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Energy & Environmental Research Center
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April 30, 2021

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: Quarterly Progress Report for the Period of January 1 – March 31, 2021, "Bakken Production Optimization Program 3.0"; Contract No. G-051-98; EERC Fund 24568

Attached please find the Energy & Environmental Research Center (EERC) Quarterly Progress Report for the subject project. If you have any questions, please contact me by phone at (701) 777-5287 or by e-mail at jsorensen@undeerc.org.

Sincerely,

DocuSigned by:
James Sorensen
0671D00C8437443...

James A. Sorensen
Director for Subsurface R&D

JAS/rlo

Attachment

c/att: Brent Brannan, North Dakota Industrial Commission

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BAKKEN PRODUCTION OPTIMIZATION PROGRAM

Quarterly Progress Report

(for the period January 1 – March 31, 2021)

Prepared for:

North Dakota Industrial Commission

Partners of the Bakken Production Optimization Program (BPOP) Consortium
- ConocoPhillips
- Equinor
- Hess Corporation
- Liberty Resources LLC
- Marathon Oil Company
- Oasis Petroleum
- Petro-Hunt, LLC
- WPX Energy
- XTO Energy, Inc.

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April 30, 2021

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TABLE OF CONTENTS

LIST OF TABLES

DocuSign Envelope ID: CB77A752-3D17-45EA-AD4C-34C8B1648624

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. This progress report presents an overview of BPOP activities from January 1 through March 31, 2021.

A wellsite model to assess tank vapor-phase behavior was developed and used to evaluate natural gas liquid recovery potential over a range of pressures. The results will be provided to partners in a comprehensive slide deck that will serve as a topical report. A detailed analysis of the operations impacting operating expenses was initiated to identify opportunities for cost reduction and form the basis for subsequent BPOP projects.

Improvements to oil- and water-fingerprinting analytical techniques continued in an effort to discriminate samples produced from different reservoirs. Reliable indicators for the oil fingerprinting and oil/source correlations were identified based on aromatic polycyclic compounds and biomarkers. The strontium isotope-based water-fingerprinting technique was improved by adding a sample preparation method.

Approximately 700 wells were added to the data set used in completion optimization calculations on the drill spacing unit level. An analysis was performed to observe well performance before and after the shut-in period of low oil demand.

Efforts to inform a Liberty Resources Bakken enhanced oil recovery (EOR) pilot design continued. Sensitivity analyses were performed to understand the potential impact of fluid injection on EOR performance. An investigation of the potential impact of application/injection of surfactant integrated with the coinjection of rich gas and water was initiated. A literature review of surfactant studies and initial modeling and simulation were conducted in collaboration with Texas A&M University and Computer Modelling Group Ltd. Efforts were initiated to integrate data provided by Oasis Petroleum Inc. with experimental rich gas extraction data generated by the EERC using rocks from an Oasis well.

The EERC holds an unwavering commitment to the health and well-being of its employees, partners and clients, and the global community. As such, precautionary measures have been implemented in response to COVID-19. Staff continue to carry out project-related activities remotely, and personnel supporting essential on-site laboratory and testing activities are proceeding under firm safety guidelines. Travel has been minimized, and protective measures are

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being undertaken for those who are required to travel. At this time, work conducted by EERC employees is anticipated to progress with minimal disruption. Challenges posed by economic variability will be met with open discussion between the EERC, the NDIC project manager, and BPOP partners to identify solutions. The EERC is monitoring developments across the nation and abroad to minimize risks, achieve project goals, and ensure the success of our partners and clients.

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BAKKEN PRODUCTION OPTIMIZATION PROGRAM

INTRODUCTION

The Bakken Production Optimization Program (BPOP) was established to facilitate Bakken petroleum system (BPS) 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.

The goals of BPOP are to:

- Provide the state and industry with science-based insight to maintain the economic and environmental sustainability of the Bakken play in North Dakota.
- Provide stakeholders with the knowledge needed to plan and implement innovative development strategies that will take the Bakken into the next decade and help achieve the Governor's goal of 2 million barrels per day of North Dakota oil production.

The anticipated ongoing outputs of BPOP are 1) increased well productivity and economic output of North Dakota's oil and gas resources; 2) decreased environmental impacts of wellsite operations; and 3) guidance to stakeholders regarding optimal, prudent development of North Dakota's Bakken petroleum resources.

ACCOMPLISHMENTS DURING REPORTING PERIOD

Several activities performed under BPOP 2.0 had continued interest from partners. Efforts continued this quarter to advance the research activities.

A journal article entitled "Comparison of CO_2 and Produced Gas Hydrocarbons to Recover Crude Oil from Williston Basin Shale and Mudrock Cores at 10.3, 17.2, and 34.5 MPa and 110 °C" was published by *Energy & Fuels* on March 31, 2021. The material is based on work performed under BPOP and the matching effort under the U.S. Department of Energy (DOE). A link to the article is available on the BPOP website.

Process Optimization

Processing produced fluids from the well to market, although simple when described in a basic flow diagram, is complicated by dynamic and variable production rates and fluids composition, extreme climate, complex business and financial models, and evolving regulations.

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By working with BPOP partners, the EERC can systematically analyze trends by assimilating data and information from multiple operators, assist in defining the challenges to improved process efficiency, and identify technological and operational solutions through process modeling and system design. Through BPOP, the EERC will continue to serve existing and new North Dakota Petroleum Council (NDPC) task force groups established to address challenges such as flaring, vapor pressure compliance, and emissions.

With input from partners, the EERC is working on a systems-level assessment of wellsite emissions resulting from both combustion sources and hydrocarbon vapor management. The goal is to develop a data-based prioritization of emission sources, characterization of those emissions, and systems-level analysis of mitigation strategies. During this reporting period, the EERC developed a wellsite model to assess tank vapor-phase behavior. Using Aspen HYSYS software, the EERC developed a typical wellsite process and, using a representative treater oil composition, estimated the composition of gas and oil streams present when pressurized oil exits the treater and enters an atmospheric pressure tank. The simulated tank vapor composition was then used to assess natural gas liquid (NGL) recovery potential over a range of pressures. This analysis was then conducted with varying levels of dilution with air to assess the impact of oxygen and nitrogen on the phase behavior of tank vapor NGLs. Results of this study have been compiled, analyzed, and summarized in a topical report, which is under review.

Lease operating expense (LOE) data were compiled, and an initial evaluation of opportunities for cost reduction was performed. A detailed analysis of the operations impacting operating expenses will be conducted to identify opportunities for cost reduction and form the basis for subsequent BPOP projects.

Fluids Characterization

The optimization of crude oil production in North Dakota requires an accurate understanding of the fluids being produced. Crude oil, associated gas, and produced water are complex mixtures, and their chemical and physical properties can vary geographically and also over the life of a single well. Over the first 6 years of BPOP, extensive fluids data have been acquired and a database of fluids information has been created. The EERC will continue to maintain and expand this valuable database and coordinate data gathering, sampling, and analysis activities to support all the program tasks.

The EERC research team has improved on oil-fingerprinting analytical techniques that are utilized by the oil and gas and analytical laboratory industries to better understand drainage mechanisms. This information will be utilized in an associated task effort to facilitate activities to enhance targeted oil recovery. Various groups of compounds have been identified using gas chromatography–mass spectrometry (GC–MS), and a retention time database for all individual hydrocarbons present in Bakken oil has been created. Several improvements to conventional fingerprinting and geochemical characterization methods were performed by expanding on the use of complex indicator compounds such as diamondoids and various polyaromatics. Older GC–MS files were reprocessed, and key geochemical indicators were developed for the Bakken source rocks and fluids. Compositional variations indicated differences in lithologies and maturity levels in various wells and Upper and Lower Bakken shales. Reliable indicators for the

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fingerprinting and oil–source correlations were identified based on aromatic polycyclic compounds and biomarkers. The research team has begun an effort to standardize biomarker analysis and reporting.

Complementary to hydrocarbon-fingerprinting efforts, in-house inductively coupled plasma (ICP)–MS instrumentation and analytical methods were modified for the purpose of conducting produced water-fingerprinting techniques using strontium (Sr) isotope analysis. Historical water chemistry data and information generated by the EERC laboratory will be used to identify compositional differences in water samples produced from various reservoirs. The fingerprinting technique was marginally improved by adding a sample preparation method. Resins were applied to remove rubidium from the solution of water samples from several formations, including the Middle Bakken, Three Forks, and Birdbear. Additional Sr measurements were performed on water samples to test the method's ability to discriminate water samples produced from different reservoirs.

Well Completion Optimization

Based on review of existing literature and results from initial work, EERC staff decided that completion optimization calculations can be improved if geologic and reservoir information is integrated into the statistical model. Available in-house and mappable geologic and reservoir data sets were enriched with fluid compositional data, and this information package was finalized for further cluster analysis. An interactive cluster calculator was created to divide the Bakken play into several subareas or clusters.

The research team completed well allocation calculations per DSU (drill spacing unit) using an improved algorithm. A new workflow added approximately 700 wells to the data set, which will be used in further completion optimization calculations on the DSU level. An analysis of the 2020 shut-in wells demonstrated various operators' strategies during the period of low oil demand. An important observation was made for well performance before and after the shut-in period.

Additional work was completed to clean and expand the data set used in the BPS cluster calculator. The results of cluster analysis were used to run completion optimization calculations per cluster. New calculations demonstrated a significant improvement in data-mining model strength in three out of four clusters of the BPS. The results suggested further improvement of the statistical model can be achieved by running calculations for a higher number of clusters.

Enhanced Oil Recovery

Two BPOP partner companies (Liberty Resources [Liberty] and Oasis Petroleum Inc. [Oasis]) continue to develop plans for future enhanced oil recovery (EOR) pilot tests, and EERC personnel conducted activities to support those planning efforts.

A Computer Modelling Group Ltd. (CMG) simulation model of a single completion stage of the Liberty East Nesson pilot area was history-matched, and the performances of the EOR scenarios of huff 'n' puff rich gas injection and coinjection of rich gas and water were evaluated.

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Sensitivity analyses with various parameters were performed to understand the potential impact of fluid injection on EOR performance for the East Nesson pilot, including gas and water injection rates; injection, soaking, and production times; and the effect of hysteresis on the gas injected. This information is informing Bakken EOR pilot design.

Application/injection of surfactant integrated with the coinjection of rich gas and water is being considered as a method of further improving EOR performance as part of the East Nesson EOR pilot. An investigation of the potential of surfactant to improve the EOR performance of coinjection of rich gas and water at the East Nesson site has been initiated by the EERC. Results will be used to inform a technical cost/benefit decision for incorporating surfactant injection.

A literature review of surfactant studies was conducted to understand the potential for surfactants to improve oil recovery in unconventional reservoirs. Results confirmed that the application of surfactants for improving oil recovery in tight, hot, unconventional oil and gas plays is largely empirical, with the mechanisms not well-understood through rigorous laboratory, field, and modeling needed to select and design surfactant programs and forecast performance.

Initial modeling and simulation of surfactant injection was conducted using the literature data available, and a sensitivity analysis with surfactant concentration was also performed. Initial results showed sufficient potential to proceed with a site-specific evaluation.

The EERC in collaboration with Liberty Resources formed an industry-leading team of experts to evaluate, select, design, and forecast performance of a surfactant program for the East Nesson pilot. The results of this endeavor will be used to inform a decision to incorporate surfactant as part of the water injection schedule for the East Nesson EOR pilot. In addition to the leading EERC, Liberty Resources, and Liberty Oilfield Services expertise, the collaboration includes Dr. David Schechter of Texas A&M University (TAMU), who provides specialized industry-leading laboratory experience in the application of surfactants to unconventional tight oil plays and CMG and an in-house modeling and software development engineering team who support state-of-the-art surfactant and fracture modeling and unconventional reservoir simulation. Biweekly meetings have been held with Liberty, CMG, and TAMU to evaluate progress and determine next steps on the East Nesson project.

Oasis contributed in-kind cost share to the program in the form of core and PVT (pressure, volume, and temperature) analyses data. Samples of Bakken and Three Forks rock collected from Oasis wells were used in rich gas extraction experiments conducted at the EERC. Efforts were initiated to integrate the results of the extraction experiments with the Oasis-provided PVT data in an effort to quantitatively describe the mechanisms controlling rich gas permeation into and mobilization of oil out of the shale and nonshale matrix of the BPS. This information will be used to better understand primary production in the Bakken and to support evaluation of rich-gas EOR opportunities. The analysis generated by the EERC will be shared with NDIC and BPOP 3.0 partners, who will have an obligation to keep such analyses (and any other data and/or information such partners are rightfully entitled to receive in connection with BPOP 3.0) confidential. Any derivative products developed by the EERC will be provided to the BPOP partners for a period of 24 months following Oasis approval, after which the derivative products will be provided to NDIC.

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Program Management and Development

The project team continued to engage partners to guide the activities to meet their needs.

The EERC is operational and open for business. Personnel who are not essential for on-site operations have transitioned to working from home. Essential project, laboratory, and field-based activities are proceeding with the incorporation of Centers for Disease Control and Prevention (CDC), the state of North Dakota, and University of North Dakota guidelines associated with COVID-19, and mitigation measures have been implemented.

In collaboration with project partners, the EERC is continually assessing potential impacts to project activities resulting from COVID-19 and/or the U.S. economic situation.

In the event that any potential impacts to reporting, scope of work, schedule, or cost are identified, they will be discussed and addressed in cooperation with NDIC.

PARTNERSHIP AND FINANCIAL INFORMATION

The original budget as proposed to NDIC OGRP is $12,000,000, as shown in Table 1.

Table 1. BPOP – Original Budget

Sponsors	Budget
NDIC Share – Cash	$6,000,000
Industry Share – Cash	$500,000
Liberty – In-Kind	$4,000,000
DOE – Cash	$1,500,000
Total	**$12,000,000**

Table 2 presents a revised expected budget based on the allocation of cost share secured by the EERC. Expenses to date are also listed in Table 2.

Table 2. BPOP – Expected Budget and Expenses to Date

Sponsors	Expected Budget	Actual Expenses as of 3/31/2021	Balance
NDIC Share – Cash	$6,000,000	$1,366,022	$4,633,978
Industry Share – Cash	$300,000	$134,274	$165,726
Oasis – In-Kind	$1,577,000	$1,577,000	$0
DOE – Cash	$1,500,000	$679,241	$820,759
Liberty Resources – In-Kind	$810,000	$0	$810,000
Industry - TBD	$1,813,000	$0	$1,813,000
Total	**$12,000,000**	**$3,756,537**	**$8,243,463**

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FUTURE ACTIVITIES

Topical reports will be submitted by April 30, 2021, under the primary research categories of subsurface operations and infrastructure investigations, subsurface investigations, and EOR. An annual presentation will be provided to OGRC at the next scheduled meeting.

Process Optimization

Activities next quarter will include continued computational simulations to evaluate operating conditions and system designs capable of reducing emissions without negatively impacting safety, crude oil properties, or gas sales. The EERC will continue to engage BPOP partners to solicit input on ways EERC staff and BPOP resources can be applied to meet their needs. Additionally, analysis of LOE data will continue, targeting opportunities to reduce the cost of Bakken oil production. Specific project scope will be developed for engineering studies, simulations, and field studies that can address LOE reduction.

Fluids Characterization

Upcoming activities include continued engagement with industry partners to understand their 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 are expected to occur in spring 2021, with results supporting the ongoing compositional evaluations of each fluid, supporting temporal evaluations, and enhancing the size and usefulness of the database to the various BPOP research efforts. This task will also support new and developing field-based EOR and gas storage projects to be conducted by the EERC and specific BPOP partners.

Efforts will continue to apply the oil-fingerprinting analytical techniques and expand the applications to benefit current and future Bakken system research efforts.

Historical water chemistry data and information generated by the EERC laboratory will continue to be compiled and will be used to identify compositional differences in water samples produced from various reservoirs. Analytical efforts to evaluate both hydrocarbon and produced water phases of Bakken production will continue to be performed.

Well Completion Optimization

The well completion optimization work will build on the existing machine learning analyses previously conducted on the BPOP analytics database. Additional data about geology and fluids (oil, gas, and water) for a subset of the wells will be incorporated into a revised database. These additional features will be used to subdivide the BPS into several clusters or subareas using one or more clustering algorithms (e.g., k-means clustering). The reservoir properties may be more similar within each cluster, which will reduce the within-group variance and thereby reduce potential confounding factors in the analysis. Further optimization calculations will be performed either by individual cluster/subarea or for the entire BPS, with the cluster information included in the predictive model. Optimization calculations will be performed on both individual wells and DSUs.

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Competitor analyses of the top ten operators will focus on both 2019 growth and 2020 optimization strategies. Wells with the highest production levels (top 5%) will be investigated. Their location, completion details, and geologic settings will be compared to the rest of Bakken wells.

Enhanced Oil Recovery

The East Nesson project team is updating the simulation model to improve performance for history matching and evaluating surfactant performance in tight fractured systems. The team will conduct a subsequent round of simulation with the refined modeling approach to inform pilot design and a decision whether to incorporate surfactant as part of the water injection component of the East Nesson EOR pilot. The more recent production data that became available for use will also be incorporated into the history-matching process to calibrate the simulation model.

The EOR pilot at the Liberty East Nesson site is tentatively scheduled to begin in August 2021 and is expected to be conducted over an approximate 4-month period based on the provisional design. Permitting through the NDIC Department of Mineral Resources is expected to occur in the coming quarter.

The EERC will continue to work with Oasis technical staff to evaluate and integrate experimental data with modeling to improve understanding of mechanisms controlling hydrocarbon interactions and mobility in Bakken rocks under reservoir conditions.

Program Management and Development

Additional research activity ideas for the next project year will be discussed with project partners.