The EERC is supporting the Natural Gas Capture and Infrastructure Development (NGCID) Task Force by leading the subcommittee focused on assessing remote capture use. The EERC also coordinated the creation of an industry survey that was distributed to North Dakota Petroleum Council membership to gather information about a variety of factors influencing flaring in North Dakota. Survey results were reviewed and compiled by EERC staff and provided to the NGCID committee to support its goal of improved gas capture.

The BPOP Annual Members Meeting was held August 7–8, 2018, in Grand Forks, North Dakota, at the EERC. Over 30 participants attended the meeting. The presentations are available on the members-only Web site.

Following the Annual Members Meeting, a survey was sent to members to solicit programmatic research priorities to help guide the remaining flexible portion of funding. Responses from four member companies were received by September 30, 2018. Additional input will be sought from the members.

Charlie Gorecki presented “Bakken Production Optimization Program (BPOP) 2.0 Update” to the Oil and Gas Research Council on August 20, 2018. Presentation items included an update on the BPOP budget, an overview of the Annual Members Meeting, a draft final report review process, and updates on activities including rich gas EOR with Liberty, the refracturing study, SWD modeling, and vapor pressure, remediation, and statistical analysis of production data activities.

A final report review process for products of BPOP was developed to provide value to the members. The general process will include 2 months of internal review, 3 months of external review by select partners and incorporation of comments, and 15 months of distribution to the members on the members-only Web site. The product will then be distributed to the public 18 months from the start of external review. The process will be shortened on a case-by-case basis.

Representatives from BPOP incurred travel costs for their participation in meetings and conferences to disseminate information and seek additional support for BPOP.

**MEMBERSHIP AND FINANCIAL INFORMATION**

The original budget as proposed to NDIC OGRP is $13,280,000, as shown in Table 1.
Table 1. BPOP – Original Budget

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>NDIC Share – Cash</td>
<td>$2,000,000</td>
<td>$2,000,000</td>
<td>$2,000,000</td>
<td>$6,000,000</td>
</tr>
<tr>
<td>Industry Share (Marathon) – In-Kind</td>
<td>$2,500,000</td>
<td>$3,500,000</td>
<td>$1,280,000</td>
<td>$7,280,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$4,500,000</strong></td>
<td><strong>$5,500,000</strong></td>
<td><strong>$3,280,000</strong></td>
<td><strong>$13,280,000</strong></td>
</tr>
</tbody>
</table>

The EERC continues to seek support for this program, and to date, additional cost share has been secured from the Bakken producers listed in Table 2. Equinor (previously Statoil) and XTO Energy joined in the last year.

Table 2. BPOP Members

<table>
<thead>
<tr>
<th>ConocoPhillips</th>
<th>Liberty Resources</th>
<th>Petro-Hunt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equinor</td>
<td>Marathon Oil</td>
<td>WPX Energy</td>
</tr>
<tr>
<td>Hess Corporation</td>
<td>Oasis Petroleum</td>
<td>XTO Energy</td>
</tr>
</tbody>
</table>

In addition, the EERC has secured $2,000,000 from DOE to complement the ongoing work to determine the feasibility of reinjecting captured rich gas into a Bakken reservoir to enhance oil recovery. Liberty is providing in-kind contributions that support this programmatic scope.

Table 3 presents a revised expected budget based on the additional cost share secured by the EERC, an increase of over 70%. Expenses to date are also listed in Table 3.

Table 3. BPOP – Expected Budget and Expenses to Date

<table>
<thead>
<tr>
<th>Sponsors</th>
<th>Expected Budget</th>
<th>Actual Expenses as of 9/30/18</th>
<th>Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>NDIC Share – Cash</td>
<td>$6,000,000</td>
<td>$3,028,917</td>
<td>$2,971,083</td>
</tr>
<tr>
<td>Industry Share – Cash</td>
<td>$1,150,000</td>
<td>$484,739</td>
<td>$665,261</td>
</tr>
<tr>
<td>Marathon – In-Kind</td>
<td>$12,615,401</td>
<td>$12,615,401</td>
<td>$0</td>
</tr>
<tr>
<td>Liberty – In-Kind*</td>
<td>$1,384,656</td>
<td>$1,384,656</td>
<td>$0</td>
</tr>
<tr>
<td>DOE – Cash</td>
<td>$2,000,000</td>
<td>$677,119</td>
<td>$1,322,881</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$23,150,057</strong></td>
<td><strong>$18,190,832</strong></td>
<td><strong>$4,959,225</strong></td>
</tr>
</tbody>
</table>

* An estimate for the total expected in-kind cost share from Liberty is not available. Liberty will periodically report actual costs to the EERC, which will be subsequently presented in the quarterly report.
FUTURE ACTIVITIES

The planned activities for the next year are described below. At this time, the flexible portion of BPOP funds for the upcoming year are being planned with member input as determined by the results of the member survey and with additional input that will be sought via interviews with member representatives.

Enhanced Oil Recovery Task

Anticipated activities over the next year will focus on continued collaboration with Liberty on the rich gas EOR pilot. The data generated from the initial injection tests will be evaluated. The lessons learned from the summer injection tests will be used to design a larger-scale injection test using a larger compressor that is anticipated to be initiated early in the next quarter. A draft white paper on the findings from the surface facility modeling of the Stomping Horse complex is also expected to be developed during the next quarter.

Experiments focused on determining the effect of pressure on the ability of the mixed C1/C2/C3 produced gas to mobilize crude oil hydrocarbons into the “miscible” phase will be conducted. The effects of pressure will be examined both in terms of the mass of oil mobilized and the molecular weight selectivity shown by the different pressures.

Flow-through experiments to examine the sorptive capacity of Bakken shale samples for rich gas components will continue to be conducted. Two instruments that will be used in future experimental activities in support of this effort, a magnetic balance and a specialized centrifuge, will be ordered for purchase next quarter.

With respect to modeling, ongoing efforts will continue to calibrate gas and water production at longer times. Once calibrated, the DSU model will allow obtaining predictions that are more reliable. Later, dynamic simulations will allow forecasting, assessing, and optimizing short-term and long-term recovery efficiencies.

Refracturing Optimization Task

The activities under the current scope of work are complete. External partner review comments will be received and incorporated into the task final report. The report will be posted on the members-only Web site.

Produced Fluid Characterization Task

Key activities for this task in the upcoming year will include developing additional partnerships with industry to further understand their specific needs related to Bakken production issues and practices and to expand the geographical extent of the sampling and analysis effort. Data collection and sample acquisition is expected to continue with results supporting the ongoing compositional evaluations of each fluid and supporting the temporal evaluations and enhancing the size and usefulness of the database to the various BPOP research efforts. Data review and
refining will also be conducted to enhance the usefulness of the database with any data gaps and additional needs being identified. Specific activities to be conducted include the following:

- Continue monthly and quarterly sample collection and analysis events on established wells.
- Review and evaluate collected data as it pertains to overall production characteristics throughout the Bakken play.
- Coordinate access and sample acquisition/analysis on additional wells throughout the basin.
- Industry partnerships will continue to be developed to further understand specific needs related to Bakken production issues and practices and to expand the geographical extent of the sampling and analysis effort.
- All fluid data and associated well production information collected will be entered into the EERC-specific database to support BPOP goals. The database structure will be refined to enhance use by BPOP researchers.
- Data collection and additional sampling and analysis will continue as needed to support BPOP goals.

**Reservoir Performance Modeling Task**

The activities under the current scope of work are complete. Continuation of similar technical work with different data sets (much larger and/or smaller data sets focusing on certain regions of the Bakken area) is in discussion to get in-depth understanding of the factors affecting and contributing to well productivity in the Bakken petroleum system.

External partner review comments will be received and incorporated into the task final report. The report will be posted on the members-only Web site.

**Water Injection Reservoir Assessment Task**

Activities will focus on completing the development of simplistic spreadsheet models to evaluate the area of influence of SWD wells in the Inyan Kara. The models are anticipated to be completed during the first quarter of the upcoming year, after which it will be presented to BPOP members for input.

**Brine Treatment and Storage Assessment**

Internal review of the PHREEQC modeling report will be completed and will be sent to select BPOP members for external review.
**Bakken Trend Analysis**

Upcoming activities for this task will be dependent on the results of the BPOP members survey, the results of which are being compiled. Possible activities may include additional trend analysis work that distinguishes the trends between parent and child wells.

**Facility Process Optimization Task**

The summary deliverables consisting of a technical brief and accompanying slides will be circulated for review by the BPOP members that provided data to the study. Finalized deliverables will then be made available to the general membership during the fourth quarter of 2018.

**Aromatic/Aliphatic Study Task**

Work will continue on the evaluation of the aromatic/aliphatic ratios within crude oil samples. Upcoming activities over the next year include ongoing collaboration with the Canadian Geological Survey and compilation of the aromatic/aliphatic results for any newly acquired rock samples. The temporal analysis of aromatic/aliphatic ratios from select producing wells will also continue as additional samples are collected.

**Environmental Support Task**

EERC staff will complete the revision of the North Dakota Remediation Resource Manual and publish the updated version.

**Program Management and Development**

Additional input on programmatic research priorities to help guide the remaining flexible portion of funding will be sought from the members. This will help develop a scope of work for BPOP Year 3 funding, which will be discussed with NDIC and members.

The EERC will continue to solicit additional industry membership in the BPOP consortium in the coming year.