**Contract No. G-040-080**
**"Bakken Production Optimization Program - 2.0"**
Submitted by: Energy & Environmental Research Center
Principal Investigator: John A. Harju

## PARTICIPANTS

| **Sponsor** | **Cost Share** |
|---|---|
| Marathon Oil Company | $ 7,280,000 (In-kind) |
| North Dakota Industrial Commission/OGRC Funding | $ 6,000,000 (cash) |
| Total Project Cost | $13,280,000 |

Project Schedule – 3 years
Contract Date – December 14, 2016
Start Date – November 1, 2016
Final Report: November 1, 2019

Project Deliverables:

| | |
|---|---|
| Quarterly Report: | January 15, 2017 ✓ |
| Quarterly Report: | April 15, 2017 ✓ |
| Quarterly Report: | July 15, 2017 ✓ |
| Annual Report: | October 15, 2017 ✓ |
| Quarterly Report: | January 15, 2018 ✓ |
| Quarterly Report: | April 15, 2018 ✓ |
| Quarterly Report: | July 15, 2018 ✓ |
| Annual Report: | October 15, 2018 ✓ |
| Quarterly Report: | January 15, 2019 |
| Quarterly Report: | April 15, 2019 |
| Quarterly Report: | July 15, 2019 |
| Final Report: | November 1, 2019 |

**OBJECTIVE/STATEMENT OF WORK:**
The EERC proposes a 3-year extension of the existing and highly successful Bakken Production Optimization Program (BPOP) to continue addressing emerging threats and issues to petroleum production in North Dakota. The goal of the project is to employ a "system of systems" approach to 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.

Some of the activities that would be considered under BPOP 2.0 include Rich-Gas EOR; Refrac Optimization; Produced Fluid Characterization; Fugitive Emissions; Hydrocarbon Sampling; Reservoir Performance Modeling; Water Injection Reservoir Assessments; Facility Process Modeling; Aromatic/Aliphatic Study; Site Equipment Survey; Regulatory Review; Assessment of Stormwater Management Practices; Saltwater Disposal Capacity Modeling; and High-Value Minerals in Produced Fluids.

Expected results include increased well productivity and economic output of North Dakota's oil and gas resources, decreased environmental impacts of wellsite operations, and 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.

**STATUS**
Contract has been executed.

**January 13, 2017 - Quarterly Report received** - a copy is posted on the website. It states in part:

- Contract was signed on December 13, 2016. This permitted task engagement in January.
- Seven tasks were identified: Enhanced Oil Recovery; Refracturing Optimization; Produced Fluid Characterization; Reservoir Performance Modeling; Water Injection Reservoir Assessment; Facility Process Optimization; Aromatic/Aliphatic Study.
- A dynamic modeling package was purchased to facilitate the work under the Facility Process Optimization Task.
- EERC staff worked with a potential new industry program partner in December to determine a possible collaboration and fit within BPOP 2.0. This potential partner has strong interest in rich gas and/or ethane-based enhanced oil recovery (EOR). This partner also wishes to begin injection by June, necessitating a rapid integration with BPOP.

**April 13, 2017 - Quarterly Report Received** - a copy is posted on the website. It states in part:

**Enhanced Oil Recovery Task**

- Obtained rock samples from the Lower and Upper Shales and the Middle Bakken laminated zones from three wells located in thermally immature, moderate maturity, and mature areas. These rock cores were extracted with both $CO_2$ and ethane at 5000 psi for 24 hours. The EERC then analyzed the extracts to determine the relative abilities of $CO_2$ and ethane to recovery both light and heavy hydrocarbons from the Shales and Middle Bakken core samples.
- Began experiments to compare the quantity of crude oil and the ability to mobilize both light and heavy hydrocarbons using ethane vs. $CO_2$ in the "miscible" phase formed at reservoir conditions.
- Completed preliminary modeling activities to evaluate compression requirements to utilize wellhead gas as the stimulation fluid for the Liberty Resources enhanced oil recovery (EOR) demonstration. The EERC is now evaluating gas temperature, pressure, and composition to achieve a range of desired well bottomhole pressures.
- Liberty Resources provided the EERC with extensive data sets related to reservoir characterization, reservoir production, surface operations, and site infrastructure.
- Liberty Resources–EERC meetings to collaborate on the rich gas EOR pilot:
    - March 23 at the Stomping Horse facility. Toured the facility and developed an intimate understanding of the site's operational and infrastructure components.
    - March 21 in Bismarck with personnel from the North Dakota Department of Mineral Resources (Oil & Gas Division). Discussed the processes for injection well permitting and unitization as they relate to the planned rich gas EOR pilot.
    - March 20–21 in Denver. Met with Liberty's geoscience team to obtain relevant site characterization data in support of developing a static geomodel of the Stomping Horse area.
    - March 16 at the Stomping Horse facility. Collected baseline oil and water samples to support planned laboratory studies in support of the rich gas EOR pilot testing.
    - February 27–28 in Grand Forks. Discussed potential rich gas EOR pilot testing at the Stomping Horse location in Williams County.

**Produced Fluid Characterization Task**

- Coordinated with EERC's BPOP 2.0 program leads to identify key information and data needs to support ongoing and planned research efforts.
- Created GIS-based maps using publicly available data to identify and evaluate trends in chemical and physical characteristics occurring within the Williston Basin Bakken Formation.

This information was used to identify existing data gaps and prioritize data needs and sample collection activities to help create a robust database of pertinent information to support industry and BPOP program research efforts.

- Created a fact sheet on BPOP 2.0 Bakken fluids characterization activities and data/sample collection needs. This fact sheet will be utilized to solicit cooperative efforts with industry partners. The fact sheet will also be useful in outreach efforts to disseminate information collected by BPOP 2.0 to industry and to the public.
- Developed partnerships with key industry partners to obtain access to confidential characterization data and for fluids sample collection access and support.
- Coordinated data collection and sample acquisitions among various program partners, then initiated analysis of collected fluids.
- EERC staff met with Liberty Resources staff to collect fluid samples from several Stomping Horse unit wells. The samples will be analyzed at the EERC to better understand the composition and origin of the fluids produced from Liberty's Stomping Horse development unit.

**Reservoir Performance Modeling Task**

- Reviewed published literature on the subject of optimal completion techniques for the Bakken.
- Completed a significant expansion of the reservoir performance database developed during the BPOP 1.0 preliminary study. The database has been expanded to 400 wells, compared to the 200 wells used in the preliminary study. The enlarged well number allows for better definition of areas of interest such as a specific field or geologically defined area. Additional geologic and well information as well as completion operations have been added. Cumulative production indicators at specific times are also added for comparison.
- Completed a decline curve analysis for the wells. Production forecast updates made for the wells that were used in the preliminary study showed good agreement with the original forecasts.

**Water Injection Reservoir Assessment Task**

- Improved the current reservoir model for the Inyan Kara Formation with an updated geologic model with modified reservoir permeability and porosity values.
    - A total of 103 saltwater disposal (SWD) wells were considered in the study region and built into the reservoir model.
    - Simulated a period spanning the years 1961 to 2020 (with history data to January 2016). 23 SWD wells were used in constructing the geologic model.
    - The first simulation case was performed after importing the field history injection rate data of all of the SWD wells.
    - As would be expected, the history of wellhead pressure for the 23 modeled wells was better matched than that of the other 80 SWD wells.
- Compared the simulated and field history wellhead pressure data to improve the history match of the reservoir model on a broad scale. Where necessary, adjustments were made to the reservoir permeability surrounding wells located in a particular area. This work is ongoing. Upon completing the necessary adjustments, additional simulations will be performed, and history matching will focus on refining the permeability values around each wellbore until an acceptable history match is achieved.

**Facility Process Optimization Task**

- EERC staff traveled to Houston on January 24–27, 2017, to attend a training session hosted by Virtual Materials Group. The training focused on dynamic simulations using our recently acquired VMGSim™ modeling software being used to assess non-steady-state operations on fugitive emissions, gas injection for EOR, and crude oil quality.
- Installed dynamic modeling software purchased in December. EERC staff then developed a facilities model and wellbore model for use in subsequent simulation tasks.
- Conducted process modeling for wellsite production operations typical of those found in the Bakken to analyze the impact of various operating parameters on fugitive emissions from storage tanks. A paper on the modeling exercise and its results was posted to the EERC's Web site at www.undeerc.org/Bakken/pdfs/CLM-BPOP%20Process%20ModBrief%20R4- Mar17.pdf.

**Aromatic/Aliphatic Study Task**

- Obtained crude oil samples from the Three Forks and Middle Bakken Formations from an operator in northeast Williams County. The operator also agreed to collect crude oil samples for aromatic/aliphatic analyses from the beginning of crude oil production into the decline curve for two wells being brought online in the next few months. These samples will be used in an attempt to determine the relative contribution of the Upper and Lower Shales to crude production.
- Completed and tested a quantitative analytical method to accurately measure aromatic/aliphatic concentrations in both rock and crude oil samples. Also began analyses of approximately 40 rock extract samples.

**Environmental Support Task**

- Attended a quarterly Environmental Peer Group meeting on February 15, 2017, in Watford City in support of a vast array of environmental focal points being pursued by BPOP 1.0 member companies.
- Provided content for an education day focused on activities of the North Dakota Petroleum Council's Hydrocarbon Task Force. The content will inform on North Dakota crude oil quality issues and how hydrocarbon spills are remediated.

**Program Management and Development**

- Obtained verbal commitments for BPOP 2.0 membership from Oasis and ConocoPhillips, joining Liberty Resources and Marathon Oil as program partners.
- Continuing membership dialogue with Continental Resources, XTO Energy, Hess Corporation, Statoil, PetroHunt, Newfield Exploration, WPX Energy, and Whiting Oil & Gas. Additionally, membership opportunities will be sought in the coming quarter from strategically important service companies.
- Soliciting potential kickoff dates for May in Houston, and soliciting potential hosting by a member company.
- Provided testimony to the North Dakota House Energy and Natural Resources Committee on HB1257 (relating to approval requirements for unitization plans) in Bismarck, North Dakota, on February 3, 2017. HB1257 was passed by the ND Legislature and signed into law by Governor Burgum. This bill lowers the threshold for unitization approval to 55%.
- Attended the SPE Canada Unconventional Resources Conference in Calgary, Alberta, on February 14–16, 2017. Participated in a full-day workshop entitled "Introduction to Re-Fracturing Fundamentals."
- Met with Rice University leaders regarding a newly developed memorandum of understanding

(MOU). While there, EERC and Rice staff discussed potential collaboration on advanced reservoir characterization technologies (nuclear magnetic resonance), produced water treatment, and nanotechnology applications.

**July 13, 2017 - Quarterly Report received** - a copy is posted on the website. It states in part:

**Enhanced Oil Recovery Task**

- Continued rock extraction experiments to compare the quantity of crude oil and the ability to mobilize both light and heavy hydrocarbons using rich gas components vs. $CO_2$ in the "miscible" phase formed at reservoir conditions.
- Studies of minimum miscibility pressure (MMP) using oil samples from the Stomping Horse area were conducted. Gases that were tested included ethane, methane, and propane and mixtures of those gases.
- Evaluated compression options for rich gas injection operations. All options identified at this time require the manufacturing of customized units, which require minimum 36-week lead times and substantial capital investment.
- Liberty Resources provided the EERC with extensive data sets related to reservoir characterization, reservoir production, surface operations, and site infrastructure.
- A geologic model of the Stomping Horse area was developed.
- A proposal was submitted to the U.S. Department of Energy (DOE) for funding to support a rich gas enhanced oil recovery (EOR) pilot project that will be conducted in close collaboration with Liberty Resources. The proposal was approved for funding through the EERC's Joint Cooperative Agreement with DOE at the end of June.
- Liberty Resources–EERC meetings to collaborate on the rich gas EOR pilot:
  - May 17 in Houston at BPOP 2.0 Kickoff Meeting. Liberty provided an update on its efforts to identify compression options and discussed its plans for the rich gas EOR pilot.
  - May 21 in Denver. EERC and Liberty personnel had a working session to discuss direction and scope of the modeling efforts.
  - June 7 in Grand Forks. Discussed modeling efforts to support the planned rich gas EOR pilot. Topics of discussion included progress to date on the development of the Stomping Horse geologic model, next steps for preparation of that model for simulations, potential injection/production scenarios that will be simulated, and the time line for modeling activities.

**Produced Fluid Characterization Task**

- Coordinated with BPOP program leads to identify key information and data needs to support ongoing and planned research efforts.
- Developed partnerships with key industry partners to obtain access for fluid sample collection.
- Conducted sampling activities for both produced water and crude oil from 18 wells in the northern portion of the Williston Basin owned by Liberty Resources, Inc. This activity required EERC staff travel to the Tioga area on April 26–27.
- Initiated analytical activities, with results being used to support program objectives.

**Reservoir Performance Modeling Task**

- Prepared and delivered a two-part presentation at BPOP 2.0 kickoff meeting covering

preliminary results of decline curve analysis for the 400 well database and multivariate analysis to identify production drivers for Bakken and Three Forks completions.

- Based on comments from the BPOP 2.0 kickoff meeting, extracted data from the NDIC Web site to estimate well spacing for each of the 400 wells at the time of their completion. Preliminary results indicate that long-term well performance is affected by well spacing and the timing of when the well was drilled in its DSU (drill spacing unit).
- Currently compiling a draft of the topical report for this task.
- EERC staff traveled to Golden, Colorado, on May 23–25, 2017, to attend an International Reservoir Technologies, Inc., informational meeting. This was in direct support to the reservoir performance modeling task.

**Water Injection Reservoir Assessment Task**

- Completed history-matching simulations for the 103 saltwater disposal (SWD) wells included in the Inyan Kara reservoir model.
- Incorporated field wellhead pressure (WHP) data into the model for each of 103 SWD wells and used for comparison to the model-predicted WHP to perform the history matching. Adjustments were made to the reservoir permeability over the entire model area as well as the localized areas surrounding individual SWD wells. Of the 103 wells, 97 were successfully history-matched.
- Finalized Inyan Kara reservoir model simulation cases.
- Planned four predictive simulation cases:
    - ♦ One case will simulate continued injection of all the SWD wells in the modeled area at the last recorded injection rates until the year 2050 to test the potential injection capacity of the Inyan Kara Formation.
    - ♦ Three cases will use the current operating wells (93 wells), with predictive simulations based on the current injection rate, maximum allowable injection rate, and maximum allowable injection pressure, respectively.
- Information on the maximum allowable injection rate and pressure for each well was compiled from the well files for each of the 103 SWD wells.

**Facility Process Optimization Task**

- Conducted process modeling simulations to evaluate the effect of treater operations and atmospheric conditions on crude oil quality. Preliminary results were summarized and shared with BPOP members, and work is ongoing to gather operational data to enable model validation.
- Hosted a meeting of select North Dakota operators in Williston, North Dakota, to discuss the various design and operational factors influencing crude oil volatility. The goal of the meeting was to discuss options and assess the need for a comprehensive process modeling and field validation effort geared toward improving Basin-wide compliance with crude oil volatility specifications. This activity required EERC staff to travel to Williston on May 9–10, 2017.
- Posted a paper summarizing EERC modeling activities assessing the impacts of process operations on tank emissions to the EERC's Web site at www.undeerc.org/Bakken/pdfs/CLM-BPOP%20Process%20ModBrief%20R4-Mar17.pdf.

**Aromatic/Aliphatic Study Task**

- Obtained and analyzed crude oil samples for aromatic/aliphatic content from five sets of co-located pairs of wells from Williams, Burke, and Divide Counties. In each pair, one well produced from the Three Forks and one well produced from the Middle Bakken:
  - For three of the wells, the Three Forks and Middle Bakken crude oils showed similar, but fairly high, total aromatic/aliphatic ratios (ca. 0.25 to 0.35).
  - For two of the wells, the Three Forks crude oils were also in the high 0.25 to 0.35 range, but the Middle Bakken crude oils had low ratios of only ca. 0.10.
  - These results strongly indicate that all of the Three Forks crude oils and three of the five Middle Bakken crude oils had significant contributions from adjacent shales (because of their relatively high ratios).
  - In contrast, the two Middle Bakken crude oils with low aromatic/aliphatic ratios appear to have little or no production from the adjacent shales.
- Applied the newly developed analytical method for quantitating aromatic and aliphatic hydrocarbon contents to 57 different samples (ranging from Three Forks to Lower, Middle, and Upper Bakken samples) obtained from nine wells. Final data reduction is under way, and additional core samples are in the process of being collected, extracted, and analyzed.
- Performed initial attempts to remove diesel cutting fluids from drill cuttings in order to allow the rock drill cuttings to be used for aromatic/aliphatic analyses. Mild solvent extractions as well as simple evaporation was used. Unfortunately, these approaches were not successful in removing the interferences from the diesel cutting fluids. The operator of these wells has promised a sample of the diesel cutting fluid, which will be used in an attempt to better "clean" the diesel fluid from drill cuttings and allow aromatic/aliphatic analyses to be performed.

**Environmental Support Task**

- EERC staff collaborated with North Dakota Petroleum Council (NDPC) members, North Dakota Department of Health (NDDH) staff, and representatives of the Northwest Landowner's Association (NWLA) as plans were formulated to promote and execute a series of educational events focused on hydrocarbon spills and hydrocarbon spills remediation.
  - The first education day event is scheduled for July 17, 2017. This first event will focus on the chemistry of produced liquid hydrocarbons, analytical methods employed to characterize produced liquid hydrocarbons, and an introduction to a risk-based approach to remediating hydrocarbon spills.
  - Subsequent education day meetings will cover:
    - Livestock and crop considerations.
    - Types of water and uses—considerations in risk-based approach.
    - A comparison of current regulations across North Dakota and other states and the science behind their employment.

**Program Management and Development**

- EERC staff traveled to Houston on May 16–18, 2017, to lead a BPOP 2.0 kickoff meeting. The meeting was hosted at Oasis Petroleum offices. EERC staff presented on several aspects of anticipated and ongoing BPOP 2.0 activities to attending and prospective members. The

program wishes to formally and publicly thank Oasis for its willingness to host this meeting. Copies of the presentations made during this meeting have been made available on the Members-Only Web site.

- New program members received during this reporting quarter include Petro-Hunt, Hess Corporation, ConocoPhillips, and Oasis Petroleum. They join existing members: NDIC, Liberty Resources, and Marathon Oil.
- A proposal was submitted to DOE for funding to support a rich gas EOR pilot project that will be conducted in close collaboration with Liberty Resources. The proposal was approved for funding through the EERC's Joint Cooperative Agreement with DOE at the end of June.
- EERC staff traveled to Bismarck on May 20–22, 2017, to participate in the meeting between Liberty Resources and the NDIC's Oil & Gas Division regarding permitting of a rich gas injection well for EOR purposes.
- Several discussions were held with BPOP members (and potential members) to discuss the feasibility of high-value material recovery from Bakken produced water. Several members are interested specifically in the recovery of lithium, which occurs at elevated concentrations in several produced water samples analyzed by the EERC.
- A summary of BPOP oil and water decline curve analysis work was presented at the Williston Basin Petroleum Conference in Regina, Saskatchewan, on May 4, 2017.
- EERC staff traveled to Denver on June 12–15, 2017, to participate in the NDPC Executive Committee meeting.

**October 13, 2017 - Annual/Quarterly Report received** - a copy of the report is posted on the website. The Annual report states in part:

**ANNUAL REPORT**

**Enhanced Oil Recovery Task (Liberty Resources' Stomping Horse Project)**

***Expansion of Enhanced Oil Recovery Effort with Significant DOE Funding***

The U.S. Department of Energy (DOE) has awarded $2,000,000, with $1,000,000 committed to date to support EERC efforts under the existing rich gas enhanced oil recovery (EOR) pilot project that will be conducted in close collaboration with Liberty Resources. The goals of the work to be conducted using the DOE funds include the following:

- Determine the effectiveness of cyclic multiwell huff and puff (CMWHP) as an injection/production scheme that can maintain conformance of the working fluid within the reservoir.
- Determine the ability of various rich gas mixtures 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.

### *Major Milestone for Liberty Resources EOR Pilot Operation*

On September 21, 2017, Liberty Resources presented its application to NDIC to gain temporary authority to use Leon-Gohrick drill spacing unit (DSU) wells as injection wells for an EOR pilot operation. The application is under consideration by NDIC, and it is anticipated that a decision may be rendered in late 2017. It is anticipated that the pilot test will be initiated no later than early to mid-2018.

## Refracturing Optimization Task

### *Refracturing (Refrac) Optimization Study Recently Engaged*

The EERC initiated a case study of the first well in Whiting Corporation's Refrac Pilot Project in which production performance was assessed. The response of the well to the refrac operation seems to be positive, with an increased oil production rate and contacting new additional reservoir volume following the operation. In parallel, the EERC began developing suggested guidelines for candidate selection in unconventional reservoirs.

## Produced Fluid Characterization Task

### *Year-Long Collection and Analysis of Samples from Across the Basin, Across All Producers*

Throughout the year, the EERC has collected crude and produced water samples from numerous wells across the basin and across many producing companies. Sampling will be repeated periodically throughout the first 12 to 18 months of production to provide a temporal aspect to well fluid composition. The EERC also issued formal solicitations to key industry partners for available fluid compositional data and access to future sample collection and analysis activities. The result of this effort will be an unprecedented database of Williston Basin produced fluid composition and insights on variation across geography, geology, and operational practices.

## Reservoir Performance Modeling Task

### *Novel Analysis of Bakken Petroleum System Reservoir Performance Completed*

Technical work on the decline curve analysis for the 400-well database and multivariate analysis to identify production drivers for the Bakken petroleum system has been completed. A draft of the topical report for this task has been completed, and it is under an internal technical review. The analysis indicates how specific drilling and completion practices may affect long- term oil production.

## Water Injection Reservoir Assessment Task

### *Significant Remaining Capacity Estimated for North Dakota's Largest Water Injection Reservoir*

The EERC injection simulations have led the EERC to predict that, with anticipated injection volumes, significant Inyan Kara Formation disposal capacity of approximately 4 to 5 billion barrels (5–6 times the current cumulative water injected) will exist at the end of the year 2050. Pressure analyses also suggest that a large portion (e.g., south half) of the simulated area will be capable of additional pressure increase even after more than 30 years of future injection, although additional disposal wells would be required in those areas. Therefore, the total injection capacity of the simulated area should be larger than the predicted capacity, as estimated by simulating only the existing wells. The ability to economically access this additional capacity has not been addressed by this study.

**Facility Process Optimization Task**

***EERC Surface Facility Process Modeling Effort Engaged to Improve Operations Efficiency and Identify Factors Influencing Crude Oil Vapor Pressure (volatility)***

The EERC has completed an initial analysis of a large set of operational data and crude oil vapor pressure data to identify trends and factors influencing crude oil vapor pressure. Results from this analysis were summarized and shared with the North Dakota Petroleum Council (NDPC) Technical Solutions Group in Dickinson, North Dakota, on September 7, 2017. Summarized and presented an overview of data analysis and modeling activities regarding surface facility design and operations strategies to achieve crude oil vapor pressure targets.

**Aromatic/Aliphatic Study Task**

***EERC Developing New Indicators of Oil Source Rock***

Work continues on developing an approach using aromatic/aliphatic ratios to identify the source rock of crude oil produced in the Bakken petroleum system. Promising results achieved to date may lead to a new approach to identifying the source of the crude oil, regardless of the age of the sample or how the sample was obtained. This, in turn, may lead to greater certainty on estimates of oil in place in the Bakken petroleum system.

**Environmental Support Task**

***EERC Leading Joint NDPC–North Dakota Department of Health (NDDH)–BPOP Educational Outreach Effort***

The first of several education day events was held in Bismarck, North Dakota, on July 17, 2017. EERC staff presented on the chemistry of unrefined hydrocarbons (crude oil), analytical methods employed to characterize produced liquid hydrocarbons, and an introduction to a risk- based approach to remediating hydrocarbon spills.

**Program Management**

The EERC continues to seek support for this program, and to date, additional cost share has been secured from the following Bakken producers: Petro-Hunt, Hess Corporation, ConocoPhillips, Oasis Petroleum, WPX Energy, Marathon Oil, and Liberty Resources. Statoil has notified us of its intent to join and has requested an invoice. Payment is anticipated in October 2017. 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 Resources is providing in-kind contributions that support this programmatic scope.

**October 13, 2017 - The Quarterly Report** states in part:

**Enhanced Oil Recovery Task**

- $1,000,000 of funding from the U.S. Department of Energy (DOE) was set up (while an additional $1,000,000 is anticipated) to support EERC efforts under the rich gas enhanced oil recovery (EOR) pilot project that will be conducted in close collaboration with Liberty Resources. The goals of the work to be conducted using the DOE funds, which was initiated during the past quarter, include the following:
  - Determine the effectiveness of CMWHP as an injection/production scheme that can maintain conformance of the working fluid within the reservoir.

  - Determine the ability of various rich gas mixtures to mobilize oil in Bakken petroleum system reservoir rocks and shales.
  - Determine the 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 through the use of 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.

- Activities to accomplish the BPOP 2.0 goals for the pilot project stated above were initiated this quarter. Specific activities include the following:
  - Laboratory-based examinations of rich gas interactions with reservoir fluids and tight rocks (including oil-rich shales) will be used to determine the ability of various rich gas mixtures to mobilize oil in the tight reservoir rocks and shales of the Bakken petroleum system. During this quarter, minimum miscibility pressure (MMP) studies were conducted using different mixtures of rich gas (ethane, methane, and propane) in oil samples from Liberty Resources Stomping Horse complex in Williams County. Initial extraction studies on rocks from the Stomping Horse area were also conducted.
  - Evaluations of the changes in gas and fluid compositions over time in both the tight oil reservoir and surface infrastructure environments will be conducted as well as examinations of how those changes affect reservoir and process facility performance. Crude oil and produced water samples were collected from a newly completed and producing well in the Stomping Horse complex to determine baseline compositions. These samples were collected September 7–18, 2017, during the first 2 weeks of well production. Sampling will be repeated periodically throughout the first 12 to 18 months of production to provide a temporal aspect to well fluid.
  - Iterative modeling of surface infrastructure and reservoir performance will be conducted using the data generated by the various project activities to optimize future commercial- scale Bakken EOR design and operations. A static geomodel of the Bakken petroleum system in the Stomping Horse area was used to create an upscaled model of the specific drill spacing unit (DSU) that will be used for the pilot project. The DSU model was the basis for history-matching modeling that was performed using data provided by Liberty Resources. Simulation modeling of several potential injection and production scenarios was also conducted. A model of the surface operations and infrastructure of the Stomping Horse complex, including the County Line Gas Plant, was created using data provided by Liberty Resources.
- On September 21, Liberty Resources presented its application before NDIC (Case No. 26035) for an order granting temporary authority to use numerous wells located in the DSU (referred to as the “Leon-Gohrick DSU”), comprised of Sections 8 and 17, T.158N., R.95W., Williams County, as injection wells for an EOR pilot operation. The application is under consideration by NDIC, and it is anticipated that a decision may be rendered in the next quarter. It is anticipated that the pilot test will be initiated no later than early to mid-2018, pending approval from NDIC. An exhibit presented by Liberty Resources that contains detailed information about the plans for pilot testing is provided in Appendix C.

**Refracturing Optimization Task**

- A literature survey is under way to learn more about past and current research and practices on refrac, the candidate well selection process, techniques and approaches, key challenges faced, and lessons learned associated with the operation.
- Development of suggested guidelines for candidate selection in unconventional reservoirs is also under way based on the findings from the literature review.
- A data set of approximately 140 existing Bakken refrac wells was obtained from the North Dakota Pipeline Authority (NDPA). Well and production data regarding these refrac wells have been compiled to understand what types of wells have been selected for refrac in the Bakken so far. Analysis of production performance of the refrac wells in the data set was begun to review and interpret the refrac responses in the Bakken. Incremental rates and estimated ultimate recovery (EUR) are determined following the refrac operation on an individual well basis, and the analysis has been completed for half of the data set.
- A case study of the first well in Whiting Corporation's Refrac Pilot Project has been initiated, with production performance assessed. The response of the well to the refrac operation seems to be positive, with an increased oil production rate and contacting new additional reservoir volume following the operation. Additional analysis is ongoing.
- EERC staff traveled to Bismarck, North Dakota, on August 1, 2017, to participate in the North Dakota Legislative Management Energy Development and Transmission Committee meeting regarding oil well refrac potential in North Dakota.

**Produced Fluid Characterization Task**

- Coordination with BPOP program leads continued to identify key information and data needs to support ongoing and planned research efforts.
- Formal solicitation of key industry partners was begun for available fluid compositional data and access to future sample collection and analysis activities.
- Crude and produced water samples were collected from a newly completed and producing Liberty Resources well. These samples were collected September 7–18, 2017, during the first 2 weeks of well production. Sampling will be repeated periodically throughout the first 12 to 18 months of production to provide a temporal aspect to well fluid composition.
- Analysis of recently acquired cuttings and fluid samples has continued. Data will continue to be analyzed and used to support multiple activities conducted within the program.
- EERC staff traveled to the Dickinson, Kildeer, and Tioga areas to retrieve produced fluid samples on July 12–15, 2017.

**Reservoir Performance Modeling Task**

- Technical work was completed on decline curve analysis for the 400-well database and multivariate analysis to identify production drivers for the Bakken petroleum system. A draft of the topical report for this task has been completed, and it is under an internal technical review.

**Water Injection Reservoir Assessment Task**

- History-matching simulations were completed for all 103 saltwater disposal (SWD) wells involved in the reservoir model for the Inyan Kara Formation. Adjustments were made to

reservoir permeability for both the whole model and surrounding wells located in particular areas. The simulated area covers approximately 1750 square miles, nearly all of which lies within McKenzie County.

- To evaluate the long-term injection capacity of the Inyan Kara Formation in the simulated area, six prediction cases were performed. Three cases were performed with semiclosed boundary conditions, and three cases were performed with open-boundary conditions. The semiclosed boundary condition can be interpreted as providing conservative results, while the open-boundary condition provides more optimistic results. However, the boundary conditions have relatively little effect on the injection capacity of the modeled area.
- The results of the prediction simulation cases are summarized and analyzed. The cumulative water injection at the end of the year 2050 indicate there remains a very large disposal capacity of approximately 4 to 5 billion barrels (5–6 times the current cumulative water injected) in the existing SWD wells.
- Pressure difference maps between the original pore pressure and the year 2017, and between 2017 and the year 2050 are investigated in this study. These maps suggest there is still a large portion (e.g., south half) of the simulated area that has room for pressure increase, even after more than 30 years of injection, although additional SWD wells would be required in those areas. Therefore, the total injection capacity of the simulated area should be larger than the predicted capacity estimated by using only the existing wells. The ability to economically access this additional capacity has not been addressed by this study.
- A draft of the final topical report is completed and is under technical review.

**Facility Process Optimization Task**

- Following the May 10 industry meeting focused on crude oil vapor reduction strategies, the EERC prepared and distributed a formal data request to gather information about operating conditions and crude properties.
- A large data set comprising operational data and crude oil vapor pressure data was reviewed and analyzed to identify trends and factors influencing crude oil vapor pressure. Results from this analysis were compiled into a PowerPoint presentation and shared with the NDPC Technical Solutions Group in Dickinson, North Dakota, on September 7, 2017. EERC personnel presented an overview of data analysis and modeling activities conducted to evaluate surface facility design and operations ability to meet crude oil vapor pressure targets. The Hydrocarbon Remediation Task Force presentation, “Summary of Hydrocarbon Information,” is attached in Appendix A.
- Three facility configurations were identified for modeling, then development began for a site-specific facility model for each configuration. Facility layout drawings, operational data, and produced fluids data have been requested and will form the basis for subsequent simulations and field validation of the model.
- Work has begun on a process model and winter field trial focused on insulated tanks and different tank fill strategies as a method for reducing crude oil vapor pressure. Facility drawings and operational data have been requested. These data will form the basis for site- specific facility modeling and a winter field trial to evaluate strategy effectiveness.

**Aromatic/Aliphatic Study Task**

- Crude oil samples were obtained from six paired Three Forks and Middle Bakken wells. Samples

from additional six Middle Bakken wells were also obtained. All of the crude oil samples were analyzed for aromatic/aliphatic content using the quantitative high-resolution gas chromatography/mass spectrometry (GC/MS) method developed earlier this year. For the paired Three Forks and Middle Bakken wells, the crude oil from all six Three Forks wells showed relatively high aromatic/aliphatic ratios, indicating significant contributions from the Lower Bakken shale into the produced oil from the Three Forks. In contrast, two out of the six Middle Bakken wells that are paired with the Three Forks wells showed relatively low aromatic/aliphatic ratios, indicating little or no contribution from the Upper and Lower Bakken shales, while the other four had higher ratios, indicating contributions from the shales to the produced crude oil. Of the crude oils produced from the additional six Middle Bakken wells, three showed low aromatic/aliphatic ratios (indicating little or no contribution from the shales), while three showed high ratios (indicating contributions from the shales).

- The newly developed analytical method for quantitating aromatic and aliphatic hydrocarbon contents has now been applied to 70 different samples (ranging from Three Forks to Lower, Middle, and Upper Bakken samples) obtained from 13 wells. Final data reduction and quality vetting are under way.
- The collection of additional core samples for aromatic/aliphatic analyses in the Liberty Resources production areas has been approved by the North Dakota Geological Survey Core Library and is scheduled to occur in late September or early October.
- Several drill cutting samples from the Middle Bakken Formation from two Liberty Resources wells were obtained and are presently being analyzed for aromatic/aliphatic ratios. The cuttings were collected from the heel to the toe of the laterals, so should allow any changes in aromatic/aliphatic ratios throughout the laterals to be investigated. 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 have not been successful. The operator of these wells has recently provided a sample of its diesel fluid, which will be used in an attempt to better "clean" the diesel fluid from drill cuttings and allow aromatic/aliphatic analyses to be performed.
- Four oily water samples with crude oil "shows" were obtained during the drilling of a well lateral in the Middle Bakken. The samples were extracted with methylene chloride to obtain the hydrocarbon fraction and are presently being analyzed for aromatic/aliphatic ratios. These samples should enable determination of the aromatic/aliphatic ratios in crude oil produced prior to hydraulic fracturing and will likely enable determination of the shale contributions to produced crude oil after hydraulic fracturing.

**Environmental Support Task**

- EERC staff continued to collaborate with NDPC members, NDDH staff, and representatives of the Northwest Landowner's Association (NWLA) during planning of additional educational events focused on hydrocarbon spill and hydrocarbon spills remediation.
- The first education day event was held in Bismarck, North Dakota, on July 17, 2017. EERC staff presented to the group regarding the chemistry of unrefined hydrocarbons (crude oil), analytical methods employed to characterize produced liquid hydrocarbons, and an introduction to a risk-based approach to remediating hydrocarbon spills. The NDPC Technology Solutions Group Meeting Presentation, "Overview of Facility Process Modeling and Data Analysis," is attached in Appendix B.

**Program Management and Development**

- EERC staff traveled to Bismarck, North Dakota, to attend the Oil & Gas Research Program meeting on August 9–11, 2017.
- EERC staff traveled to Bismarck, North Dakota, to attend the NDIC meeting on September 20–21, 2017.
- EERC staff traveled to Calgary, Alberta, Canada, to attend the Society for Organic Petrology 34th Annual Meeting on September 21–24, 2017.
- EERC staff traveled to Washington, D.C., to attend the National Petroleum Council meeting on September 24–26, 2017.
- EERC staff attended the NDPC Annual Meeting in Grand Forks, North Dakota, on September 27–28, 2017.
- EERC staff traveled to Pittsburgh, Pennslvania, to attend the Interstate Oil & Gas Compact Commission Annual Meeting on September 30 – October 4, 2017, also participating in the Environmental & Safety Committee meeting.

**January 12, 2018 Quarterly Report received**. The full report is available on the website. The report states in part:

**Enhanced Oil Recovery Task**

During this past quarter, work was performed under U.S. Department of Energy (DOE) award to support EERC efforts under the rich gas enhanced oil recovery (EOR) project that is being conducted in close collaboration with Liberty Resources. Four milestones were accomplished, including the project kickoff meeting, completion of the initial assessment of test site rich gas quality and quantity, finalization of a fluids sampling collection and analysis plan, and completion of an initial reservoir geocellular model. Specific activities conducted during this past quarter are presented below.

- Activities to accomplish the BPOP 2.0 goals for the pilot project stated above were conducted this quarter. Specific activities include the following:
  - Laboratory-based examinations of rich gas interactions with obtained reservoir fluids and core/cuttings are being conducted to determine the ability of various rich gas mixtures to mobilize oil in the Bakken petroleum system. During this reporting period, experiments were conducted in conjunction with the DOE award mentioned previously. Rock extractions were begun using pure methane, ethane, and propane on both Middle Bakken and Lower Bakken Shales from four Liberty wells located close to the junction of Burke, Williams, and Mountrail Counties. Extractions with methane and ethane were completed, and extractions with propane were begun. Analysis of the hydrocarbon recovery rates with the different fluids from the four Middle Bakken and four Lower Bakken Shales was also begun.
  - 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. Crude oil and produced water samples were collected from a newly completed and producing well in the Stomping Horse complex to determine baseline compositions. These samples have been received at the EERC from collections occurring between September 7 and November 18, 2017. Sample collection will continue periodically

throughout the first 12 to 18 months of production to provide a temporal aspect to well fluid.

- Iterative modeling of surface infrastructure and reservoir performance was conducted using the data generated by the various project activities to optimize the EOR pilot test design and operations. The DSU (drill-spacing unit) model created in the previous quarter was the basis for history-matching modeling that was performed using data provided by Liberty Resources. Simulation modeling of several potential injection and production scenarios was also conducted. A model of the surface operations and infrastructure of the Stomping Horse complex, including the County Line Gas Plant, has been created. Results from the reservoir and surface modeling are also being used to support the selection and design of gas treatment and compression operations for the pilot test. Modeling results to date show significant improvements in oil production above the base case.
- An initial reservoir surveillance and operational monitoring plan was developed. The plan was incorporated into the injection permit application that was submitted to NDIC by Liberty Resources.

**Refracturing Optimization Task**

- A membership meeting was held November 14 in Houston to discuss Bakken refracturing potential and a project execution plan to evaluate the issue. Several key EERC staff members traveled to Houston in support of this meeting:
  - Justin Kringstad, North Dakota Pipeline Authority, presented his previous work evaluating refracture results to date.
  - A literature survey was completed to learn more about past and current research and practices on refracturing, the candidate well selection process, techniques and approaches, key challenges faced, and lessons learned associated with the operation. Survey results were presented at the meeting.
  - Refracturing performance evaluation of 60 Bakken wells was presented.
  - Neal Nagel, consultant, presented concepts relevant to refracturing.
  - Marathon, ConocoPhillips, and WPX presented their observations on the subject.
  - Group discussion was held to help guide future EERC activity.

**Produced Fluid Characterization Task**

- During this reporting period, Marathon Oil was able to coordinate work in several areas. This work involved sampling of cuttings and poststimulation produced fluids of three different wells. The in-kind cost share reported in Table 1 includes pad and facilities construction and 33 days of drilling rig operation.
- Formal solicitation of produced fluids data from key industry partners has continued as we build a database of information on produced water, crude oil, and associated gas. 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.
- Crude and produced water samples have continued to be collected from a newly completed and producing Liberty Resources well. These samples have been collected since initial production of the well in early September throughout the first few months of production. Sampling will be repeated periodically throughout the first 12 to 18 months of production to provide a temporal aspect to produced fluid composition.

- Analysis of recently acquired cuttings and fluid samples has continued. Data will continue to be analyzed and used to support multiple activities conducted within the program.
- EERC staff traveled to the Liberty Resources field office in Tioga to retrieve samples on November 9, 2017.

**Reservoir Performance Modeling Task**

- Technical work and a draft topical report was completed on decline curve analysis for the 400-well database and multivariate analysis to identify production drivers for the Bakken petroleum system. Internal technical review is in progress.

**Water Injection Reservoir Assessment Task**

- A draft of the final topical report entitled "Modeling and Simulations of the Inyan Kara Formation to Estimate Saltwater Disposal Capacity: Final Report" was provided to select partners for review. Comments from one of the reviewers were incorporated into the report. If no additional input is received by the end of January, the report will be finalized and provided to NDIC and all member companies.
- Additional modeling outputs were compiled and provided to two program members after they enquired about what additional data had been generated by the model.

**Brine Treatment and Storage Assessment**

- This task was begun during the reporting period and will be reported in future quarterly and annual reports.
- A presentation was compiled summarizing the challenges associated with brine treatment and the pros and cons of current and emerging brine treatment technologies.

**Facility Process Optimization Task**

- Two operating companies have volunteered to provide facility design and operating data to allow the EERC to build a site-specific process model and evaluate different strategies to help meet crude oil vapor pressure targets. Communication has continued between EERC researchers and facilities personnel to acquire the necessary information, review vapor pressure data, and define modeling activities.
- Confidentiality agreements are being prepared with member companies to enable sharing of site-specific facilities information. Agreements will likely be complete early 2018.

**Aromatic/Aliphatic Study Task**

- An agreement was reached with the Canadian Geological Survey in which the EERC will provide approximately 40 Lower and Upper Bakken Shale samples collected to represent both the geographical and the thermal maturity variations throughout the Bakken reservoir. The Canadian Geological Survey has agreed to conduct 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 will be performed on the 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.

- The newly developed analytical method for quantitating aromatic and aliphatic hydrocarbon contents has now been applied to 70 different samples (ranging from Three Forks to Lower, Middle, and Upper Bakken samples) obtained from 13 wells. Final data reduction and quality vetting have been completed. Determination of the aromatic/aliphatic ratios on the new samples described above has begun.
- The collection of additional core samples for aromatic/aliphatic analyses in the Liberty Resources production areas approved by the North Dakota Geological Survey Core Library has been completed.
- 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.

**Environmental Support Task**

- EERC staff participated in the second education day of the Hydrocarbon Remediation Task Force on October 10, 2017, along with North Dakota Petroleum Council (NDPC) members, North Dakota Department of Health (NDDH) staff, and representatives of the Northwest Landowner's Association (NWLA).
- EERC staff prepared a set of slides summarizing the risk-based corrective action program in the state of Oklahoma and presented this information in a conference call to the NDPC Hydrocarbon Remediation Working Group on December 20, 2017.

**Program Management and Development**

- EERC staff traveled to San Antonio, Texas, to attend the Society of Petroleum Engineers Forum on EOR in Unconventional Reservoirs, November 6–10, 2017.
- A project kickoff meeting for the parallel DOE-sponsored effort was held via WebEx on December 14, 2017.
- EERC staff traveled to Pittsburgh, Pennsylvania, to participate in the Interstate Oil & Gas Compact Commission (IOGCC) Annual Meeting and to attend the associated Environmental & Safety Committee Meeting, held September 30 – November 4, 2017.
- EERC staff traveled to Dickinson, North Dakota, to present at the Western Dakota Energy Association annual meeting, held November 1–3, 2017.
- EERC staff traveled to Bismarck, North Dakota, to present at the North Dakota Legislature's Water Topics Overview Interim Committee meeting on October 12, 2017.
- EERC staff traveled to Houston, Texas, to participate in the NorTex Petroleum Cluster $CO_2$ Conference, held October 3–6, 2017.

- EERC staff traveled to Minneapolis, Minnesota, to participate in the AIChE 2017 meeting, held November 1–2, 2017.

**April 13, 2018 Quarterly Report received.** The full report is posted on the website. The report states in part:

**Enhanced Oil Recovery Task**

During this reporting period, work was performed under the U.S. Department of Energy (DOE) award to support EERC efforts under the rich gas enhanced oil recovery (EOR) project that is being conducted in close collaboration with Liberty Resources LLC (Liberty). Specific activities conducted during this past quarter are presented below.

- Activities to accomplish the BPOP 2.0 goals for the pilot project stated above were conducted this quarter. Specific activities include the following:
  - Laboratory-based examinations of rich gas interactions with obtained reservoir fluids and core/cuttings are being conducted to determine the ability of various rich gas mixtures to mobilize oil in the Bakken petroleum system. During this reporting period, experiments were conducted in conjunction with the DOE award mentioned previously. Laboratory studies were conducted to determine minimum miscibility pressure (MMP) values for different rich gas components (methane, ethane, propane) and $CO_2$ (for comparative purposes) in crude oil from the Stomping Horse complex. A modified rising capillary-vanishing interfacial tension technique was used for the MMP studies. The MMP experiments were conducted in duplicate using crude oil from the Three Forks Formation at a temperature of 127°C (260°F). MMP values for $CO_2$ in Stomping Horse oil were determined as a point of comparison with previous EERC studies focused on the potential for $CO_2$ EOR in the Bakken, with the results of those previous studies serving as a benchmark to evaluate the relative effectiveness of the rich gas components on MMP. The results of the MMP experiments conducted this past quarter showed that for the Stomping Horse crude oil, MMP values for methane are double those of $CO_2$, MMP for ethane is half that of $CO_2$, and MMP for propane is half that of ethane. Activities to develop methods to mix stable methane–ethane–propane mixtures for lab experiments were also initiated during this past quarter.

  - Rock extractions were conducted using pure methane, ethane, and propane on both Middle Bakken and Lower Bakken Shales from four Liberty wells located close to the junction of Burke, Williams, and Mountrail Counties. Extractions with methane and ethane were completed, and extractions with propane were conducted. Analysis of the hydrocarbon recovery rates with the different fluids from the four Middle Bakken and four Lower Bakken Shales was also conducted. Key observations from the results of the rock extraction experimental activities include the following:
    - Methane is significantly slower than ethane and propane when it comes to mobilizing oil from both Middle Bakken and Bakken shale samples.
    - Methane shows a very high bias against the mobilization of higher-molecular-weight hydrocarbons in both Middle Bakken and Bakken shale samples.
    - The results of ethane and propane are similar when it comes to their ability to mobilize oil from the rock samples. Both showed faster rates of oil recovery than methane, and both were better at mobilizing high-molecular-weight hydrocarbons

than methane.

- 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.
- Iterative modeling of surface infrastructure and reservoir performance was conducted using the data generated by the various project activities to optimize the EOR pilot test design and operations. The DSU (drill-spacing unit) model created in the previous quarter was the basis for history-matching modeling that was performed using data provided by Liberty. Simulation modeling of several potential injection and production scenarios was also conducted. A model of the surface operations and infrastructure of the Stomping Horse complex, including the County Line Gas Plant, has been created. Results from the reservoir and surface modeling are also being used to support the selection and design of gas treatment and compression operations for the pilot test. Modeling results to date show significant improvements in oil production above the base case.

- Biweekly conference calls were held with staff from Liberty to discuss progress on the various aspects of the project.
- Biweekly conference calls with DOE were held to provide updates on the status and progress of the various aspects of the project.

**Refracturing Optimization Task**

- The original work plan was revised, taking into account the feedback received at the November 14, 2017, membership meeting.
- Production analysis of the refrac wells in the Bakken was completed to evaluate the performance of refracturing by determining the uplift in daily production as well as the incremental estimated ultimate oil recovery.
- The economic analysis of refracturing was conducted and completed to quantify the profit associated with the incremental oil attributable to the refracturing in the Bakken.
- Work to identify the wells across the Bakken that fit a certain criteria that may make them a candidate for refracturing in the near future is in progress.

**Produced Fluid Characterization Task**

- On January 20, 2018, Marathon Oil Company (Marathon) provided access to collect and analyze samples (gas, oil, and water) from a non-stimulated well in Dunn County. Data obtained from analysis of the sample will be compared to similar data from Bakken and Three Forks wells with multiple stage stimulations. Information obtained may help provide insight into possible sources of produced water in typical stimulated Bakken wells.
- Formal solicitation of produced fluids data from key industry partners has continued as the EERC builds a database of information on produced water, crude oil, and associated gas. These data will be integrated into the EERC-managed Bakken fluids database for support in understanding basin-wide characteristics related to production and other reservoir/well

statistics.

- Crude and produced water samples have continued to be collected from three newly completed and producing Liberty wells. These samples have been collected since initial production of each well throughout the first several months of production. Sampling will be repeated periodically throughout the first 12 to 18 months of production from each well to provide a temporal aspect to produced fluid composition.
- Analysis of recently acquired cuttings and fluid samples has continued. Data will continue to be analyzed and used to support multiple activities conducted within the program.
- EERC staff traveled to the Liberty well sites near Tioga, North Dakota, to conduct sample collection on January 19, February 1, and March 20, 2018.

**Reservoir Performance Modeling Task**

- Technical work and a draft topical report were completed on decline curve analysis for the 400-well database and multivariate analysis to identify production drivers for the Bakken petroleum system. Internal technical review is complete, and a final editing is in process.

**Water Injection Reservoir Assessment Task**

- Additional input on the draft final topical report was received and the report is being modified accordingly.
- The results of the Inyan Kara modeling effort are being used to develop a simplistic model that will allow users to estimate the radius of influence of individual saltwater disposal (SWD) wells based on basic geologic characteristics (cumulative sand thickness, average porosity, average permeability), injection rate, and period of performance.

**Brine Treatment and Storage Assessment**

- During the reporting period, geochemical modeling was conducted using PHREEQC to evaluate the potential for scale and NORM (naturally occurring radioactive material) precipitation if Bakken produced water is concentrated as a result of treatment. Until specific water treatment technologies of interest are identified by member companies, a generic evaluation was performed using Bakken water chemistry data compiled by the EERC and assuming no selective removal of ions from the brine stream.
- Information was gathered on several brine treatment technologies that may be of interest to member companies. One technology in particular, developed by MGX Minerals Inc., couples brine treatment with resource recovery (i.e., lithium). The company claims that the technology has been commercially applied to recover metals from oilfield brines. EERC staff have reviewed several of the technical reports published by the company and plans to hold a call with them this coming quarter.

**Facility Process Optimization Task**

- Facility design, operational data, and crude oil samples have been obtained from two operating companies. Computational models have been developed, and work is ongoing to validate model predictions with actual system performance.
- Crude oil samples have been submitted to a third-party lab, and analysis is pending.

**Aromatic/Aliphatic Study Task**

- Forty Lower and Upper Bakken Shale samples were obtained that represent both the

geographical and thermal maturity variations throughout the Bakken reservoir. These were provided to the Canadian Geological Survey both as native rock samples for "extended slow-heating rock-eval" analysis and as polished epoxy casts for vitrinite reflectance. These analyses are currently being performed by the Canadian Geological Survey in a collaborative study with the EERC. 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. Initial rock-eval analyses have already been provided to the EERC by the Canadian group.

- Fifteen of the 40 rock samples described above had previously had their aromatics/aliphatics measured. During this quarter, the additional 25 rock samples from 11 new wells have been prepared and analyzed for aromatic/aliphatic ratios so that we have complete data sets to match with the thermal maturity analyses described above. Data reduction for the 25 samples was begun.
- Eleven crude oil samples collected over 3 months starting at initial production in a new well 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. These initial samples show no significant shifts in aromatic/aliphatic ratios, but samples will continue to be collected and analyzed.

**Environmental Support Task**

- EERC staff participated in the third education day of the Hydrocarbon Remediation Task Force on January 26, 2018, along with North Dakota Petroleum Council (NDPC) members, North Dakota Department of Health (NDDH) staff, and representatives of the Northwest Landowner's Association (NWLA). At this meeting, EERC staff presented on two subjects:
  1) past research by the Total Petroleum Hydrocarbon Criteria Working Group and
  2) the risk- based corrective action program used by Oklahoma to remediate crude oil spills.
- EERC staff participated in a working group meeting to compile and discuss several other state risk-based corrective action programs in anticipation of the next Hydrocarbon Remediation Task Force meeting.
- EERC staff began compiling additional hydrocarbon remediation material to update the previously published North Dakota Remediation Resource Manual.

**Program Management and Development**

- EERC staff traveled to San Antonio, Texas, to attend an ASTM International crude oil sampling and analysis workshop and Crude Oil Quality Association meeting February 19–23, 2018.
- EERC staff traveled to Denver, Colorado, to attend the NDPC Natural Gas Capture and Infrastructure Development (NGCID) meeting, held March 21, 2018. The EERC is supporting the NGCID group by leading the subcommittee focused on assessing remote capture use. The EERC also coordinated the creation of an industry survey which was distributed to NDPC 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.
- EERC staff traveled to Calgary, Alberta, Canada, to take a training course on Unconventional

Reservoir Rate-Transient (Production Data) Analysis on March 12, 2018.

- EERC staff traveled to Calgary, Alberta, Canada, to attend the Society of Petroleum Engineers Canada Unconventional Reservoirs Conference on March 13–14, 2018.
- EERC staff traveled to Nashville, Tennessee, to attend the Carbon Capture Utilization & Storage Conference, held March 18–23, 2018.
- EERC staff traveled to Houston, Texas, to present at the Houston Geological Society Mudrocks Conference, held March 5–7, 2018.

**July 15, 2018 Quarterly Report received on July 13, 2018.** The full report is posted on the website along with the planned future activities for the next quarter. The report states in part that the following accomplishments took place during the April - June, 2018 time period:

**Enhanced Oil Recovery Task**

Develop broader understanding of reservoir interactions with reinjected rich gas as a means of improving ultimate recovery, reducing flaring, and reducing emissions. During this reporting period, work was performed under the U.S. Department of Energy (DOE) award to support EERC efforts under the rich gas enhanced oil recovery (EOR) project that is being conducted in close collaboration with Liberty Resources LLC (Liberty). Specific activities conducted during this past quarter are presented below.

- Activities to accomplish the BPOP 2.0 goals for the pilot project stated above were conducted this quarter. Specific activities include the following:

– Laboratory-based examinations of rich gas interactions with obtained reservoir fluids and core/cuttings are being conducted to determine the ability of various rich gas mixtures to mobilize oil in the Bakken petroleum system. During this reporting period, experiments were conducted in conjunction with the DOE award mentioned previously. Laboratory studies were conducted to determine minimum miscibility pressure (MMP) values for mixtures of ethane and methane in crude oil from the Stomping Horse complex. MMP values were measured for pure ethane, pure methane, and different ethane/methane mixtures, ranging from 10% methane to 80% methane. A modified rising capillary vanishing interfacial tension technique was used for the MMP studies. The MMP experiments were conducted in duplicate using crude oil from the Three Forks Formation at a temperature of 127°C (260°F) to mimic in situ reservoir temperature at the Stomping Horse pilot unit. The results of the MMP experiments on ethane/methane mixtures conducted this past quarter showed that for the Stomping Horse crude oil, mixed ethane and methane MMPs show an exponential response to methane concentration. Activities to develop methods to mix stable ternary methane–ethane–propane mixtures for lab experiments were also conducted during this past quarter. A successful method has yet to be 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 of methane, ethane, and/or propane as the pressure increases and which molecular weight hydrocarbons revert to the lower phase as pressure drops. Results indicate that, at 5000 psi, ethane and propane mobilize similar concentrations of hydrocarbons, but at lower pressures, ethane becomes much less effective. Methane is poor at any pressure. Propane efficiently mobilizes hydrocarbons at all pressures from 1500 to 5000 psi, while ethane requires the higher pressures. At 5000 psi, ethane and propane efficiently mobilize the heavier hydrocarbons (determined up to C36) effectively, but ethane is less efficient at lower pressures. Methane only mobilizes low molecular weight hydrocarbons (smaller than C12) at any pressure, leaving most mid- and higher-molecular weight hydrocarbons in the reservoir.

– A set of comparative rock extraction hydrocarbon recoveries using pure methane, ethane, and propane on Middle Bakken and Lower Bakken Shale rock samples was conducted under lower-pressure conditions to determine the effect of pressure on the performance of those gases. Key observations from the results of the rock extraction experimental activities include the following:

- With propane, total hydrocarbon recovery shows little pressure dependence, but higher pressures are needed for higher molecular weight hydrocarbons.
- With ethane, total hydrocarbon recovery is highly dependent on pressure (i.e. higher pressures result in more effective recovery), particularly with respect to mobilizing higher molecular weight hydrocarbons.
- Ethane recovers total hydrocarbons and higher molecular weight hydrocarbons better than propane at 5000 psi but not at 1500 and 2500 psi. These results correlate with ethane and propane molar density.
- Methane performs poorly regardless of pressure. It only recovers the most volatile hydrocarbons, even at 5000 psi.

– 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.

– Iterative modeling of surface infrastructure and reservoir performance was conducted using the data generated by the various project activities to optimize the EOR pilot test design and operations. The DSU (drill-spacing unit) model created in the previous quarter was the basis for history-matching modeling that was performed using data provided by Liberty. Simulation modeling of several potential injection and production scenarios was also conducted. A model of the surface operations and infrastructure of the Stomping Horse complex, including the County Line Gas Plant, has been created. Results from the reservoir and surface modeling are also being used to support the selection and design of gas treatment and compression operations for the pilot test. Modeling results to date show significant improvements in oil production above the base case.

– Liberty Resources has plans to initiate rich gas injection during the next quarter (third quarter of 2018) into a well on the Leon pad in the Stomping Horse complex in Williams County. It is anticipated

that initial injection will be conducted with up to 1400 psi of rich gas at a maximum rate of 1.8 MMcf/day. Current plans call for increasing the pressure and the rate of injection depending on reservoir performance and compression capabilities.

- Biweekly conference calls with DOE were held to provide updates on the status and progress of the various aspects of the project.
- Biweekly conference calls were held with staff from Liberty to discuss progress on the various aspects of the project.

**Refracturing Optimization Task**

Facilitate broad industry engagement regarding candidate selection criteria, refrac execution, and post execution evaluation.

- Work was completed to identify the wells across the Bakken that fit a certain criteria that may make them a candidate for refracturing in the near future.
- A full report was drafted by putting together the individual sections (literature review on candidate well selection, refrac production performance, refrac economic analysis, and identification of potential candidates for refrac across the Bakken).
- The report has been through an initial round of internal review and is currently being revised for final review.

**Produced Fluid Characterization Task**

Collect and analyze data on crude oil, associated gas, and produced water to gain a better understanding of the resource and support facilities process and reservoir modeling.

- On April 10, 2018, EERC personnel were on-site to conduct a second round of sampling and analysis of fluids and gas from an unstimulated well owned by Marathon Oil Company (Marathon) in Dunn County. Data obtained from analysis of these samples will be compared to similar data from Bakken and Three Forks wells with multiple-stage stimulations. Information obtained may help provide insight into possible sources of produced water in typical stimulated Bakken wells.
- Formal solicitation of produced fluids data from key industry partners has continued as the EERC builds a database of information on produced water, crude oil, and associated gas. These data will be integrated into the EERC-managed Bakken fluids database for support in understanding basin wide characteristics related to production and other reservoir/well statistics.
- Crude and produced water samples have continued to be collected and analyzed from three newly completed and producing Liberty wells. These samples were collected by EERC personnel on location on April 10 and May 31, 2018. These samples have been collected since initial production of each well throughout the first several months of production. Sampling will be repeated periodically throughout the first 12 to 18 months of production from each well to provide a temporal aspect to produced fluid composition.
- Analysis of recently acquired cuttings and fluid samples has continued. Data will continue to be analyzed and used to support multiple activities conducted within the program.

**Reservoir Performance Modeling Task**

Identify key reservoir and well performance metrics to enable better planning of surface facility development.

- The final report for the decline curve analysis for the 400-well database and multivariate analysis to identify production drivers for the Bakken is complete and undergoing review.

**Water Injection Reservoir Assessment Task**

Identify key reservoir and well performance metrics to enable better planning of surface facility development.

- The final report for the Inyan Kara modeling effort is complete and undergoing review.
- Work continues on development of simplistic models that will allow users to estimate the radius of influence of individual saltwater disposal (SWD) wells based on basic geologic characteristics (cumulative sand thickness, average porosity, and average permeability), injection rate, and period of performance.

**Brine Treatment and Storage Assessment**

Assess current and emerging methods and technologies to overcome challenges related to and improve brine treatment and storage.

- During the reporting period, geochemical modeling using PHREEQC to evaluate the potential for scale and NORM (naturally occurring radioactive material) precipitation in Bakken produced water was completed. The goal was to assess the likelihood of NORM-containing scale to precipitate if Bakken produced water were concentrated as a result of brine treatment. Several ranges of Bakken brine concentrates were evaluated. The results of this work will be provided to members at the upcoming annual meeting in August.

**Bakken Trend Analysis**

A data set of over 11,000 wells is being used to evaluate trends based on well completion practices that have been categorized based on single vs. multistage, proppant loading, and water use. The volume of water injected into each well during stimulation was subtracted from the first year of water production to more accurately account for generation of formation fluids. The initial results of this work will be presented during the annual meeting in August.

**Facility Process Optimization Task**

Develop a foundational tool for holistic examination of the coupled effects of several operations variables on fugitive emissions, crude oil properties, and equipment performance.

- There is no progress to report during this quarter.

**Aromatic/Aliphatic Study Task**

Evaluate oil composition as a tool to identify the source of produced oil and improve the understanding of oil recovery.

- In addition to the 40 Lower and Upper Bakken Shale samples that were extracted and analyzed last quarter, an additional 33 rock core samples including several Middle Bakken, Three Forks, Pronghorn, and additional Upper and Lower Bakken Shales were extracted and analyzed for their aromatic/aliphatic ratios. These samples were selected to give complete profiles of multiple wells, including all relevant source and reservoir rocks.
- All of the 73 rock samples have been analyzed for aromatic/aliphatic ratios, and the raw data have undergone initial data reduction.

- The collaboration with the Canadian Geological Survey has expanded from the 40 Bakken shale samples previously reported to include a Lower Bakken Shale extracted at three pressures (1500, 2500, and 5000 psi) using pure methane, ethane, and propane. The extracted rock samples were provided to the Canadian Geological Survey for "extended slow-heating rock-evaluation" analysis to determine the fractions of hydrocarbons extracted by each of the nine extraction conditions.
- An update on the aromatic/aliphatic tracer studies was posted on the BPOP 2.0 members-only Web site.

**Environmental Support Task**

Educate the public and stakeholders on key, energy-related environmental issues and aid in the development of practical resources.

- EERC staff participated in the fourth education day of the Hydrocarbon Remediation Task Force on May 2, 2018, along with North Dakota Petroleum Council (NDPC) members, North Dakota Department of Health (NDDH) staff, and representatives of the Northwest Landowner's Association (NWLA). The Task Force heard presentations about risk-based corrective action programs in the state of Montana and the province of Alberta.
- EERC staff drafted additional hydrocarbon remediation text based on information presented at the NDDH education days for inclusion in the updated North Dakota Remediation Resource Manual. Draft text has been internally and externally reviewed.

**Program Management and Development**

- BPOP 2.0 Year 2 invoices were sent to all members.
- EERC staff gave a technical presentation regarding the progress and outcomes from the Refracturing Optimization and Reservoir Performance Modeling tasks to the UND–SINOPEC meeting on May 7, 2018, at the University of North Dakota.
- EERC staff traveled to Bismarck, North Dakota, to attend the Williston Basin Petroleum Conference, May 22–24, 2018.
- EERC staff traveled to San Antonio, Texas, to participate in SPE Workshop: Shale Development Optimization – The Quest for Efficiency and Profitability Continues, May 8–10, 2018.
- EERC staff traveled to Watford City, North Dakota, on May 31, 2018, to attend the North Dakota–Montana Environmental Peer Group meeting.

**October 16, 2018 - Quarterly Report Received for the Period of July 1 - September 30, 2018** - a copy is posted on the website. It states in part:

**Enhanced Oil Recovery Task**

The goal of the BPOP 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 (Liberty) at its Stomping Horse complex in Williams County, North Dakota. The 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. This past quarter, DOE also 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 this task include the following:

- Determine the effectiveness of cyclic multiwell huff and 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.

Specific activities conducted under this task during the past quarter include the following:

- Fluid (oil, gas, water) samples from wells in the Stomping Horse complex were collected and analyzed in early July 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 July 2018 in wells of the Leon–Gohrick drill spacing unit (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 2018. Another injection operation was conducted in the first Three Forks well in September 2018. 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 next quarter using a larger compressor.
- Laboratory-based examinations of rich gas interactions with crude oils and core/cuttings obtained from the Stomping Horse area were conducted to determine the ability of various rich gas mixtures to mobilize oil in the Bakken petroleum system. Results showed that gas mixtures with higher proportions of ethane and/or propane were most effective at mobilizing oil from the rocks, although in some cases pressure also played a substantial role. Laboratory studies previously conducted to determine minimum miscibility pressure (MMP) values for different rich gas components (methane, ethane, and propane individually) using a Middle Bakken crude oil were expanded to include several different ratios of produced gas methane/ethane/propane mixtures. Results showed higher percentages of ethane and/or propane in a rich gas mixture can have a significant impact on lowering MMP values.
- An overview of the laboratory-based experiments, modeling and simulation results, and field-based activities to date was presented at three meetings/conferences this quarter. “Bakken Rich Gas EOR Project” was presented at the Annual Members Meeting held at the EERC August 7–8, 2018, and is available on the members-only Web site. “Bakken Rich Gas EOR Project” was

presented at the DOE Mastering the Subsurface Meeting in Pittsburgh, Pennsylvania, on August 15, 2018 (Appendix A). “Stomping Horse Bakken EOR Project – Science & Technology in Action” was presented at the North Dakota Petroleum Council Annual Meeting in Fargo, North Dakota, on September 25, 2018 (Appendix B).

- Modeling and dynamic simulation activities provide technical support and guidance to the design of the pilot injection/production scheme. Static geocellular modeling of the Bakken petroleum system at the Stomping Horse location and dynamic simulations of potential EOR schemes have been used to predict EOR performance using a cyclic multiwell huff ‘n’ puff scheme. A geocellular model of the Stomping Horse DSU has been created using data provided by Liberty. History-matching exercises, using detailed operational data provided by the project partner have been conducted to validate the geocellular model. Several potential pilot test operational scenarios have been tested with dynamic simulations.
  - During the past quarter, the team has continued work on the calibration of the DSU- scale geologic model, which was previously constructed. The geologic model captures site-specific features such as geologic structure, lithofacies distribution, and initial reservoir pressure and saturation spatial distribution. The DSU model was built to incorporate operational data collected during the field test. The model uses a tailored equation-of-state model, calibrated with pressure–volume–temperature laboratory measurements (provided by Liberty), which allows simulating both lean and rich gas injection operations. The DSU model domain incorporates two well pads, with 11 horizontal wells, perforated in the Middle Bakken or the Three Forks Formations, totaling more than 500 hydraulic fractures. In this quarter, the DSU model was successfully calibrated to reproduce field-observed fluid rates (gas, oil, and water phases) during the first year of historical production. In addition, the model honors the oil production rates during the collected historical period (from August 2013 to December 2017). Furthermore, preliminary results on the evaluation of the EOR performance using a mechanistic model have shown that 1) injectivity does not seem to be an issue, and 2) higher injection pressures (and therefore higher injected fluid densities) seem to sustain hydrocarbon recovery.

- Laboratory-based flow-through tests using Bakken shale core plugs and rich gas components were initiated to determine the permeability and sorption behavior of rich gas components in Bakken shale. Orders will be placed for the purchase of a high- pressure magnetic balance and specialized centrifuge for use in these investigations.
- Laboratory-based investigations of the miscibility behavior of rich gas components and Middle Bakken crude oil from the Stomping Horse complex under different temperature and pressure conditions were initiated. The purpose of these experiments, which use the same test cell as the MMP studies, is to quantitatively determine hydrocarbon partitioning between different phases to determine which hydrocarbon species are most mobilized as pressure increases and which are lost as pressure decreases.
- Surface facility modeling of the Stomping Horse complex using a dynamic computational modeling package, VMGSim, was completed. The purpose of this modeling was to evaluate the potential effects of rich gas EOR activities on the operations of the infrastructure of the Stomping Horse complex, including compressors, separators, pipes, and the County Line gas-processing plant. Results of the modeling indicate rich gas EOR will not adversely affect surface facility operations at the Stomping Horse complex. A white paper on the results of

these surface facility modeling activities will be prepared during the next quarter.

- Biweekly conference calls with DOE were held to provide updates on the status and progress of the various aspects of the project.
- Biweekly conference calls were held with staff from Liberty to discuss progress on the various aspects of the project.

**Refracturing Optimization Task**

The refracturing optimization study was conducted to 1) analyze production performance of wells that have been refractured (or restimulated) in the Bakken Formation, 2) investigate the economics of well refracturing, and 3) evaluate the overall potential for Bakken-wide 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 low, middle and high 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.

In this reporting quarter, the internal review and revision of the final report was completed. A final version of the report was sent out for review by select BPOP members. Upon completion of the review by the selected members, the report will be distributed to the entire BPOP membership for an 18-month period before the report is fully public (Appendix C, Slide 5).

**Produced Fluid Characterization Task**

The produced fluids 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 include thorough review and compilation of relevant publicly available data, establishing industry partnerships to enable acquisition of nonpublic information and potential access for sample acquisition, conducting sampling and analysis efforts to support project needs, and performing a review of relevant information to identify specific data needs.

Key accomplishments for this quarter include continued collaboration 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 and providing a temporal evaluation of compositional changes throughout a well's production life. Specific activities conducted this quarter include the following:

- 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 at two locations in the northern and southern portions of the Bakken play in North Dakota.

- Began sampling and analysis activities on fluid samples from two adjacent producing Bakken wells (one stimulated and one nonstimulated) for the purpose of evaluating compositional differences that may indicate possible fluid migration pathways.
- Conducted additional sample collection and analysis on four separate wells for the purpose of a temporal evaluation of compositional changes throughout the production life of newly established wells.
- Reviewed and refined collected data/information for inclusion in the previously developed database and to identify specific data gaps/needs.

**Reservoir Performance Modeling Task**

There has been a trend of increasing initial oil production rates over time, which is related, at least in part, to advances in technology and improvements in engineering practice over time.

However, some older wells outperform younger wells despite the 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. This study employed multivariate statistical analysis to evaluate the factors that influence well production performance in the Bakken. The database compiled for this work includes 400 wells completed in the Bakken and Three Forks Formations with a broad geographic distribution. Approximately 30 different factors (completion-related and geology-related) were analyzed to assess their effects on short- term (6-month) and long-term (60-month) production using a multivariate statistical approach.

This quarter, the final topical report was sent out for reviews by select BPOP members. Once the reviewers' comments are received and addressed, the finalized report will be distributed to all BPOP members for a period of 18 months, after which, the document will be available to the public.

**Water Injection Reservoir Assessment Task**

Because of industry's current reliance on the Inyan Kara Formation as a 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 is complete and a report summarizing the approach, results, and conclusions 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. This report and accompanying presentation will be available to the public in October 2019.

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 past quarter, two additional spreadsheet models were developed and included in the overall spreadsheet package.

**Brine Treatment and Storage Assessment**

The goal of the brine treatment and storage assessment task is to assess current and emerging brine treatment technologies that are of interest to BPOP members. One of the questions surrounding this topic is whether or not concentrating Bakken brine during the treatment process will result in precipitation of NORM (naturally occurring radioactive material). Geochemical modeling using PHREEQC to evaluate the potential for scale and NORM precipitation in Bakken produced water was completed, and the results were compiled into a report during this quarter. The report will undergo internal review this next quarter before being provided to select BPOP members for review.

**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 fluids production 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.

**Facility Process Optimization Task**

The overall goal of this task is to apply process simulation to the operation of Bakken surface facilities to improve performance, reduce emissions, and ultimately streamline operating costs. These 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 quarter, this task focused on the issue of weather-induced changes to crude oil vapor pressure. Typically, vapor pressure specifications 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 from two BPOP member sites. Specific accomplishments during the quarter included the following:

- Modeling was completed for two member surface facilities regarding the effects of cold-weather operation on oil vapor pressure. The analysis included predicting performance of the as-sampled facilities and evaluating design changes that could ensure vapor pressure compliance during cold weather.
- Results from this study were summarized into a short technical brief and an accompanying set of presentation slides for dissemination to the BPOP membership.
- Individual teleconferences were held with both BPOP members that provided data to the study. During each call, preliminary modeling results were discussed and helpful improvements were noted.
- A summary presentation of the cold-weather vapor pressure modeling work was provided to BPOP members during the Annual Members Meeting on August 8, 2018.

**Aromatic/Aliphatic Study Task**

Analyses at the EERC of the aromatic and aliphatic hydrocarbons in rock core samples from across the Williston Basin have shown that the aromatic/aliphatic ratios (A/A ratios) are ca. 4- to 10-fold higher in the source rocks (Upper and Lower Bakken shales) than in the Middle Bakken and Three Forks reservoir rocks typically targeted for oil production. High A/A ratios are always associated with the less thermally mature oil in the Upper and Lower Bakken shales, and lab studies suggest that they can be used to better understand both thermal maturity in the shales and oil migration across the Williston Basin. A/A ratios in oil samples from closely spaced Middle Bakken and Three Forks wells show varying contributions of the adjacent shales to produced crude oil, and suggest that monitoring the A/A ratios over the life of a well could reveal changes in the relative contribution of the adjacent shales to produced oil and, therefore, assist in well management decisions over the life of the well. Studies on rock core samples are continuing to increase the understanding of thermal maturity and oil migration across the Basin, and crude oil samples collected temporally during oil production from several wells are being analyzed to determine the efficacy of using A/A ratios to facilitate well management.

- Data reduction is continuing on the 40 Lower and Upper Bakken shale samples that were extracted and analyzed as reported in previous quarters, 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 reported in the last quarter. 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.
- 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 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.
- An update of these experiments and the results to date was presented at the BPOP Annual Members Meeting.

**Environmental Support Task**

The environmental support task was largely focused on providing assistance to our members on issues related to brine and hydrocarbons spills and the associated cleanup. In addition to spill remediation-related efforts, EERC staff participated in activities associated with wellsite emissions and the like.

Activities during this quarter included the following:

- EERC staff continued the process of updating the North Dakota Remediation Resource Manual with additional hydrocarbon remediation text based on information presented during the North Dakota Department of Health education days. This included facilitating several conference calls with contributing authors from Oasis Petroleum to review draft text.

**Program Management and Development**

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 agenda is provided in Appendix D. 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.

Charles 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 analysis study, SWD modeling, vapor pressure modeling, environmental support activities, and statistical analysis of production data. A copy of the presentation is provided in Appendix C.

A 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 members 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.

**FUTURE ACTIVITIES**

The planned activities for the next quarter are detailed 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 quarter 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 member 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 upcoming activities for this task 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. 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.

**Reservoir Performance Modeling Task**

The activities under the current scope of work are complete. External member 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 expanding and reviewing simplistic spreadsheet models to evaluate the area of influence of SWD wells. The spreadsheet models will also be presented to the 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 task 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 quarter include ongoing collaboration with the Canadian Geological Survey and compilation of the aromatic/aliphatic results for the rock samples that have been analyzed to date. 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.

Updated 12/17/2018