EERC
Energy & Environmental Research Center
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November 1, 2019

Ms. Karlene Fine
North Dakota Industrial Commission
ATTN: Oil and Gas Research Program
State Capitol – 14th Floor
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840

Dear Ms. Fine:

Subject: EERC Proposal No. 2020-0073 Entitled "Bakken Production Optimization Program 3.0" in Response to the North Dakota Industrial Commission Oil and Gas Research Program Solicitation

The Energy & Environmental Research Center (EERC) is pleased to propose a continuation of a well-established research program that encourages and promotes the use of new technologies that have a positive economic and environmental impact on oil and gas exploration and production in North Dakota.

Enclosed please find an original and one copy of the subject proposal along with a check for $100. The EERC, a research organization within the University of North Dakota, an institution of higher education within the state of North Dakota, is not a taxable entity; therefore, it has no tax liability.

This transmittal letter represents a binding commitment by the EERC to complete the project described in this proposal. If you have any questions, please contact me by telephone at (701) 777-5355, by fax at (701) 777-5181, or by e-mail at cgorecki@undeerc.org.

Sincerely,

Charles D. Gorecki
CEO

CDG/kal

Enclosures

c/enc: Brent Brannan, OGRC

Oil and Gas Research Program

North Dakota

Industrial Commission

Application

Program Title: Bakken Production Optimization Program 3.0

Applicant: Energy & Environmental Research Center

Principal Investigator: Charles D. Gorecki

Date of Application: November 1, 2019

Amount of Request: $6,000,000

Total Amt. of Proposed Project: $12,000,000

Duration of Project: 3 years

Point of Contact (POC): Charles D. Gorecki

POC Telephone: (701) 777-5355

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POC Address:

15 North 23rd Street, Stop 9018

Grand Forks, ND 58202-9018

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ABSTRACT

The Energy & Environmental Research Center (EERC) proposes a 3-year extension of the existing and highly successful Bakken Production Optimization Program (BPOP). The first 6 years of BPOP were sponsored by the North Dakota Industrial Commission (NDIC) Oil and Gas Research Program (OGRP) and many of the Williston Basin's premier operating companies.

Objective: To continue to offer solutions to optimize petroleum production and reduce the environmental impacts of the development of Bakken resources in North Dakota.

Expected Results: Results will include increased well productivity and economic output of North Dakota's oil and gas resources, decreased environmental impacts of wellsite operations, and guidance to stakeholders regarding optimal, prudent development of North Dakota's Bakken petroleum resources.

Duration: 3 years (May 1, 2020 – April 30, 2023).

Total Program Cost: The total value of the project is $12,000,000. This proposal requests $2,000,000 annually for 3 years ($6,000,000 total) from OGRP. The U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL) will provide $1,500,000 of cash. Liberty Resources, LLC (Liberty) will provide in-kind contributions (valued at $4,000,000) in the form of an enhanced oil recovery pilot test. Consistent with the first 6 years of this program, the EERC anticipates sustained industry partnership and stakeholder engagement in the form of annual partnership fees. Those contributions will be reported to NDIC as received, increasing the total value of the program. The attendant budget includes $500,000 from annual partnership fees. The full value of these fees is anticipated to exceed $2,000,000.

Participants: DOE NETL and Liberty have committed to provide initial cost share. The EERC anticipates the ongoing support of at least six companies, such as ConocoPhillips; Equinor; Hess Corporation; Oasis Petroleum, Inc.; Petro-Hunt; WPX Energy; and/or XTO Energy, which have engaged in cofinancing BPOP during previous project activities. Additional partners are anticipated to join as the program continues.

PROJECT DESCRIPTION

The Energy & Environmental Research Center (EERC) proposes to extend the scope of the existing and highly successful North Dakota Industrial Commission (NDIC) Oil and Gas Research Program (OGRP)-sponsored Bakken Production Optimization Program (BPOP), managed by the EERC. The EERC proposes a 3-year continuation of this program that optimizes petroleum production in North Dakota. The proposed extension is a continuation of the collaborative effort between the state of North Dakota, North Dakota's petroleum industry, and the U.S. Department of Energy (DOE) to develop solutions to challenges in the Bakken. Accomplishments over the past 6 years are provided in Appendixes A and B.

Industry and state stakeholders have expressed a desire to maximize productivity of individual wells and drill spacing units (DSUs), increase the ultimate recovery of oil, and minimize the environmental impact of operations in the Bakken. Industry and the state are collectively interested in minimizing costs associated with managing fugitive emissions, produced water, oil conditioning for transport, and flared gas. The proposed efforts will address challenges in these areas.

Continuing BPOP offers an opportunity for North Dakota to continue its investment in the future of the state. The success of BPOP to date suggests a high likelihood of significant return on investment. Throughout the first 6 years of the program, the EERC has demonstrated that the strength of BPOP rests in its ability to rapidly address ever-changing technical priorities. It is envisioned that there will be an ongoing need to adapt and meet those challenges, both anticipated and unanticipated. Key questions that will be addressed during the next 3 years of BPOP include:

- How do we move Bakken enhanced oil recovery (EOR) from pilot to commercial scale?
- What is the best development strategy for Bakken and Three Forks resources over the next decade?
- How do we manage long-term, large-volume water and rich gas coproduction?
- How can recent technology advances (e.g., artificial intelligence, machine learning [ML], big data analytics [BDA]) be applied to oil and gas resource development in North Dakota?

Goals and Objectives: The goals of the proposed BPOP efforts are to:

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

Methodology: BPOP will continue to be organized along multiple technical topic areas as state and industry priorities dictate. The flexibility of the stakeholder-driven program will provide the ability to address emerging issues as needed. The research topic areas, described below, fall into four broad categories: 1) surface operations and infrastructure investigations, 2) subsurface investigations, 3) EOR, and 4) ML and BDA applied to the Bakken.

1. Surface Operations and Infrastructure Investigations

Surface activities include work related to production facilities, characterization of produced fluids (i.e., gas, oil, and water), and other production optimization tasks not related to the reservoir. These activities contribute to improved understanding of the materials being produced, increased efficiency in their processing and handling, and improved waste management. Specific focus areas are described below.

Process Optimization – Processing produced fluids from the well to market, although simple when described in a basic flow diagram, is complicated by dynamic and variable production rates and fluids composition, extreme climate, complex business and financial models, and evolving regulations. By working with BPOP partners, the EERC can systematically analyze trends by assimilating data and information from multiple operators, assist in defining the challenges to improved process efficiency, and identify technological and operational solutions through process modeling and system design. Through BPOP, the EERC will continue to serve existing and new North Dakota Petroleum Council (NDPC) task force groups established to address challenges such as flaring, vapor pressure compliance, and emissions.

Fluids Characterization – The optimization of crude oil production in North Dakota requires accurate understanding of the fluids being produced. Crude oil, associated gas, and produced water are complex mixtures, and their chemical and physical properties can vary geographically over the life of a well. Over the first 6 years of BPOP, a large amount of fluids data has been acquired, and a database of fluids information has been created. The EERC will continue to maintain and expand this valuable database and coordinate data gathering and sampling and analysis activities to support the other technical tasks. Additionally, the purchase of a crude oil analyzer capable of providing compositional information about the complex mixture that constitutes crude oil is proposed. This analyzer will provide data to support fluids characterization and computational modeling of wellsite process equipment.

2. Subsurface Investigations

Several activities will support subsurface investigations beyond EOR, including evaluation of factors controlling reservoir drainage and production efficiency, assessment of trends in well completion and fluids production, well completions optimization, and assessment of produced water management options.

Investigation of Improved Reservoir Drainage and Production Efficiency – Improving the efficiency of reservoir drainage and subsequent production operations is critical to improving ultimate recovery from Bakken wells. BPOP will continue to investigate the impact and interactions of phase behavior, well spacing, changing GOR (gas-to-oil ratio), allocation of produced oil to its source interval, and associated gas reinjection on resource recovery and system performance. Knowledge gained from this activity will help to guide well-spacing optimization, DSU development, and production facility design and operation.

Well Completions and Fluids Production Trend Analysis – Overall trends in well completion practices and fluids production will be evaluated to better understand reservoir performance as a whole and to predict future gas and water production volumes. This information will be used to evaluate potential impacts to surface infrastructure, including future gas-gathering and transportation needs as well as potential future saltwater disposal (SWD) requirements.

Well Completions Optimization – As a result of interest from the state and industry, a key focus of BPOP 2.0 was evaluation of the production performance of refractured Bakken wells. As advancements are made in both fracturing and refracturing techniques, the EERC will continue to assess the performance of different completion techniques on well performance. This activity will include evaluation of parameters such as well spacing, treatment size, and completion type on the production of oil, gas, and water from hydraulically fractured and refractured wells.

Produced Water Management – Produced water disposal into the Inyan Kara Formation and the resulting local pressurization issues created by SWD continue to be topics of interest to BPOP partners. BPOP will continue to assess options for produced water management, including the feasibility of recycling and reuse, SWD into other subsurface targets, or possible reinjection into the Bakken for pressure maintenance.

3. Enhanced Oil Recovery

The goal of the EOR task is to develop knowledge that will support broad commercial implementation of EOR in the Bakken play. Previous BPOP EOR activities have demonstrated that injected fluids can be contained within a DSU and that injectivity is not a constraint on operations. Liberty Resources, LLC (Liberty) has expressed a desire to conduct a new Bakken EOR pilot at a new location, with elements of the pilot being conducted as part of BPOP 3.0. Lessons learned from EOR testing by Liberty under BPOP 2.0 will be applied toward the design and execution of that new EOR pilot. Key findings will be available to the partners. Specific EOR activities are described below.

Rich Gas–Oil Fluid Behavior and Rock Extraction Studies – Previous laboratory testing on oil and rocks has shown that differences in rich gas composition as an EOR injection gas can affect minimum miscibility pressure (MMP) values as well as the ability of the injected gas to mobilize oil from Bakken and Three Forks rocks. Laboratory investigations will be conducted to determine the effect of different potential injection gas mixtures on the MMP of oil from the new pilot reservoir. These studies will also examine the fluid's ability to recover oil from rock samples collected in the area of the new pilot test. An atomic force microscopy-based infrared spectroscopy (AFM-IR) system will be used to better understand

the hydrocarbon content and extractability within the Bakken petroleum system (including the shales) to assess the efficacy of using different rich gas blends for EOR. The AFM-IR system will also be used to evaluate the geomechanical properties of Bakken rocks pre- and postexposure to different rich gas blends. The laboratory data will support the design and execution of the new pilot and provide information applicable to all partners.

Modeling of EOR Reservoir Components – Static geocellular modeling of the Bakken petroleum system at the new pilot location and dynamic simulations of potential EOR schemes will be used to predict scheme performance and support the design of the new pilot test. A geocellular model of the pilot DSU will be created using data from the NDIC well file database and data provided by the operator. A history-matching exercise using detailed operational data will be used to validate the geocellular model. The validated model will serve as a platform for dynamic simulations of various potential pilot test schemes.

Pilot Performance Assessment – An assessment of pilot test performance is essential to determine the technical and economic viability of commercial-scale Bakken EOR. A reservoir surveillance plan will be developed by the EERC in close collaboration with Liberty. The deployment of reservoir surveillance and operational monitoring equipment will be conducted by Liberty. Data generated by the pilot monitoring equipment will be processed and interpreted by EERC personnel. A data management system (DMS) will be developed by the EERC to support reservoir surveillance and data interpretation activities. A server will be purchased to support the operation of the DMS.

4. ML and BDA Applied to the Bakken

ML and BDA (which are considered components of "artificial intelligence") can provide valuable insights into production activities and support program partners' ability to increase production efficiency in North Dakota. As part of the EERC's ongoing Fossil Energy Research Cooperative Agreement (No. DE-FE0024233) with DOE through NETL, DOE has recently committed $1,500,000 to support EERC efforts to apply ML and BDA toward EOR in the Bakken.

The EERC will conduct activities that use ML and BDA to address questions related to improving EOR operations and developing long-term strategies for overall Bakken resource development. The ML and BDA efforts will include development of real-time visualization, forecasting, and control (RTVFC) tools to improve and streamline reservoir surveillance and virtual learning tools to support optimized EOR strategies at larger scales. These activities will demonstrate the role ML and BDA can play in improving the technical and economic feasibility of EOR in the Bakken, as well as inform long-term oil and gas development strategies for North Dakota. Specific ML and BDA activities are described below.

RTVFC Tools for Improved Reservoir Surveillance – The EERC will apply ML and BDA to reservoir surveillance data from Bakken pilots. These efforts will yield a data-to-knowledge tool that will accelerate the process from data collection to data interpretation and through data integration so that subsurface conditions can be understood more quickly. Data from Bakken EOR tests available from NDIC and/or BPOP partners will be used to develop and validate RTVFC tool concepts on DSU and multi-DSU scales to enable enhanced control of subsurface operations. These activities will result in RTVFC tools that can be applied to future pilots and/or commercial operations.

Virtual Learning Tools to Investigate Alternative Injection Scenarios – The application of ML and BDA to data sets from field tests will support the development of virtual learning for Bakken EOR. ML and BDA interjected into current reservoir simulations can increase the efficiency of computation and solving of complex problems to understand key mechanisms during the EOR process. Use of virtual learning tools for EOR will allow operators to rapidly explore and test various strategies for optimizing reservoir development and management, operations, and monitoring designs. Virtual learning will be used to integrate factors such as water injection, timing of injection, and coordination of operations across multiple DSUs into next-generation modeling of alternative injection scenarios for the Bakken.

Anticipated Results: BPOP will continue to provide the state and industry with knowledge to address key issues related to production optimization. The EERC anticipates the results of BPOP will likely lead to increased well productivity and economic output, decreased environmental impacts of operations, and improvements in the ability of the state to anticipate development trends and plan accordingly.

Facilities, Resources, and Techniques to Be Used: The EERC employs a multidisciplinary staff of about 200 and has 254,000 square feet of state-of-the-art offices, laboratories, and technology demonstration facilities, which enable staff to address a wide variety of research topics. The EERC houses eight analytical laboratories, including water resource characterization, petroleum resource characterization, and environmental chemistry. These laboratories have decades of experience and have been instrumental in previous Bakken research. The EERC has extensive geologic modeling and reservoir simulation capabilities, including high-end workstation computers and a dedicated high-performance parallel computing cluster.

Environmental and Economic Impacts While Program Is under Way: The breadth of the program means the environmental and economic impacts will be wide-ranging and difficult to predict. The first 6 years of the program are evidence of the positive impact the program has had on North Dakota environmental concerns and economics related to Bakken development, such as a revision of setback regulations. Previous BPOP impacts are outlined in the BPOP 1.0 Executive Summary provided in Appendix A, the BPOP 2.0 annual reports in Appendix B, and on the BPOP website.

Ultimate Technological and Economic Impacts: Ultimately, BPOP will provide broad technical and economic impacts. Each research task will have the potential to bolster oil and gas industry operations by improving resource recovery, decreasing costs, reducing environmental impacts, and increasing revenue. With original oil in place (OOIP) estimates for the Bakken Petroleum system ranging from 300 to 900 billion barrels, the impact of successful EOR operations alone could extend the lifetime of the play by decades, yielding billions of barrels of incremental oil and billions of dollars of economic impact to North Dakota.

Why the Project Is Needed: The last 6 years of this program resulted in unprecedented cooperation among state and industry partners in addressing headline issues. Multiple program partners have openly stated that the type of cooperation facilitated by this program exists nowhere else in the petroleum industry. BPOP efforts to date are summarized in Appendixes A and B. It is anticipated that similar

progress can be made on critical topics such as EOR, future resource development strategies, rich gas and fugitive emissions management, produced water management, and other topics over the next 3 years.

STANDARDS OF SUCCESS

Success will be measured in the program's ability to address the oil and gas industry's critical issues as identified by OGRP and BPOP partners, ultimately resulting in more efficient resource development and cost savings. Developing options to help ensure the success of the oil and gas industry in North Dakota while conserving the state's resources leads to a strong state economy and the creation of jobs to support all aspects of oil and gas development. Annual meetings with OGRP and BPOP partners will be held, as a measure of success, to discuss project status and receive feedback and guidance. Success will also be measured by delivery of high-impact products to state and industrial stakeholders that meet the goals of BPOP.

The current OGRP-approved process of reporting will be employed to deliver results. BPOP partnership provides partners premium access to reporting of results from BPOP activities for a period of 15 months following review by select partners prior to release to the public on the BPOP website. Annual topical reports will be prepared in each of the four research areas, with specific topics to be determined based on the partnership-guided activities. These reports will be available to BPOP partners for 15 months prior to release to the public. High-level progress updates will be provided in quarterly reports, in an executive summary format, to OGRP for inclusion on the OGRP website for immediate access by the public. An annual briefing to OGRP will highlight the successes of BPOP and next steps. A final report summarizing BPOP program achievements and challenges will be prepared. Presentations at technical conferences and public outreach events will cover pertinent topic areas.

BACKGROUND/QUALIFICATIONS

The EERC is a high-tech, nonprofit branch of the University of North Dakota. Resumes of key personnel are provided in Appendix C. Charles Gorecki, EERC CEO, will serve as Program Manager. John Harju, EERC Vice President for Strategic Partnerships, will serve as Senior Program Advisor. Other key EERC

personnel will include James Sorensen, EERC Director of Subsurface R&D; Bethany Kurz, EERC Assistant Director for Integrated Analytical Solutions; Chad Wocken, EERC Assistant Director for Transformational Energy; and Loreal Heebink, Senior Project Management Specialist.

MANAGEMENT

The EERC manages over 200 contracts a year, with a total of more than 1330 clients in 53 countries. Systems are in place to ensure that projects are managed within budget, schedule, and scope. Mr. Gorecki will oversee the entire program, with assistance in management of program activities and tasks by Ms. Kurz, Mr. Sorensen, and Mr. Wocken. This will involve integration of tasks, public outreach to communities and local stakeholders, program reporting, collaboration with industry and OGRC, recruiting of new partners, and strategic studies. The EERC will be responsible for coordination and execution of tasks, with assistance provided by program partners, and will disseminate results. Quarterly reports will be submitted to NDIC and partners 30 days after the end of each calendar quarter to provide highlights of ongoing research and anticipated future activities. A program kickoff meeting will be scheduled for summer 2020 to prioritize research areas with input from state and industry. At minimum, annual meetings will be scheduled to provide updates on research activities and discuss the direction of future activities.

TIMETABLE

This effort is proposed as a 3-year program (May 1, 2020 – April 30, 2023). Figure 1 summarizes the preliminary program timetable. Additional timetable detail will be developed as the program evolves.

BUDGET

The total estimated cost for the proposed effort is $12,000,000. $6,000,000 is requested from OGRP ($2,000,000/year). Cost share will include $1,500,000 cash from DOE. Liberty will provide in-kind cost share at a value of $4,000,000, which will include costs associated with acquisition of working fluids, compression, pilot design, well preparation, reservoir surveillance and monitoring, and pilot operations. Letters of commitment can be found in Appendix D. Current partner companies have expressed a desire

Figure 1. Preliminary program timetable.

to continue participation in the program. The current budget includes an anticipated $500,000 of these partnership fees. The budget shown in Table 1 is based on previous EERC experience with large programs such as the proposed. Budget justification can be found in Appendix E. The purchase of a crude oil analyzer capable of providing compositional information about the complex mixture that constitutes crude oil is proposed. This analyzer will provide data to support fluids characterization and computational modeling of wellsite process equipment. The purchase of a server is proposed to host software license files and GIS (geographic information system) data files and to support the operation of the DMS. The purchase of a high-end workstation is proposed under the DOE match, which will ensure researchers have sufficient computer capacity to perform ML activities.

CONFIDENTIAL INFORMATION AND PATENTS/RIGHTS TO TECHNICAL DATA

This proposal has no confidential information. No patentable technologies are expected to be created.

Table 1. Budget Breakdown

Project Associated Expense	NDIC Share	Industry Share	Federal Share	Total Project
Direct Costs				
Labor	$ 3,299,112	$ 292,016	$ 908,597	$ 4,499,725
Travel	$ 109,921	$ 10,500	$ 37,675	$ 158,096
Equipment > $5000	$ 72,797	$ -	$ 11,800	$ 84,597
Supplies	$ 115,475	$ 5,056	$ 32,793	$ 153,324
Communications	$ 1,292	$ -	$ 230	$ 1,522
Printing & Duplicating	$ 4,373	$ -	$ 280	$ 4,653
Food	$ 7,500	$ -	$ -	$ 7,500
Laboratory Fees & Services				
Natural Materials Analytical Research Lab	$ 12,214	$ -	$ -	$ 12,214
Process Chemistry & Development Lab	$ 37,079	$ -	$ -	$ 37,079
GC/MS Lab	$ 230,197	$ -	$ -	$ 230,197
Graphics Services	$ 36,571	$ -	$ 7,982	$ 44,553
Software Solution Services	$ 34,012	$ -	$ 1,280	$ 35,292
Technical Software Fee	$ 22,520	$ -	$ -	$ 22,520
Engineering Services Fee	$ 15,030	$ 2,986	$ -	$ 18,016
Total Direct Costs	$ 3,998,093	$ 310,558	$ 1,000,637	$ 5,309,288
Facilities & Administration	$ 2,001,907	$ 189,442	$ 499,363	$ 2,690,712
Total Cash Requested	$ 6,000,000	$ 500,000	$ 1,500,000	$ 8,000,000
In-Kind Cost Share				
Liberty	$ -	$ 4,000,000	$ -	$ 4,000,000
Total In-kind Cost Share	$ -	$ 4,000,000	$ -	$ 4,000,000
Total Project Costs	$ 6,000,000	$ 4,500,000	$ 1,500,000	$ 12,000,000

BPOP 2.0 partners included ConocoPhillips; Equinor; Hess Corporation; Oasis Petroleum, Inc.; Petro-Hunt; WPX Energy; and XTO Energy and are anticipated to participate in BPOP 3.0.

STATUS OF ONGOING PROJECTS

The EERC is currently engaged in four OGRP-funded projects. These ongoing projects, listed in Table 2, are current on all deliverables.

Table 2. Current EERC Projects Funded by OGRP

Project Title	Contract Award #
Plains CO_2 Reduction Partnership – Phase III	G-015-030
Bakken Production Optimization Program 2.0	G-040-080
NDIC Emerging Issues	G-000-004
iPIPE: Intelligent Pipeline Integrity Program	G-046-88
Underground Storage of Produced Natural Gas – Conceptual Evaluation and Pilot Project(s) (HB 1014)	G-049-092

APPENDIX A

BAKKEN PRODUCTION OPTIMIZATION PROGRAM 1.0
EXECUTIVE SUMMARY

Bakken Production Optimization Program

EXECUTIVE SUMMARY

A premier public–private partnership harnessing the best minds in North Dakota and in industry to **maximize productivity of the Bakken oil play** while simultaneously reducing its environmental footprint.

This summary of Bakken Production Optimization Program (BPOP) achievements at the end of calendar year 2015 was produced at the request of the **North Dakota Industrial Commission (NDIC)** and the associated **Oil and Gas Research Program,** which funded a portion of the work performed in this program. This summary is intended for public distribution and is intended to relay the ongoing successes of this **premier public–private partnership** in advancing North Dakota's economic and environmental interests directly related to exploration and production of oil from the Bakken and Three Forks Formations.

BAKKEN PRODUCTION OPTIMIZATION PROGRAM

BAKKEN PRODUCTION OPTIMIZATION PROGRAM

In June 2013, a consortium comprising the Energy & Environmental Research Center (EERC), Continental Resources, Inc., and several of the largest oil producers in the state was awarded North Dakota Oil and Gas Research Program funding to complete a 3-year, $117 million project with the **goal of improving Bakken system oil recovery** while simultaneously reducing its environmental footprint. The program was designed to accomplish the following:

- Maximize oil production from Bakken and Three Forks wells by employing an "all of the above" approach
  - Perform reservoir characterization
    - Develop data sets to determine whether the oil of the second and third benches in the Three Forks Formation should be considered separate and unique from those of the first bench
    - Predict future reservoir sweet spot areas
  - Improve drilling/stimulation/completion/production techniques and sequences
    - Determine optimal well spacing for development in the Middle Bakken and first, second, and third benches of the Three Forks
- Optimize wellsite surface operations
  - Reduce operating costs
  - Reduce development and operations impacts to surrounding landowners
  - Reduce demands on surrounding infrastructure and water resources

THE HAWKINSON PROJECT

$112M

- Drilling 11 New Wells
- Completions
- Reservoir Engineering
- Expansion Applications via 3-D Seismic

Pilot hole logs, core data, other data gathering from multiple wells to create a 3-D picture of what happens during and after the hydraulic fracture treatments in a multistage horizontal well. Continental analyzed this data set to:

- Assess total resource available in the second and third benches of the Three Forks Formation.
- Confirm whether these benches are distinct and independent of the existing Middle Bakken.
- Predict areas of future sweet spots.

EERC

$4.5M

- Optimization of Wellsite Operations

Site logistics, waste management, on-site hydrocarbon utilization, water management, process optimization, and systems failure analysis with an eye on decreased environmental impact.

> *The Bakken Production Optimization Program is a remarkable example of how state and industry can and do work together to better define the North Dakota petroleum resource and to maximize productivity of the E&P work in the state.*
>
> –Jessica Unruh, North Dakota Senate District 33

ANTICIPATED OUTCOMES

ECONOMIC

- Increased well productivity and economic output of North Dakota's oil and gas resources.
- Increased revenue for the state, royalty owners, and operators from added product streams captured earlier in the well's life cycle.
- Reduced demand for infrastructure construction and maintenance.
- Reduced road maintenance costs, wastewater production, waste disposal costs, and freshwater use.
- Significant increases to estimates of recoverable hydrocarbons.

ENVIRONMENTAL

- Decreased environmental impacts of wellsite operations.
- Less truck traffic, resulting in decreased diesel emissions, road dust, and spills.
- Reduced land use impacts.
- Reduced gas flaring.
- Evaluation of technologies to recycle wastewater and decrease freshwater demand.
- Improved TENORM (technologically enhanced naturally occuring radioactive material) waste disposal operations.

EDUCATIONAL

- Greatly increased understanding of Bakken–Three Forks reservoirs.
- Public education and outreach.

Serving on Energy and Natural Resources has allowed some insight and perspective useful for judging our oil and gas play. BPOP is helping greatly to bring efficiency, innovation, and coordination as we had hoped it would when creating this public–private entity.

–Phil Murphy, North Dakota Senate District 20

A PREMIER PARTNERSHIP

This program has been cited as an exemplary model by others nationwide. It has demonstrated that state lawmakers, state regulators, and industry can work together for positive results for shareholders and taxpayers alike.

PUBLIC–PRIVATE

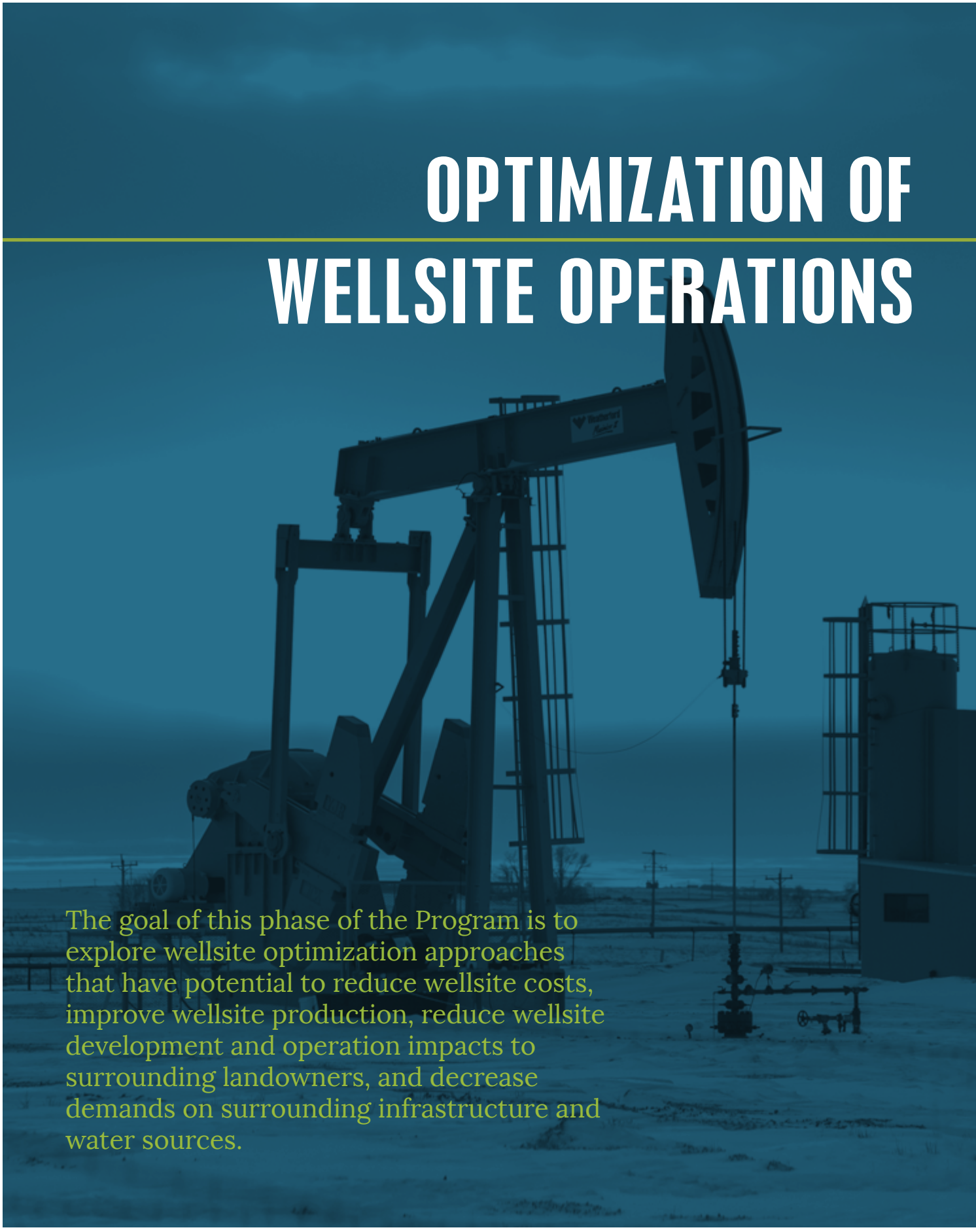
BPOP has demonstrated how effective a public–private partnership can be. Significant achievements directly attributable to this program have made measurable, positive impacts to how the business of oil and gas exploration and production is accomplished in North Dakota. This program has been cited as **an exemplary model** by others nationwide. It has demonstrated that state lawmakers, state regulators, and industry can work together for positive results for shareholders and taxpayers alike.

This document contains a **high-level summary** of the significant work performed by a public–private team, with each member pulling in the same direction. The work of this program has yielded **scientific results that will increase economic benefit** to the state of North Dakota, its landowners, its mineral rights holders, and the industry driving the shale revolution while simultaneously decreasing the impacts of this industrial activity on the environment of North Dakota and the region.

PROGRAM MEMBERS

- Continental Resources, Inc.
- Marathon Oil Corporation
- Whiting Petroleum Corporation
- North Dakota Oil and Gas Research Program
- ConocoPhillips Company
- Nuverra Environmental Solutions
- Hitachi
- Hess Corporation
- Oasis Petroleum, Inc.
- SM Energy
- XTO Energy, Inc.

OPTIMIZATION OF WELLSITE OPERATIONS



The goal of this phase of the Program is to explore wellsite optimization approaches that have potential to reduce wellsite costs, improve wellsite production, reduce wellsite development and operation impacts to surrounding landowners, and decrease demands on surrounding infrastructure and water sources.

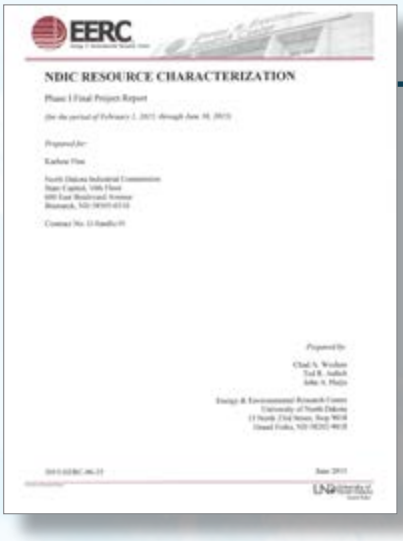
The EERC is conducting activities for Optimization of Wellsite Operations. These activities were driven by the common needs of all Program members. In general, the Program is addressing the headline issues of 2013–2016. Flaring reduction, TENORM disposal, and saltwater spills all became focus areas of the Program. Opportunities for improved water use and handling were also addressed within Program activities. The Program also collaborated with the EERC's ongoing activities with the U.S. Department of Energy (DOE) on the topic of improvements to methodologies of crude oil characterization for purposes of rail transport safety.

The goal of this phase of the Program is to **explore wellsite optimization approaches** that have potential to reduce wellsite costs, improve wellsite production, reduce wellsite development and operation impacts to surrounding landowners, and decrease demands on surrounding infrastructure and water sources.

Following is a summary of major activities in which the Program was engaged during the 2013–2015 period of performance.

> *Hess has been very pleased to participate in the Oil and Gas Research Program. This effort has brought the state's collective intellect and experience together on a significant challenge: improving the overall oil recovery from the Bakken and Three Forks reservoirs.*
>
> –Stephen McNally, General Manager – North Dakota, Hess Corporation

FLARING REDUCTION



Flaring Task Force

The EERC supported the North Dakota Petroleum Council's (NDPC's) Flaring Task Force at the direction of BPOP membership. As the Flaring Task Force formulated a multistage plan to decrease flaring rates, BPOP provided flaring statistics analysis that served as the foundation for these plans. The BPOP team presented the resulting plan to the Governor in January 2014. This plan was eventually endorsed by the Governor and is now integral to regulations enforced by the North Dakota Department of Mineral Resources.

Flaring Database

The EERC supported Program membership in their efforts to implement technologies and practices to utilize stranded wellhead gas and reduce gas-flaring volumes by creating a database containing 65+ technologies that claim to utilize wellhead gas economically for beneficial purposes. This database continues to add technologies and is used by industry to screen potential solutions to stranded gas challenges. The database can be examined at www.undeerc.org/Flaring_Solutions/Search.aspx.

Flaring Fact Sheet

A series of fact sheets was created to educate and inform the general public on key Bakken headline issues from 2013 to 2015. The flaring fact sheet explains what associated gas is, why flaring occurs, how flaring is regulated, and what North Dakota is doing to reduce flaring.

Crude Oil Characterization

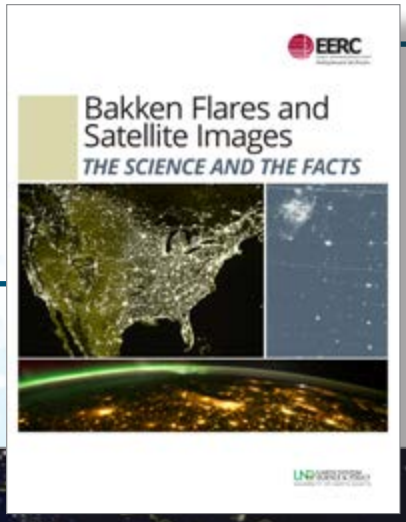
Rail accidents that occurred between 2013 and 2015 involving unconventional crude oil raised questions about the safety of rail transport of crude oil. In an effort to address these questions, DOE commissioned a study to investigate the properties of crude oil as they relate to its safe handling and transport. DOE contracted Sandia National Laboratories to conduct the study, and the EERC was contracted to provide technical support in execution of the project. In parallel, NDIC established a contract with the EERC to enable greater participation in the project and fund progress reporting to NDIC.

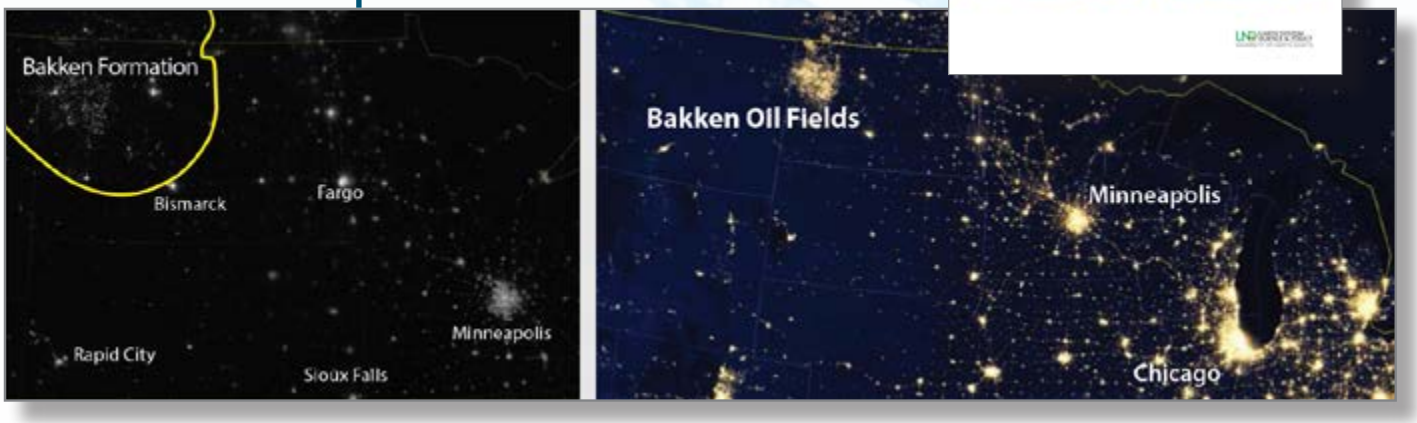
The key objectives of the crude oil characterization research project are to characterize and define tight crude oils based on their chemical and physical properties and to identify properties that could contribute to an increased potential for accidental combustion. The project scope of work consists of two primary tasks:

1. A literature survey of public sources of information on crude oil properties.
2. A conceptual crude oil characterization plan that describes the necessary sampling and the analytical and experimental activities needed to provide a comprehensive characterization of crude oil properties.

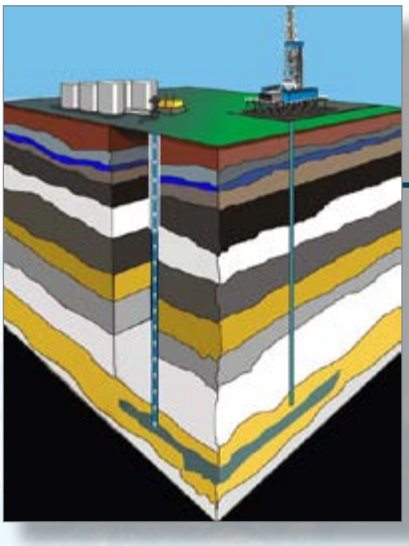
These Phase I tasks have been completed. The Phase I report, summarizing publicly available information on crude oil properties, was released in June 2015, and is available at http://energy.sandia.gov/tight-oil-study/. Additionally, work has begun on preparation of a crude oil characterization plan that will outline the tasks needed to collect the information necessary to evaluate crude oil properties and their relevance to the likelihood and severity of a combustion incident resulting from transport. A document describing the crude oil characterization plan is expected to be completed in 2016.

FLARING REDUCTION CONTINUED





WATER OPPORTUNITIES ASSESSMENT



Bakken Flares and Satellite Images Fact Sheet

Researchers from the EERC and the University of North Dakota's (UND's) Department of Earth System Science and Policy joined forces to better understand these bright satellite images. With images available through the National Oceanic and Atmospheric Administration (NOAA), improved methodologies were developed for identifying, characterizing, and processing flare images for several locations in western North Dakota.

In summary, this study produced images which, when including only light attributable to combustion sources (flared associated gas), would look more like the image at far left. This image shows faint, yet discernible, patches of light on a nighttime map of North Dakota, distinctly different from the various night sky images in newspaper and trade magazines (at left) that compare the Bakken region to New York City, Boston, and Chicago.

Bakken Water Opportunities Update

This report provides a summary of water use and handling trends in the Bakken, estimation of future water supply demand and disposal needs, an overview of potential treatment technologies, considerations for recycling and reuse, a summary of the implications of the report findings for our partners, and recommendations for future work.

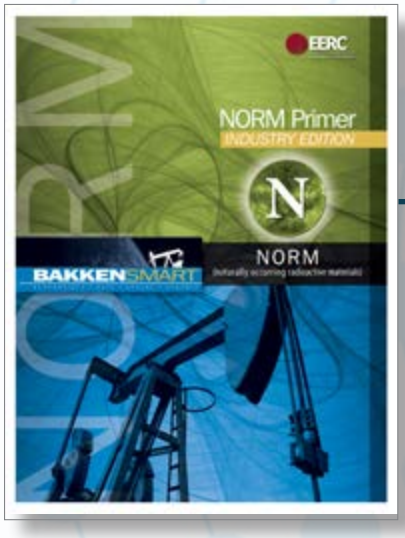
Water Fact Sheet

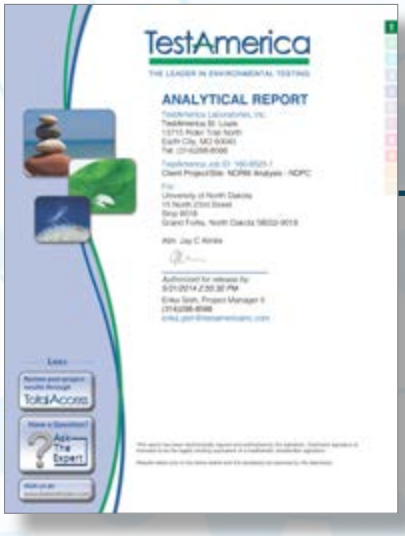
A series of fact sheets was created to educate and inform the general public on key Bakken headline issues from 2013 to 2015. The water fact sheet explains how water is used in oil and gas production, where producers obtain freshwater for operations, options available for water treatment and reuse, and water-handling costs.

Dakota Sandstone Capacity Modeling

Ongoing efforts through the optimization program are focused on evaluating the capacity of various formations in the Williston Basin as saltwater injection targets. This work will help us to better understand the volumes of brine that can be disposed of in these formations and where that additional storage capacity exists.

TENORM WASTE DISPOSAL





NORM Task Force

BPOP representatives served as subject matter experts and advisors to NDPC's NORM Task Force and to state interests throughout 2013–2015. During that period, the topic of TENORM was in the headlines regularly. Illegal dumping of filter socks from oilfield operations was casting a negative light on the state and the industry. BPOP was able to provide expert analysis on draft TENORM disposal regulations proposed by North Dakota's Department of Health (NDDH) in 2014. BPOP personnel provided public testimony before the North Dakota Legislature's Energy Development and Transmission Committee and during three public hearings held by NDDH to solicit public comments on the proposed TENORM in-state disposal rules.

NORM Fact Sheet

A series of fact sheets was created to educate and inform the general public on key Bakken headline issues from 2013 to 2015. The NORM fact sheet explains what NORM is, a layman's description of radiation, what levels of radioactivity are hazardous, how NORM is regulated in North Dakota, and how NORM waste is disposed of safely.

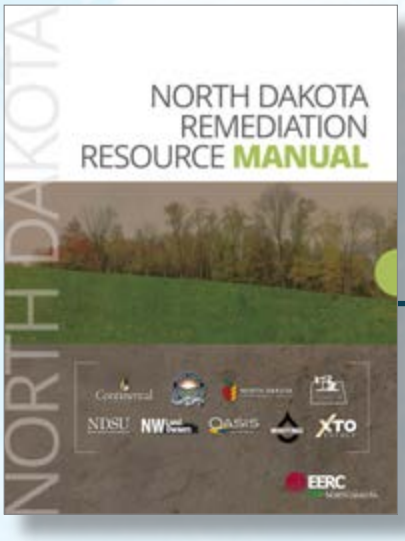
NORM Primer

The NORM Primer was produced to provide the reader with a brief, highly readable summary of the breadth of radiation science behind NORM regulations. Because radiation is one of the most complex topics in physics and because biological damage due to radiation is an inexact science, it is impossible to reduce the volume of knowledge in radiation physics to a single booklet. Therefore, this booklet was meant to provide the reader with enough information to begin asking good questions. It served as a mechanism to ensure that industry and state interests were speaking with commonality on facts.

Minisurvey of TENORM in Drill Cuttings, Produced Water, and Flowback Water

The EERC coordinated a TENORM sampling effort among several oil producers of the NDPC NORM Task Force. Fifty samples of drill cuttings, produced water, and flowback water were analyzed for radium content. The results of this survey were shared with industry and with NDDH. The EERC also supported the NORM Task Force in interpretation of the results. This work supported comments written by industry in response to NDDH's release of a draft of its new rules for in-state TENORM disposal.

SPILLS REMEDIATION



Saltwater Spills Task Force

BPOP provided subject matter expertise to NDPC's Saltwater Spills Task Force during 2014 and 2015. BPOP also enlisted the assistance of North Dakota State University's (NDSU's) Range Science, Soil Science, and Agricultural Extension Programs to ensure that all remediation and reclamation efforts for industry and the state were grounded in solid science. It is through this partnership with the EERC, NDSU, the Saltwater Spills Task Force, and industry at large that the Spills Primer and the Remediation Resource Manual were created.

Spills Fact Sheet

A series of fact sheets was created to educate and inform the general public on key Bakken headline issues from 2013 to 2015. The spills fact sheet explains the types of spills associated with oil and gas production, what happens when a spill occurs, and how spills are cleaned up and provided an objective perspective on spill statistics.

Reclamation Fact Sheet

A series of fact sheets was created to educate and inform the general public on key Bakken headline issues from 2013 to 2015. The reclamation fact sheet explains the reclamation process, who is typically involved in a reclamation project, how disturbed areas are reclaimed, and how spill sites are reclaimed.

Spills Cleanup Primer

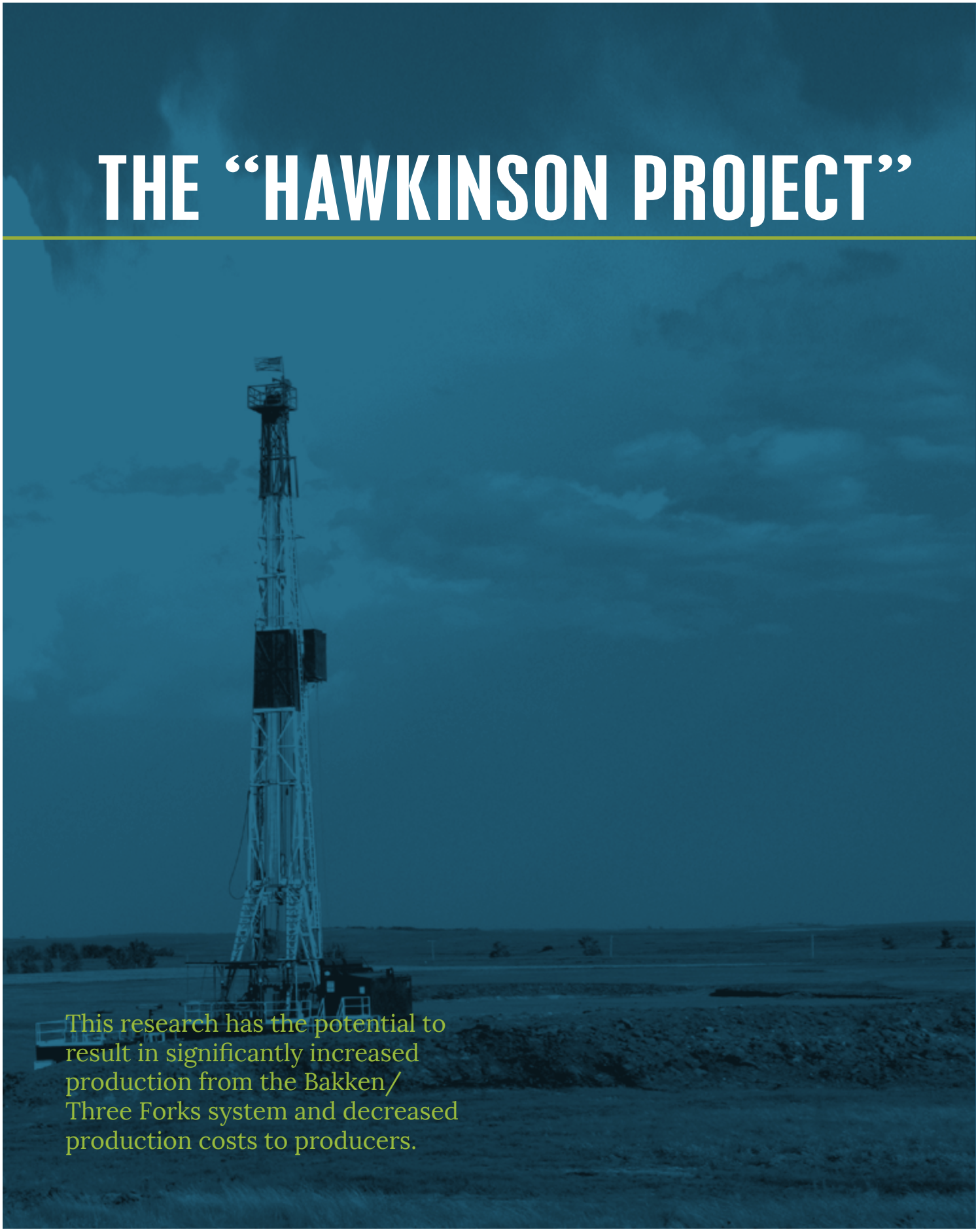
The Spills Cleanup Primer is intended to provide the reader with a fundamental understanding of hydrocarbon and brine spills from oil and gas production and the related remediation and reclamation of these spills. As oil and gas production in the Williston Basin has increased, the number and volume of spills have also increased; however, when normalized by actual volumes produced, spill rates have actually decreased. The primer is designed to inform the reader on spills, how spills are regulated, what measures are taken to minimize their impacts, and how spills are cleaned up. Material presented in this document regarding techniques, processes, and technologies to address spills is intended to be informational only; actual performance of spill-related activities will vary.

North Dakota Remediation Resource Manual

BPOP and the Saltwater Spills Task Force collaborated to create a field guide to aid those involved in the remediation and reclamation of sites impacted by oil field-related spills. Remediation information included in this document is for spills limited to soil impacts and does not address remediation related to groundwater impacts. In addition, the information is specific to the execution of these activities in North Dakota and may not be wholly applicable to other areas of the country.

This document is organized as an instruction manual with distinct sections for different topics such as soil types, spill evaluation, and determining when no further actions are necessary. This manual is based on practical, reproducible, and field-friendly procedures. Users can reference individual sections specific to their needs without having to read the entire document.

THE "HAWKINSON PROJECT"



This research has the potential to result in significantly increased production from the Bakken/ Three Forks system and decreased production costs to producers.

The Hawkinson Project, executed by Continental, was a research project aimed at **significantly increasing total production** and production rates from North Dakota oil wells where oil reserves of the second and third benches of the Three Forks Formation, located just below the Bakken oil formation, are being explored. This research has the potential to result in **significantly increased production** from the Bakken/Three Forks system and decreased production costs to producers.

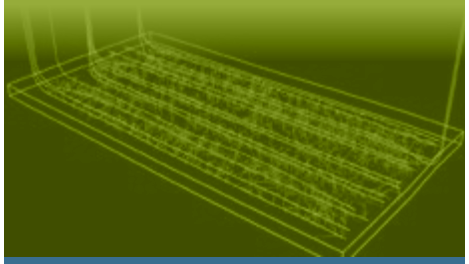
The Hawkinson Project was conducted in four phases.

PHASE I

Drilled 11 consecutive wells within a single unit and collected log and core data.

PHASE II

Completed 11 wells and collected microseismic and vertical seismic profile data.



PHASE III

Performed reservoir engineering analyses. Analyzed the data from Phases I and II. Integrated these data and analysis results into cohesive stimulation modeling and numerical reservoir simulations.

PHASE IV

Performed field acquisition, processing, and analysis of 3-D seismic survey.

A project to explore unit spacing and reservoir characteristics specific to North Dakota's Bakken/ Three Forks system.

Location of the Hawkinson Project in North Dakota.

Aerial view of surface operations associated with the Hawkinson Project.

NEED FOR THE PROJECT

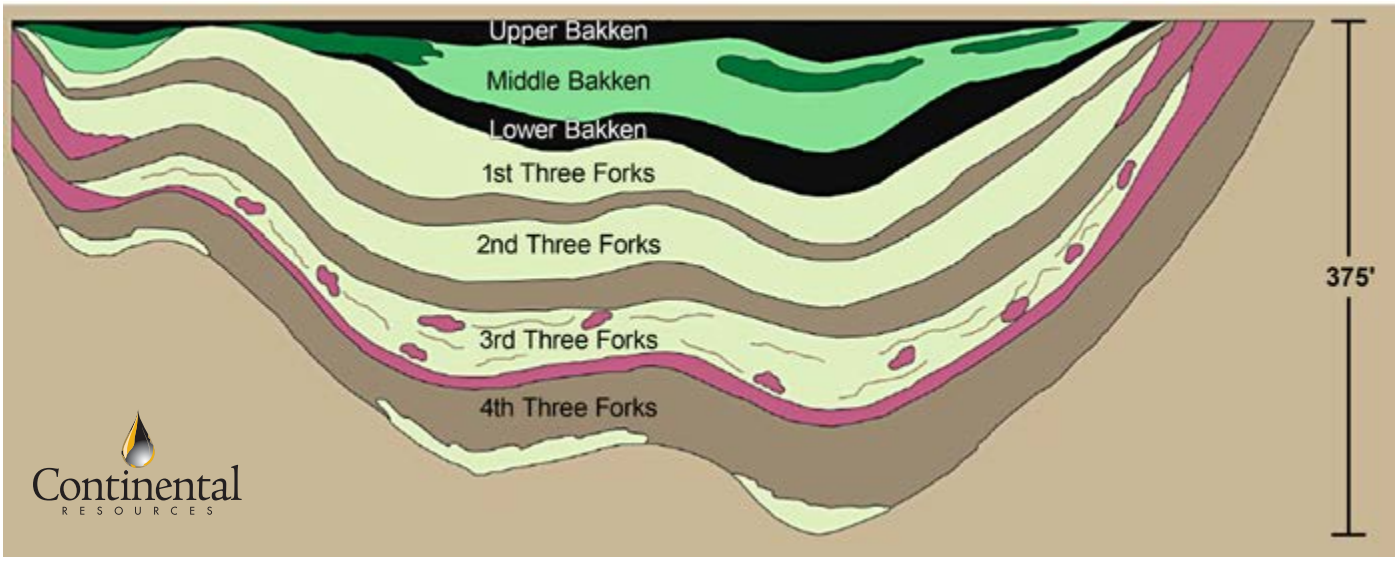
The Hawkinson Project area has already proved productive for the Middle Bakken and first, second, and third benches of the Three Forks zones. The Bakken Formation immediately overlies the Three Forks Formation. This stratigraphic relationship combined with geochemical similarities of the respective formation fluids has led many in the Williston Basin to theorize that the Three Forks zone is in communication with the oil-producing middle member of the Bakken. As a result, **petroleum resource estimations have typically summed the two together**. However, Continental had previously proved in its evaluation of the Middle Bakken and first bench of the Three Forks with the Mathistad Project that **these formations are indeed separate.**

The upper three benches of the Three Forks Formation have recently **shown great promise** as potentially prolific oil-producing zones in North Dakota. The second bench of the Three Forks zone had an initial production rate of 1140 barrels of oil equivalent a day in the Continental-operated Charlotte 2-22H well. The Charlotte 3-22H had an initial production rate of 953 barrels of oil equivalent a day from the third bench of the Three Forks.

Before the completion of this project, the stratigraphic interval used by the North Dakota Oil and Gas Division to define the Bakken Pool included the Sanish zone in most North Dakota oil fields. The result of this approach was that production information specific to the Sanish was limited, making a definitive determination of the uniqueness of the different benches of the Three Forks–Sanish play difficult. Acquiring new data focused on demonstrating that the different benches in the Three Forks are separate from the Bakken has now provided the state of North Dakota and the oil industry in the state with **new insight** that can be used to:

1. Develop realistic assessments and estimates of the first three benches of the Three Forks oil reserves.
2. Design and implement effective and efficient E&P (exploration and production) strategies for defining and developing an emerging second and third bench Three Forks play in North Dakota.

The upper three benches of the Three Forks Formation have recently shown great promise as potentially prolific oil-producing zones in North Dakota.



General layering of the Bakken and Three Forks pay zones.

INDUSTRY FIRSTS

DRILLING

- Drilled sequentially 11 long laterals in four formations within a single unit
- Four cemented liners, seven openhole packers

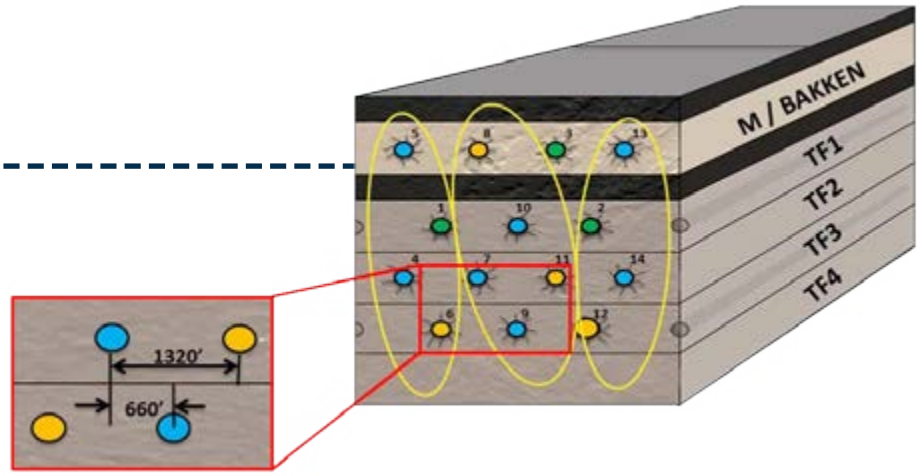
COMPLETIONS

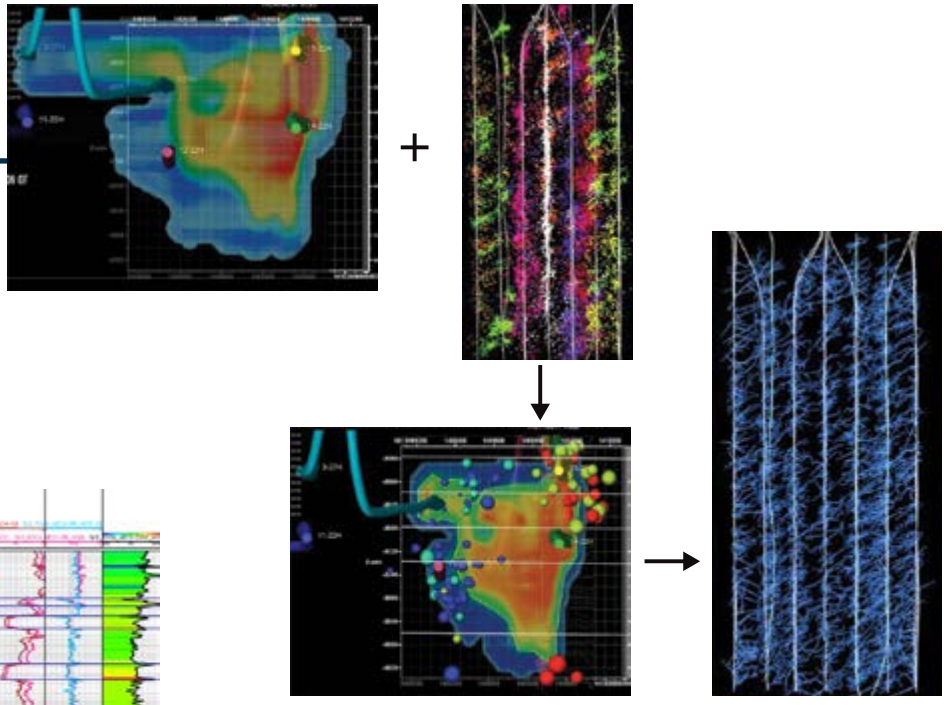
- Completed 11 wells sequentially
- Tractored longest lateral USIT (ultrasonic imaging tool) runs (>21,000' MD)
- 63 days' continuous, 24/7, microseismic recording field operations

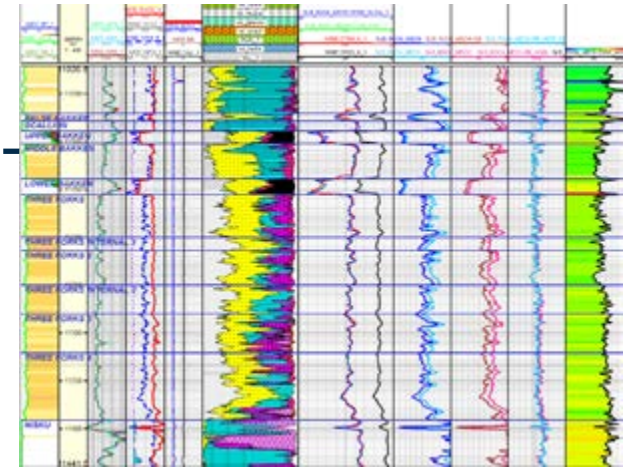
MICROSEISMIC

HISTORICALLY LARGEST TO DATE IN THE INDUSTRY

- Ten treatment wells sequentially monitored
- 283 stimulated stages recorded
- 171 tool monitoring days
- Longest laterals with three monitoring wells (>21,000' MD)
- Most footage of tractored tools in a single project (microseismic >270,000'; USIT >40,000')
- Longest lateral footage pulling ten geophone shuttles (>21,000' MD)
- Highest BHT (bottomhole temperature) project designed with three monitor wells (266°F)
- ~1,200,000 microseismic event picks generated
- 3-D full elastic modeling to design microseismic data collection
- Measured, via VSP (vertical seismic profiling), and applied "Q" to the microseismic data


M / BAKKEN
TF1
TF2
TF3
TF4
1320'
660'





RESULTS AND DISCUSSION

The compressed development schedule provided the opportunity to collect a data set unique in its scope and quality. During the stimulations, Continental collected bottomhole pressure (BHP) data in three existing "parent" wells and microseismic data. Stimulation fluids were tagged with chemical tracers. Produced fluids were sampled, and the concentration of these chemical tracers was recorded. Subsequently, pulse tests were conducted.

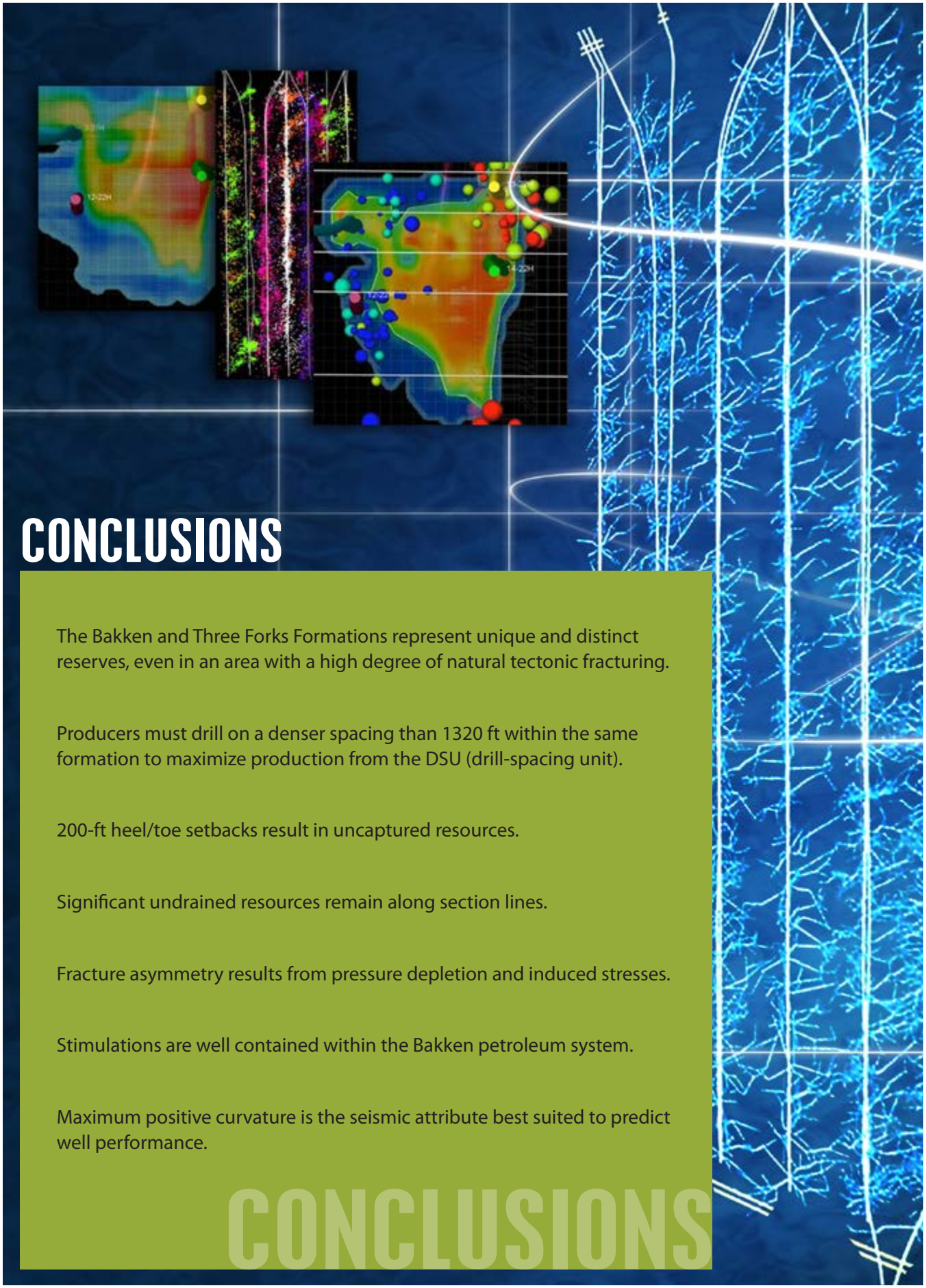
The microseismic data set collected was **uniquely comprehensive** and carefully designed to ensure high quality. Continental recorded treatment of 283 stages among ten wellbores extending across the entire 1- by 2-square-mile unit in this project. Comparatively, most microseismic projects usually include only a single treatment wellbore and record the stimulation of only five to 40 stages.

The diverse and multidisciplined data set was analyzed with a variety of methods. Where appropriate, data from one source were integrated with data from another to **improve analyses**. Where possible, results from prior analyses were incorporated into subsequent ones. Where different analyses used different data to analyze the same property, results were reconciled. The variety of available data allowed a **unique opportunity to compare and reconcile** multiple analyses.

The subsurface portion of the work resulted in a **one-of-a-kind effort** to give a 3-dimensional picture of what happens during and after hydraulic fracture treatments in multistage horizontal wells in the Middle Bakken as well as the first, second, and third benches of the Three Forks Formation. **This had not been previously attempted.**

This activity provided previously unknown information regarding potential Bakken development, helping to determine the optimal number of wellbores that need to be placed in each zone for proper development. Knowing the appropriate number of wellbores needed will help the industry know how many wells will ultimately need to be drilled in spacing units in North Dakota in the Bakken Pool.

The potential economic impact of understanding the number of wells needed to be drilled in the future for primary development, alone, will lend **confidence** to the effort to build infrastructure in the region and will develop estimates for potential oil industry employment over the long term.



CONCLUSIONS

The Bakken and Three Forks Formations represent unique and distinct reserves, even in an area with a high degree of natural tectonic fracturing.

Producers must drill on a denser spacing than 1320 ft within the same formation to maximize production from the DSU (drill-spacing unit).

200-ft heel/toe setbacks result in uncaptured resources.

Significant undrained resources remain along section lines.

Fracture asymmetry results from pressure depletion and induced stresses.

Stimulations are well contained within the Bakken petroleum system.

Maximum positive curvature is the seismic attribute best suited to predict well performance.

CONCLUSIONS

PROGRAM WORK CONTINUES

BPOP is currently in its third year of activity. Hawkinson Project work is formally complete, but strong interest from program members in the implications of the results of the Hawkinson Project means that **informal activity in these areas will continue.** The membership is currently discussing additional verification of these groundbreaking findings, which may lead to new recommendations to the state of North Dakota regarding DSU development.

The **EERC continues work in several tasks under Optimization of Wellsite Operations** and intends to continue to do so as long as program funding and member interest exist. Flaring minimization, water management, TENORM disposal, and saltwater spills continue to be hot topics demanding focused attention. Industry has also expressed interest in well failure analysis, storm water management, and artificial lift improvements. The Program stands **ready to address** any issues common to all members of this productive and unique consortium-driven program.

The current period of performance ends in June 2016.

To discuss BPOP's activities or results, contact:

John A. Harju
Vice President for Strategic Partnerships
(701) 777-5157
jharju@undeerc.org

Energy & Environmental Research Center
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

www.undeerc.org

Bakken Production Optimization Program

EXECUTIVE SUMMARY

EERC

UND UNIVERSITY OF NORTH DAKOTA

APPENDIX B

BAKKEN PRODUCTION OPTIMIZATION PROGRAM 2.0 ANNUAL REPORTS

APPENDIX B-1

2017 BPOP ANNUAL REPORT

EERC
Energy & Environmental Research Center
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October 13, 2017

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

Dear Ms. Fine:

Subject: Annual Report (November 2016 – September 2017) and Quarterly Progress Report for the Period of July 1 – September 30, 2017, Entitled "Bakken Production Optimization Program 2.0"; Contract No. G-040-080EERC Fund 22010

Enclosed please find the Energy & Environmental Research Center (EERC) combined Annual and Quarterly Progress Report for the subject project. If you have any questions, please contact me by phone at (701) 777-5276 or by e-mail at bkalk@undeerc.org.

Sincerely,

Brian P. Kalk
Director of Energy Systems Development

BPK/rlo

Enclosure

E-Mailed Report Only: Brent Brannan, NDIC Oil and Gas Research Council
Lynn Helms, NDIC Department of Mineral Resources, Oil and Gas Division
Ron Ness, North Dakota Petroleum Council

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October 13, 2017

Mr. Jeffrey Parker
Marathon Oil Company
5555 San Felipe
Houston, TX 77056

Dear Mr. Parker:

Subject: Annual Report (November 2016 – September 2017) and Quarterly Progress Report for the Period of July 1 – September 30, 2017, Entitled "Bakken Production Optimization Program 2.0"

Enclosed please find the Energy & Environmental Research Center (EERC) combined Annual and Quarterly Progress Report for the subject project. If you have any questions, please contact me by phone at (701) 777-5276 or by e-mail at bkalk@undeerc.org.

Sincerely,

Brian P. Kalk
Director of Energy Systems Development

BPK/rlo

Enclosure

E-Mailed Report Only: Vitaly Kuchinskiy, Marathon Oil Company
B.J. Boening, Marathon Oil Company
Vernon Moore, Marathon Oil Company
Curtis Ryland, Marathon Oil Company

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October 13, 2017

Mr. Gordon Pospisil
Vice President of Business Development
Liberty Resources LLC
1200 17th Street, Suite 2200
Denver, CO 80202-5854

Dear Mr. Pospisil:

Subject: Annual Report (November 2016 – September 2017) and Quarterly Progress Report for the Period of July 1 – September 30, 2017, Entitled "Bakken Production Optimization Program 2.0"

Enclosed please find the Energy & Environmental Research Center (EERC) combined Annual Quarterly Progress Report for the subject project. If you have any questions, please contact me by phone at (701) 777-5276 or by e-mail at bkalk@undeerc.org.

Sincerely,

Brian P. Kalk
Director of Energy Systems Development

BPK/rlo

Enclosure

E-Mailed Report Only: Bryan Bugg, Liberty Resources

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October 13, 2017

Mr. Jason Swaren
Vice President of Operations
Oasis Petroleum
1001 Fannin, Suite 1500
Houston, TX 77002

Dear Mr. Swaren:

Subject: Annual Report (November 2016 – September 2017) and Quarterly Progress Report for the Period of July 1 – September 30, 2017, Entitled "Bakken Production Optimization Program 2.0"

Enclosed please find the Energy & Environmental Research Center (EERC) combined Annual and Quarterly Progress Report for the subject project. If you have any questions, please contact me by phone at (701) 777-5276 or by e-mail at bkalk@undeerc.org.

Sincerely,

Brian P. Kalk
Director of Energy Systems Development

BPK/rlo

Enclosure

E-Mailed Report Only: Jim Jolly, Oasis Petroleum
Jay Knaebel, Oasis Petroleum
Steven Cottle, Oasis Petroleum

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October 13, 2017

Ms. Stephanie Erickson
Supervisor, Reservoir Characterization/Base Reservoir Engineering
Williston Asset
Rockies Business Unit
ConocoPhillips
600 North Dairy Ashford
EC3-13-13W086
Houston, TX 77079

Dear Ms. Erickson:

Subject: Annual Report (November 2016 – September 2017) and Quarterly Progress Report for the Period of July 1 – September 30, 2017, Entitled "Bakken Production Optimization Program 2.0"

Enclosed please find the Energy & Environmental Research Center (EERC) combined Annual and Quarterly Progress Report for the subject project. If you have any questions, please contact me by phone at (701) 777-5276 or by e-mail at bkalk@undeerc.org.

Sincerely,

Brian P. Kalk
Director of Energy Systems Development

BPK/rlo

Enclosure

E-Mailed Report Only: Kyrre Johansen, ConocoPhillips

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October 13, 2017

Mr. Jeff Herman
Region Land Manager
Petro-Hunt, LLC
400 East Broadway, Suite 414
PO Box 935
Bismarck, ND 58501

Dear Mr. Herman:

Subject: Annual Report (November 2016 – September 2017) and Quarterly Progress Report for the Period of July 1 – September 30, 2017, Entitled "Bakken Production Optimization Program 2.0"

Enclosed please find the Energy & Environmental Research Center (EERC) combined Annual and Quarterly Progress Report for the subject project. If you have any questions, please contact me by phone at (701) 777-5276 or by e-mail at bkalk@undeerc.org.

Sincerely,

Brian P. Kalk
Director of Energy Systems Development

BPK/rlo

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E-Mailed Report Only: Jason Stangel, Petro-Hunt, LLC

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www.undeerc.org

October 13, 2017

Mr. Brent Lohnes
Director, Field & Plant Operation
Hess Corporation
3015 16th Street Southwest
Minot, ND 58701

Dear Mr. Lohnes:

Subject: Annual Report (November 2016 – September 2017) and Quarterly Progress Report for the Period of July 1 – September 30, 2017, Entitled "Bakken Production Optimization Program 2.0"

Enclosed please find the Energy & Environmental Research Center (EERC) combined Annual and Quarterly Progress Report for the subject project. If you have any questions, please contact me by phone at (701) 777-5276 or by e-mail at bkalk@undeerc.org.

Sincerely,

Brian P. Kalk
Director of Energy Systems Development

BPK/rlo

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E-Mailed Report Only: Vicky Sand, Hess Corporation

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www.undeerc.org

October 13, 2017

Mr. William Westler
WPX Energy
3500 One Williams Center, MD 38
Tulsa, OK 74172

Dear Mr. Westler:

Subject: Annual Report (November 2016 – September 2017) and Quarterly Progress Report for the Period of July 1 – September 30, 2017, Entitled "Bakken Production Optimization Program 2.0"

Enclosed please find the Energy & Environmental Research Center (EERC) combined Annual and Quarterly Progress Report for the subject project. If you have any questions, please contact me by phone at (701) 777-5276 or by e-mail at bkalk@undeerc.org.

Sincerely,

Brian P. Kalk
Director of Energy Systems Development

BPK/rlo

Enclosure

E-Mailed Report Only: Brian Wold, WPX Energy

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October 13, 2017

Rafael Longoria, PhD
Researcher Reservoir Geology and Petrophysics
R&T ST SOG
Statoil Gulf Services LLC
6300 Bridge Point Parkway, Building 2, Suite 100
Austin, TX 78730

Dear Dr. Longoria:

Subject: Annual Report (November 2016 – September 2017) and Quarterly Progress Report for the Period of July 1 – September 30, 2017, Entitled "Bakken Production Optimization Program 2.0"

Enclosed please find the Energy & Environmental Research Center (EERC) combined Annual and Quarterly Progress Report for the subject project. If you have any questions, please contact me by phone at (701) 777-5276 or by e-mail at bkalk@undeerc.org.

Sincerely,

Brian P. Kalk
Director of Energy Systems Development

BPK/rlo

Enclosure

BAKKEN PRODUCTION OPTIMIZATION PROGRAM 2.0
ANNUAL REPORT (NOVEMBER 2016 – SEPTEMBER 2017)
INCLUDING QUARTERLY PROGRESS REPORT
JULY–SEPTEMBER 2017

BACKGROUND

The Energy & Environmental Research Center (EERC) was awarded an extension to the previously conducted and highly successful North Dakota Industrial Commission Oil and Gas Research Council (NDIC OGRC)-sponsored Bakken Production Optimization Program (BPOP). The purpose of this extension is to facilitate a 3-year continuation of the program to address emerging opportunities and challenges related to petroleum production in North Dakota. The extension is a continuation of the collaborative effort between the state of North Dakota and the North Dakota petroleum industry to apply North Dakota resources to provide North Dakota solutions to North Dakota challenges and opportunities.

The goals of BPOP 2.0 are 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.

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

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

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

The anticipated outcomes of BPOP 2.0 are 1) increased well productivity and economic output of North Dakota's oil and gas resources, 2) decreased environmental impacts of wellsite operations, and 3) 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.

The following section briefly summarizes the highlights of each task area achieved during Year 1 (November 1, 2016, through September 30, 2017) of BPOP 2.0. The section that follows contains greater detail on the achievements of the July–September 2017 quarter.

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.

The original budget as proposed to the NDIC Oil and Gas Research Program (OGRP) is $13,280,000 is shown in Table 1.

Table 1. BPOP 2.0 – Original Budget

Sponsors	Y1 Nov 2016 to Oct 2017	Y2 Nov 2017 to Oct 2018	Y3 Nov 2018 to Oct 2019	Total
NDIC Share – Cash	$2,000,000	$2,000,000	$2,000,000	**$6,000,000**
Industry Share (Marathon Oil) – In-Kind	$2,500,000	$3,500,000	$1,280,000	**$7,280,000**
Total	**$4,500,000**	**$5,500,000**	**$3,280,000**	**$13,280,000**

Table 2 presents a revised expected budget based on the additional cost share secured by the EERC, an increase of nearly 20%. Expenses to date are also listed in Table 2.

Table 2. BPOP 2.0 – Expected Budget and Expenses to Date

Sponsors	Expected Budget	Actual Expenses as of 9/30/17	Balance
NDIC Share – Cash	$6,000,000	$1,607,607	$4,392,393
Industry Share – Cash	$500,000	$91,758	$408,242
Marathon– In-Kind	$7,280,000	–	$7,280,000
Liberty Resources – In-Kind*	$90,133	$90,133	–
DOE – Cash	$2,000,000	$1,979	$1,998,021
Total	$15,870,133	**$1,791,477**	$14,078,656

*An estimate for the total expected in-kind cost share from Liberty Resources is not available.

QUARTERLY PROGRESS REPORT (July – September 2017)

ACCOMPLISHMENTS DURING REPORTING PERIOD

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.

MEMBERSHIP AND FINANCIAL INFORMATION

The original budget as proposed to NDIC OGRP is $13,280,000, as shown in Table 3.

Table 3. BPOP 2.0 – Original Budget

Sponsors	Y1 Nov 2016 to Oct 2017	Y2 Nov 2017 to Oct 2018	Y3 Nov 2018 to Oct 2019	Total
NDIC Share – Cash	$2,000,000	$2,000,000	$2,000,000	**$6,000,000**
Industry Share (Marathon Oil) – In-Kind	$2,500,000	$3,500,000	$1,280,000	**$7,280,000**
Total	**$4,500,000**	**$5,500,000**	**$3,280,000**	**$13,280,000**

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 the U.S. Department of Energy 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.

Table 4 presents a revised expected budget based on the additional cost share secured by the EERC, an increase of nearly 20%. Expenses to date are also listed in Table 4.

Table 4. BPOP 2.0 – Expected Budget and Expenses to Date

Sponsors	Expected Budget	Actual Expenses as of 9/30/17	Balance
NDIC Share – Cash	$6,000,000	$1,607,607	$4,392,393
Industry Share – Cash	$500,000	$91,758	$408,242
Marathon Oil – In-Kind	$7,280,000	–	$7,280,000
Liberty Resources – In-Kind*	$90,133	$90,133	–
DOE – Cash	$2,000,000	$1,979	$1,998,021
Total	**$15,870,133**	$1,791,477	$14,078,656

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

FUTURE ACTIVITIES

The planned activities for the next quarter are detailed below.

Enhanced Oil Recovery Task

- Future activities under this task will be focused on supporting the rich gas EOR pilot test at Liberty Resources Leon-Gohrick DSU in the Stomping Horse complex.

- Gas handling and compression strategies will continue to be evaluated, with a goal of identifying cost-effective, timely solutions.

- Reservoir-, facility-, and gas compression-modeling activities will be coordinated to ensure the development of an integrated EOR strategy.

- Sampling and analysis of fluids (oil, gas, and water) from the Stomping Horse complex will continue.

- Rock samples from wells in the Stomping Horse area will be collected and used for rock extraction studies of the Bakken shales and the productive zones of the Middle Bakken and Three Forks Formations.

- Reservoir-modeling activities will be continued. In particular, additional potential injection and production schemes will be modeled as part of the effort to support the determination of final design and operational parameters of the pilot test.

- A monitoring plan for the pilot test will be developed in close collaboration with Liberty Resources. The selection, design, and application of monitoring techniques for the pilot test will be documented. In addition to providing the fundamental data needed to assess pilot performance, the monitoring program for the Leon-Gohrick DSU test will also establish the effectiveness of selected monitoring techniques as a means of reservoir surveillance and injection conformance monitoring in the Bakken petroleum system.

Refracturing Optimization Task

- A literature survey on refracs will be completed. General candidate selection guidelines will be generated, after incorporating operator recommendations. General guidelines will be compared with production performance results from Bakken refracs.

- Planning for an industry kickoff meeting will be completed. This plan will be used to encourage operator participation and data contribution to the refrac evaluation.

- A BPOP 2.0 Members-only meeting focused on refracs will be held, likely in Houston, in early mid-November.

Produced Fluid Characterization Task

- Sample, analysis and data interpretation from recent sampling events will continue.

- Additional sampling of crude and produced water will continue on new wells.

- Data collection and additional sampling and analysis will continue as needed to support BPOP program goals.

- All fluid data and associated well production information collected will be entered into the EERC-specific database to support BPOP goals. The database structure will be refined to enhance use by BPOP researchers.

- Industry partnerships will continue to be developed to further understand specific needs related to Bakken production issues and practices and to expand the geographical extent of the sampling and analysis effort.

Reservoir Performance Modeling Task

- A draft of the final topical report will be completed.

Water Injection Reservoir Assessment Task

- A final topical report entitled "Modeling and Simulations of the Inyan Kara Formation to Estimate Saltwater Disposal Capacity: Final Report" will be finalized and submitted to members and NDIC.

Facility Process Optimization Task

- Facility-modeling activities will be performed to assess different strategies and their impact on crude oil quality. BPOP members have identified several field sites for site-specific modeling and subsequent winter field trials. Data will be compiled, site-specific models will be created, and planning of field trials will be conducted.

Aromatic/Aliphatic Study Task

- The EERC will continue collecting and analyzing additional rock samples from a broader geographic distribution of the Bakken Formation. The EERC anticipates that it will obtain core samples from the Three Forks, Middle Bakken, and upper and lower shales collected near the paired Three Forks and Middle Bakken crude oil wells. These core aromatic/aliphatic ratios will be compared to crude oil ratios from the nearby Three Forks and Middle Bakken wells. Core samples from other locations will also be collected and analyzed in order to better represent the whole Bakken–Three Forks areas.

- An operator who agreed to collect crude oil samples for aromatic/aliphatic ratio analyses from the beginning of crude oil production into the decline curve has begun to provide temporal samples. After a sufficient number have been collected, we will analyze them to determine any changes in aromatic/aliphatic ratios. These samples will be used in an attempt to determine the relative contribution of the upper and lower shales to crude production over the life of the well. The aromatic/aliphatic analyses of the four oily water samples discussed above will also be completed.

- Diesel fluid expected to be provided by the operator who supplied the drill cuttings will be analyzed for the individual aromatic and aliphatic hydrocarbons to determine whether

differentiation from the native rock hydrocarbon compositions that can be exploited to allow diesel-based drill cuttings to be used for aromatic/aliphatic analyses.

- Evaluation of the aromatic/aliphatic ratios determined in the rock core samples across the reservoir will begin in an attempt to better understand shale maturity including investigating the use of extended rock evaluation.

Environmental Support Task

- The second education day event is scheduled for October 10, 2017, and will focus on the following topics:
  - Resources to be protected, the uses of these resources, and the pathways leading to these resources
  - Current NDDH standards used by existing programs

Program Management and Development

- The EERC will continue to solicit additional industry membership in the BPOP consortium during the coming quarter.

APPENDIX A

HYDROCARBON REMEDIATION TASK FORCE PRESENTATION – SUMMARY OF HYDROCARBON INFORMATION

Summary of Hydrocarbon Information

Hydrocarbon Remediation Task Force
July 17, 2017
Bismarck, North Dakota

Chad Wocken, Principal Engineer
Brad Stevens, Senior Research Engineer

Critical Challenges. Practical Solutions.

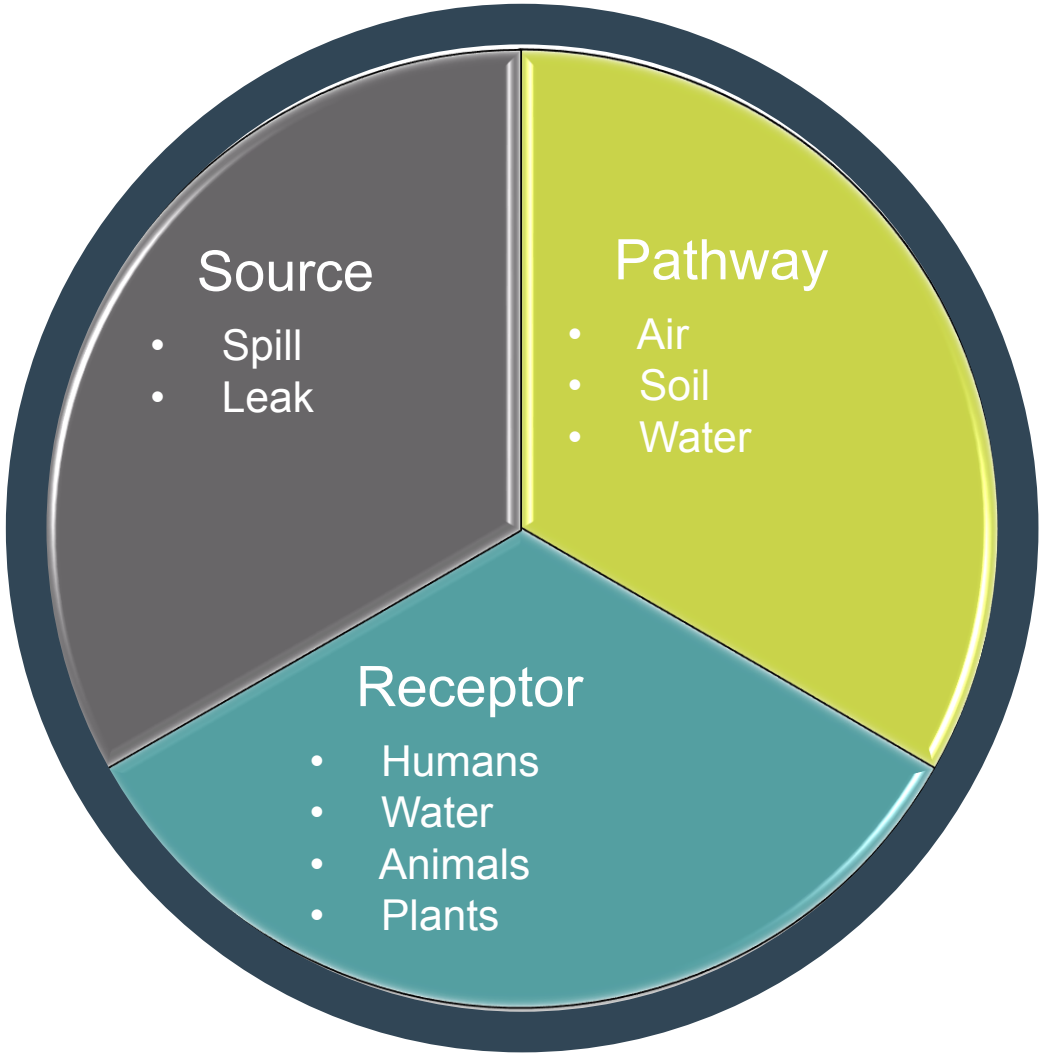
Overview/Outline

- Crude Oil Chemistry
- Crude Oil in the Environment
- Risk-Based Decision Making

<u>Subsequent HC Task Force Meeting Topics</u>

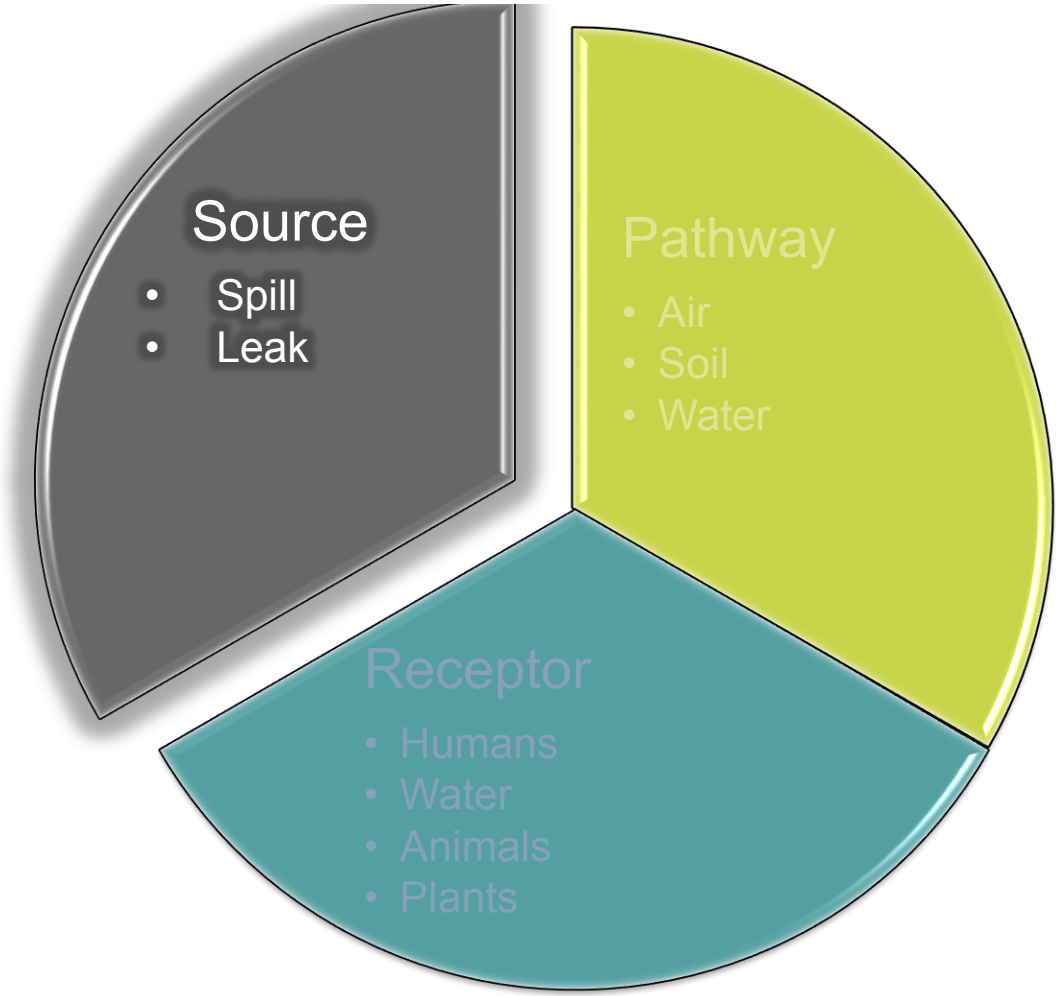
- Livestock and crop
- Water types and uses
- Review of North Dakota and other state regulations

Elements of a Spill

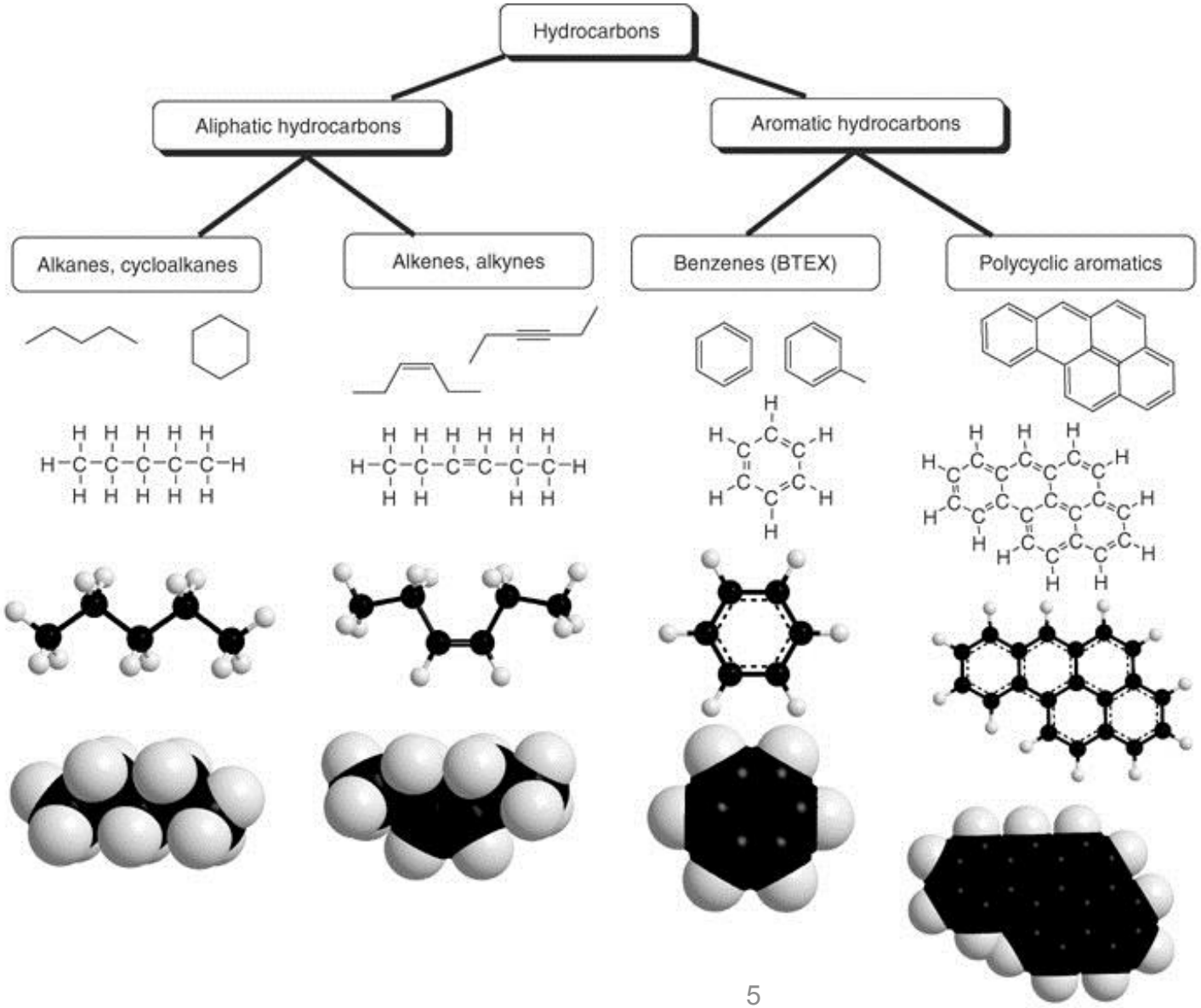


Crude Oil Chemistry

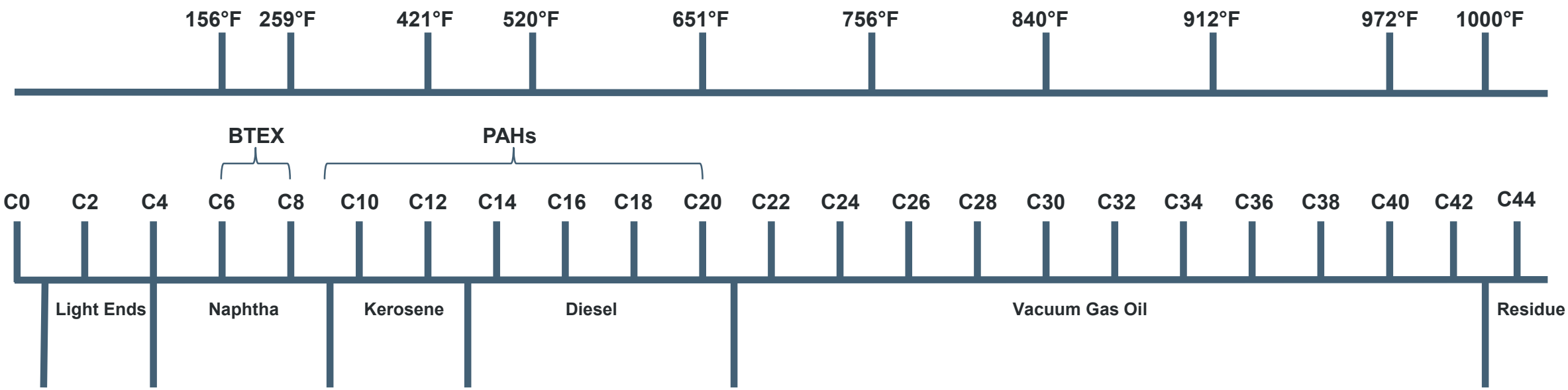
- Spills and leaks of unrefined hydrocarbon products:
  - Crude oil
  - Condensate
- Examples of sources:
  - Well-site equipment
  - Pipelines and gathering lines
  - Trucks, trains, etc.



Crude Oil – Complex Mixture of Hundreds of Chemicals



Carbon Number and Boiling Point

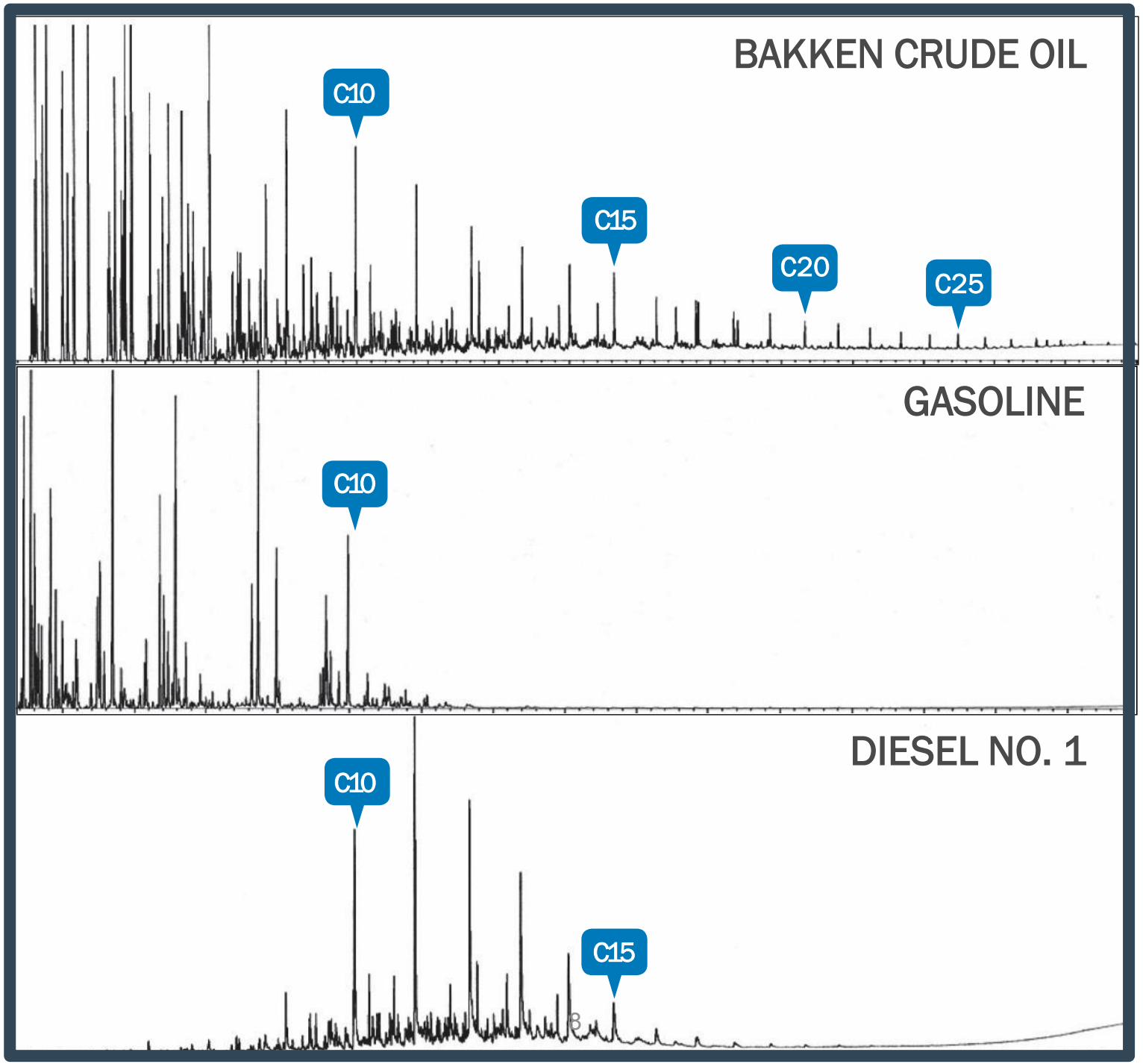


Crude Oil Properties

Property	Units	Bakken Crude[1]	West Texas Int.[1]	LLS[1]	Mayan[2]
API Gravity	Degrees	>41	40	35.8	20
Sulfur	weight %	<0.2	0.33	0.36	
Distillation Yield:	volume %				
Light Ends	C1 – C4	3	1.5	1.8	0.5
Naphtha (gasoline range)	C5 – 330°F	30	29.8	17.2	9.5
Kerosene (jet fuel range)	330°F – 450°F	15	14.9	14.6	10
Diesel	450°F – 680°F	25	23.5	33.8	20
Vacuum Gas Oil (fuel oil range HCs)	680°F – 1000°F	22	22.7	25.1	18
Vacuum Residue	1000+°F	5	7.5	7.6	42
Total		100	100	100	100
Selected Properties:					
Light Naphtha Octane	(R+M)/2	NA	69	71	-
Diesel Cetane		>50	50	49	-
VGO characterization (K=factor)		≈12	12.2	12.0	-

[1] Source: Hill, D., et.al North Dakota Refining Capacity Study, Final Technical Report DOE Award No. DE-FE0000516, January 5, 2011

[2] Source: Espinosa-Pena, M., et.al. Simulated Distillation Yield Curves in Heavy Crude Oils: A comparison of Precision between ASTM D-5307 and ASTM D-2892 Physical Distillation. Energy & Fuels 2004, 18, 1832-1840


BAKKEN CRUDE OIL
C10
C15
C20
C25
GASOLINE
C10
DIESEL NO. 1
C10
C15

EERC

Comparison of HC Properties

	Crude Oil	Gasoline	Diesel No. 2	Fuel Oil (No. 6)
Density, g/mL	~0.94	~0.73	~0.83	~0.95
Boiling Range, °C	<40 to >700	40 – 200	200 – 325	350 – 700
Carbon Number	C1 – C34+	C4 – C12	C8 – C21	C12 – C34

Total Petroleum Hydrocarbon Criteria Working Group Series, Volume 2, Composition of Petroleum Mixes. Thomas L. Potter, Kathleen E. Simmons, May 1998.

Crude Oil Chemicals of Concern

- Benzene, Toluene, Ethylbenzenes, Xylenes (BTEX)
  - Most commonly found in gasoline or low boiling fraction of crude.
  - Tend to be most water-soluble fraction of crude oil.[3]
  - The most volatile of the aromatic compounds.[3]
- Poly-nuclear Aromatic Hydrocarbons (PAHs)
  - Typically found in diesel fuel or high boiling fraction of crude oil.
  - More likely to partition into soils due to their low water solubility and high K_{oc} values.[3]

	Crude Oil	Gasoline	Diesel
Benzene, % by weight	0.0–0.6[1]	1.6–2.3[2]	0.0026[3]–0.1[2]
BTEX, % by weight	<2[3]	17–25[2]	0.036–1.6[2]
PAHs, % by weight	<0.003[1]	4.1–7.2[2]	0.15–11.6[2]

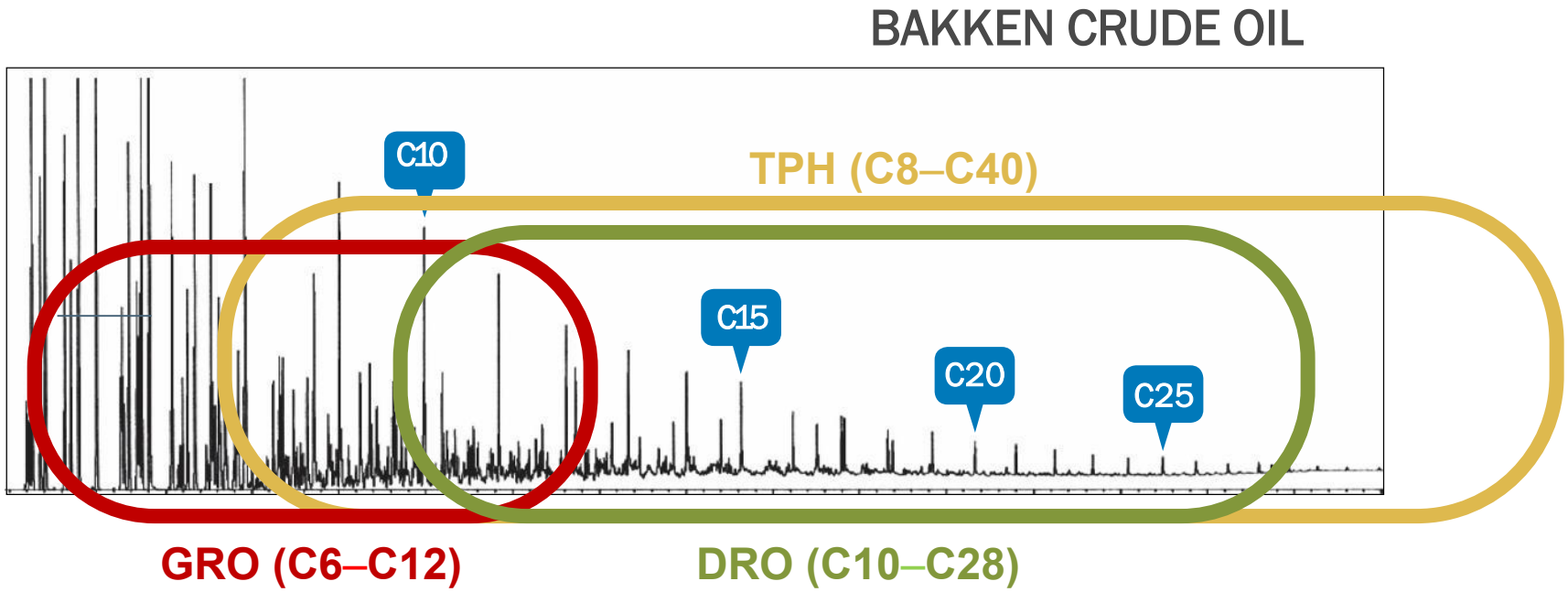
[1] API Publication No. 4709, Risk-Based Methodologies for Evaluating Petroleum Hydrocarbon Impacts at Oil and Natural Gas E&P Sites.
[2] Total Petroleum Hydrocarbon Criteria Working Group Series, Volume 2, Composition of Petroleum Mixtures, Thomas L. Potter, Kathleen E. Simmons, May 1998
[3] USGS, Fate and Transport of Petroleum Hydrocarbons in Soil and Ground Water at Big South Fork Nation River and Recreation Area, 2002–2003.

Hydrocarbons Are Measured Using Multiple Analytical Methods

Analytic Method		Target	Carbon Range	Boil Point Range
EPA 418.1 – TPH		Total petroleum hydrocarbons	C8–C40	
EPA 413.1 – Oil & Grease		Oil & grease		
EPA 8015M – GRO		Gasoline range organics	C6–C12	60°–220°C
EPA 8015M – DRO		Diesel range organics	C10–C28	
EPA 8015M – MRO		Motor oil range organics	<C28–C35	
SW-846 – EPA 3611/3630	TPHCWG	Fractionated TPH	C6–C35	
Modified TPHCWG	PERF	Fractionated TPH	C6–C44	
MassDEP VPH Method	Massachusetts, Montana	Volatile petroleum hydrocarbons	C5–C12 aliphatics, BTEX, MTBE, naphthalene, C9–C10 aromatics	
MassDEP EPH Method	Massachusetts, Montana	Extractable petroleum hydrocarbons	C9–C36 aliphatics, C11–C22 aromatics	
EPA 8021		BTEX, Naphthalene	C6–C10	
EPA 8270		PAHs		

Notes:
EPA = U.S. Environmental Protection Agency
TPHCWG = Total Petroleum Hydrocarbon Working Group
MassDEP = Massachusetts Department of Environmental Protection
TPH = total petroleum hydrocarbons
GRO = gasoline range organics
DRO = diesel range organics
MRO = motor oil range organics
VPH = volatile petroleum hydrocarbons
EPH = extractable petroleum hydrocarbons
BTEX = benzene, toluene, ethylbenzene, xylenes
PAH = polycyclic aromatic hydrocarbons

Comparison of TPH, GRO, and DRO Measurements



Summary of Fractionated Analytical Methods

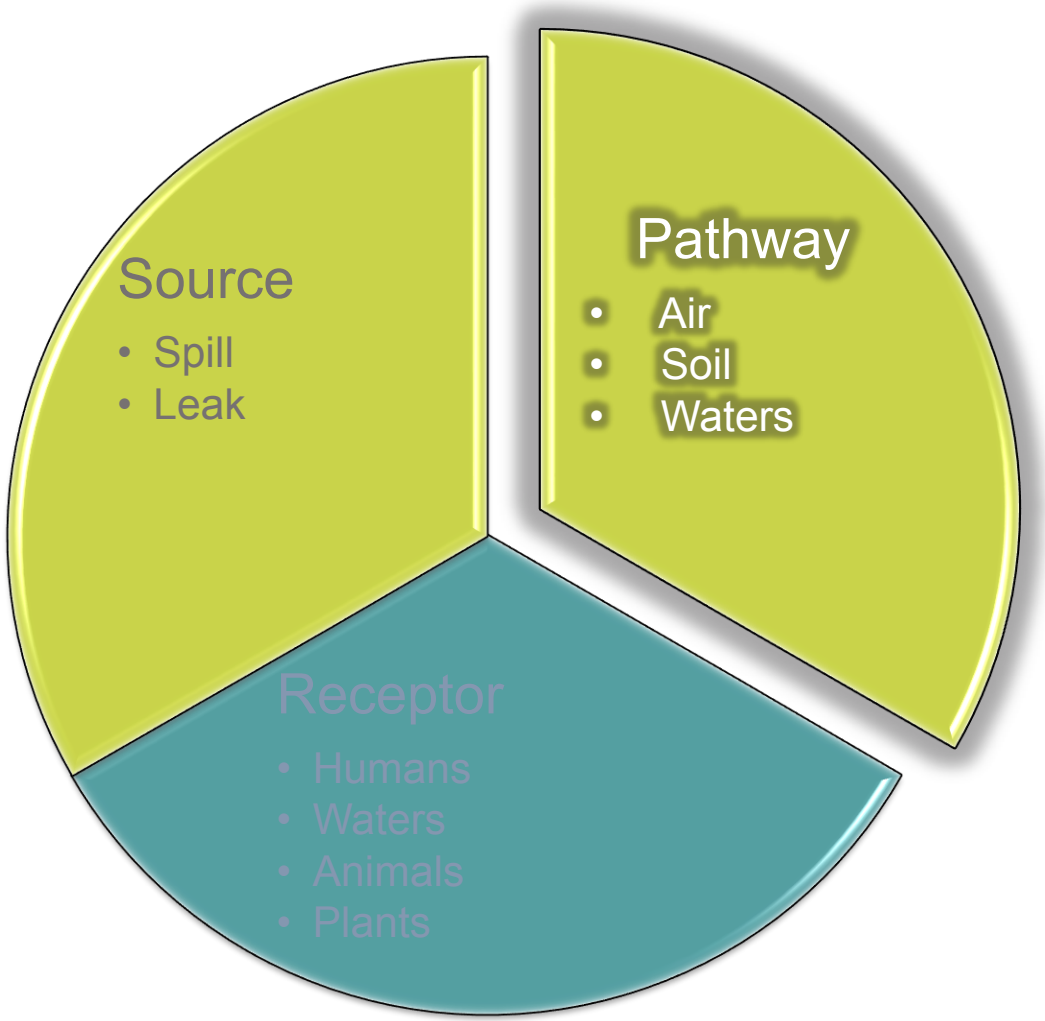
- Several analytical methods exist that provide greater detail about the types of hydrocarbons present in a crude oil:
  - Total Petroleum Hydrocarbon Working Group (TPHCWG)
    - ♦ Fractionated method, identify groups of compounds with similar fate and transport properties
    - ♦ Measured HCs in the range of C6–C35; breaking them into:
      - 6 aliphatic fractions
      - 7 aromatic fractions
  - Petroleum Environmental Research Forum (PERF)
    - ♦ Modified TPHCWG method to expand range of HC analysis
    - ♦ C6–C44+; inclusive of high MW molecules present in crude oil
  - Massachusetts Department of Environmental Protection
    - ♦ “Volatile” petroleum hydrocarbons
      - C5–C12 aliphatics, BTEX, MTBE, naphthalene, C9–C10 aromatics
    - ♦ “Extractable” petroleum hydrocarbons
      - C9–C36 aliphatics,C11–C22 aromatics

Crude Chemistry Review

- Bakken crude is classified as a light sweet crude oil possessing similar physical and chemical properties to West Texas Intermediate
- Gasoline and diesel are refined products
  - Derived from different fractions (boiling ranges) of crude
  - Contain different chemicals at different concentrations compared to crude
- Crude oil is a complex mixture of chemicals, each chemical (class of chemicals) has different properties
- Hydrocarbon characterization is complicated:
  - Complex mixture of chemicals with different properties
  - Analytical methods each have unique applications and limitations
  - Multiple analytical methods often necessary to achieve accurate characterization

Crude Oil in the Environment

- Typical pathways:
  - Air
  - Soil
  - Water

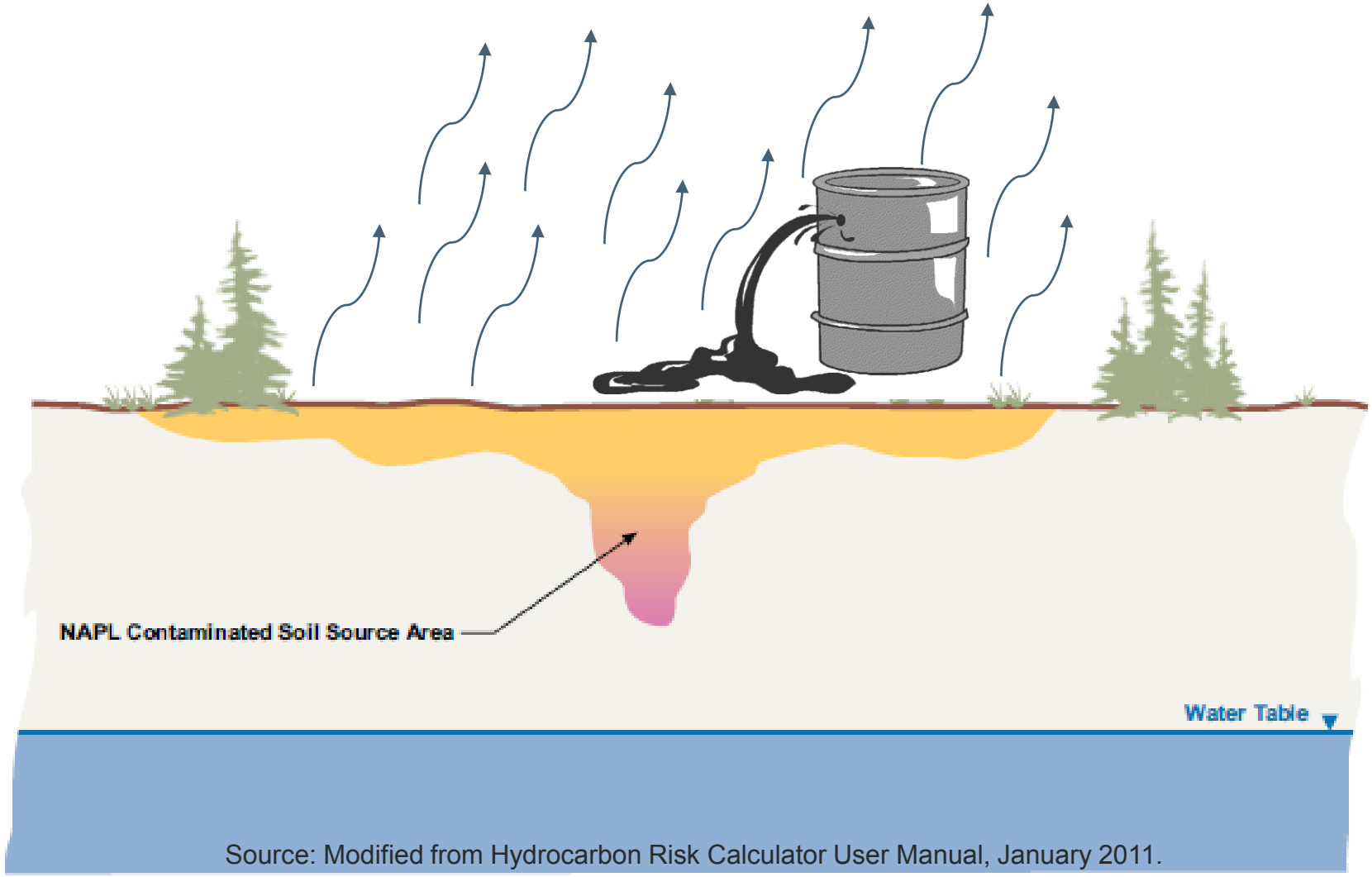


US Department of Health and Human Services Bulk Migration of Oil

- Petroleum releases migrate through soil via two pathways:
  - Bulk oil infiltrating the soil under forces of gravity and capillary action
  - Individual compounds separating from the mixture and dissolving into air or water
- Infiltration is typically fast relative to dissolution
- Factors affecting the rate of bulk oil infiltration include:
  - Soil moisture
  - Terrain
  - Climate
  - Rate of release
  - Vegetation
  - Soil particle size
  - Soil types
  - Oil viscosity

Compounds Separate and Migrate Independently Driven by Their Respective Properties

- Volatility
- Solubility
- Sorption potential
- Biodegradation



Source: Modified from Hydrocarbon Risk Calculator User Manual, January 2011.

Volatility

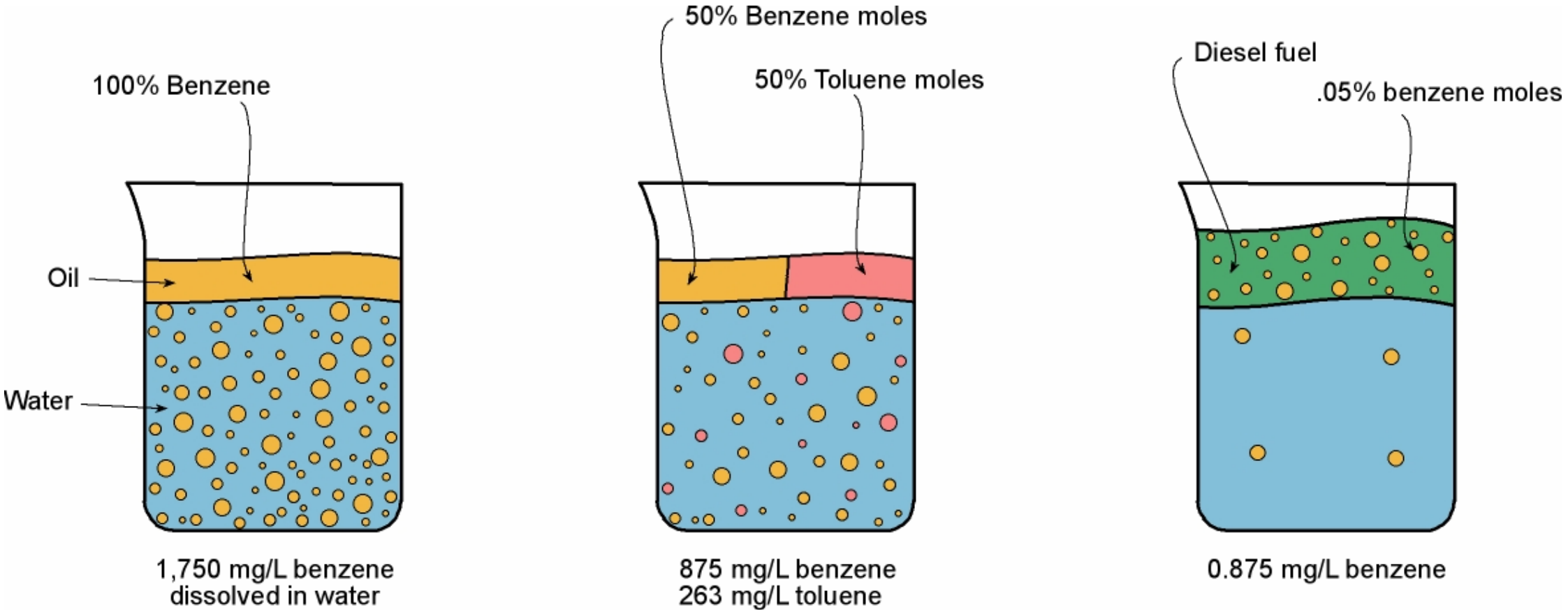
- Vapor pressure is the physical property used to represent volatility
- Vapor pressure
  - >10^{-2} mmHg, hydrocarbon is likely in air phase
  - Between 10^{-2} and 10^{-7}mmHg, hydrocarbon in both vapor and liquid phase
  - <10^{-7} mmHg, hydrocarbon is likely in liquid phase
- Volatilization impacted by air and soil temperature, humidity, wind, soil type, moisture content, oil composition, solar radiation, and thickness of oil layer.
- Volatilization of BTEX from soil increases with decreasing moisture content.
- Alkanes greater than C18 exhibit limited volatilization at ambient temperature.

Solubility

- Measured as the milligrams of pure chemical dissolved in one liter of water at standard temperature and pressure.
- Chemicals that dissolve into rainwater or groundwater migrate away from the source.
- Solubility decreases with increasing molecular weight of the hydrocarbon.
- For compounds with similar carbon numbers, solubility decreases aromatic>alkanes>isoalkanes.
- Solubility of HCs in water is impacted by the presence of other hydrocarbons
  - One study measured an effective solubility of benzene from crude oil at 1.9 mg/L compared to 27 mg/L when pure benzene was allowed to partition into water.[1]
- Based on modeling, C6–C12 aromatics are most likely to seriously impact groundwater water due to their mobility and toxicity.[2]

[1] USGS, Fate and Transport of Petroleum Hydrocarbons in Soil and Ground Water at Big South Fork Nation River and Recreation Area, 2002–2003.

[2] Ohio EPA, Soil Leaching to Ground Water Evaluation for Total Petroleum Hydrocarbons (TPH) Guidance, January 2014.



Source: Three- and Four-Phase Partitioning of Petroleum Hydrocarbons and Human Health Risk Calculations, December 2006.

Organic Carbon-Water Partition Coefficient (K_{OC})

- Describes how easily HCs migrate between organic carbon in the soil and water.
- Lower MW hydrocarbons have lower sorption potential than heavier hydrocarbons
  - K_{OC} <50 L/kg – very mobile
  - K_{OC} 50–150 L/kg – mobile (benzene)
  - K_{OC} 150–500 L/kg – intermediate mobility (toluene, ethylbenzene, xylenes)
- Lighter-fraction PAHs are removed primarily by volatilization. Heavier-fraction PAHs bind more readily to soil organic matter and remain in the top soil horizon.[1]

[1] USEPA OSWER Directive 9285.7-78, Ecological Soil Screening Levels for Polycyclic Aromatic Hydrocarbons (PAH), Interim Final.

Biodegradation

- Organic hydrocarbons in the environment will degrade naturally through microbial activity, producing carbon dioxide, water, and microbial biomass.
- Rate of biodegradation is independent of oil concentration at 0.5–1.0% by volume:
  - Rate of degradation decreases at higher concentrations.
  - Degradation stops at saturation conditions, typically 30%–50% by volume oil in soil.
- Heavy metals inhibit biodegradation:
  - Concentrations leading to inhibition are higher than found in crude oil.

Biodegradation – Chemical Composition

- Rate of degradation dependent upon chemical composition:
  - C10–C22 n-alkanes, n-alkyl aromatics and aromatics are more readily degraded.
  - C4–C9 n-alkanes, n-alkyl aromatics, and aromatics are biodegradable at low concentrations; generally removed by volatilization.
  - C1–C4 compounds are highly volatile and degraded by few specialized microbes.
  - C22+ n-alkanes, n-alkyl aromatics, and aromatics not readily biodegradable.
  - PAHs with four or more rings are resistant to biodegradation.

Biodegradation – Environmental Factors

- Rate of degradation dependent upon environmental factors:
  - Oxygen content – anaerobic decomposition is extremely slow.
  - Soil pH – typically slightly above 7 is optimal.
  - Moisture content – typically between 50%-70% of the water-holding capacity.
  - Temperature – optimal 64°–86°F (18°–30°C).
  - Nutrient concentrations – N, P, K, Na, S, Ca, Mg, Fe, Mn, Zn, Cu.
    - ♦ N is typically the limiting nutrient.

Comparison of Key Chemical Properties

	Hexane (C6, alkane)	Benzene (C6, aromatic)	Dodecane (C12, alkane)
Vapor Pressure, mmHg	151[1]	95[1,2]	0.1178[1]
Solubility, mg/L	9.5[1]	1750–1800[1,2,3,4]	0.0037[1]
K_{oc}, L/kg	3410[1]	59.0–81.2[1,2,3,4]	1,260,000[1]

[1] TPHCWG Volume 3, Appendix B.
[2] Risk-Based Decision-Making for Assessing Petroleum Impacts at Exploration and Production Sites, McMillan, Magaw, Carovillano, 2001.
[3] Williams, S.D., Ladd, D.E., and Farmer, J.J., 2006, Fate and transport of petroleum hydrocarbons in soil and ground water at Big South Fork National River and Recreation Area, Tennessee and Kentucky, 2002–2003: U.S. Geological Survey Scientific Investigations Report 2005-5104.
[4] EPA Soil Screening Guidance: Technical Background Document, 1996.

Crude Oil in the Environment Review

Volatility

- C1–C10 readily volatilize.[1]
- C11–C22 volatilize over several days.[1]
- C23+ minimally volatilize.[1]
- Light crude oil may lose 20%–40% of its mass immediately. Up to 1/3 of medium-grade crude oil will evaporate within 24 hours.[1]
- Evaporation rates are 10 to 1000 times faster than dissolution rates.[1]

Solubility/Soil Sorption

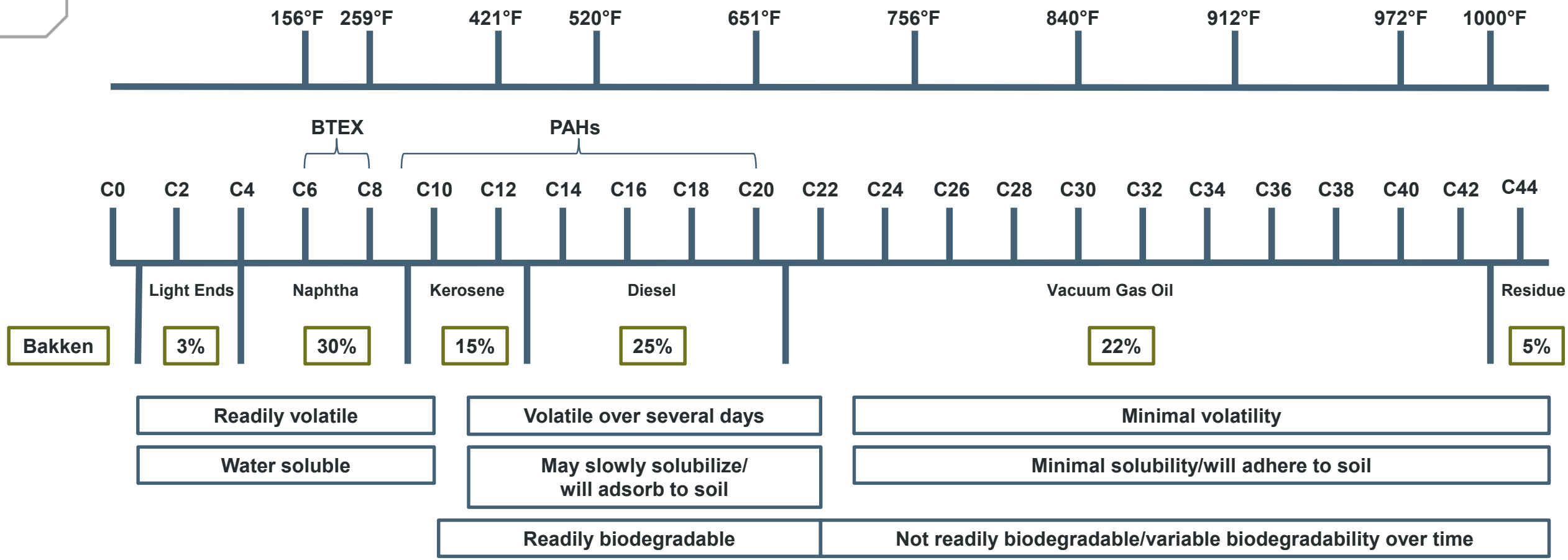
- Less than 5% of crude oil will dissolve in water.[2]
- C1–C10 has some water solubility.[1]
- C11–C22 may slowly dissolve in water, and will adsorb to soil.[1]
- C23+ minimal solubility, will adhere to soil.[1]

Biodegradability

- Literature indicates that 1% wt Tof crude oil in soil will biodegrade readily
- Hydrocarbons up to 1% wt will not significantly affect plant growth or groundwater quality.[3]

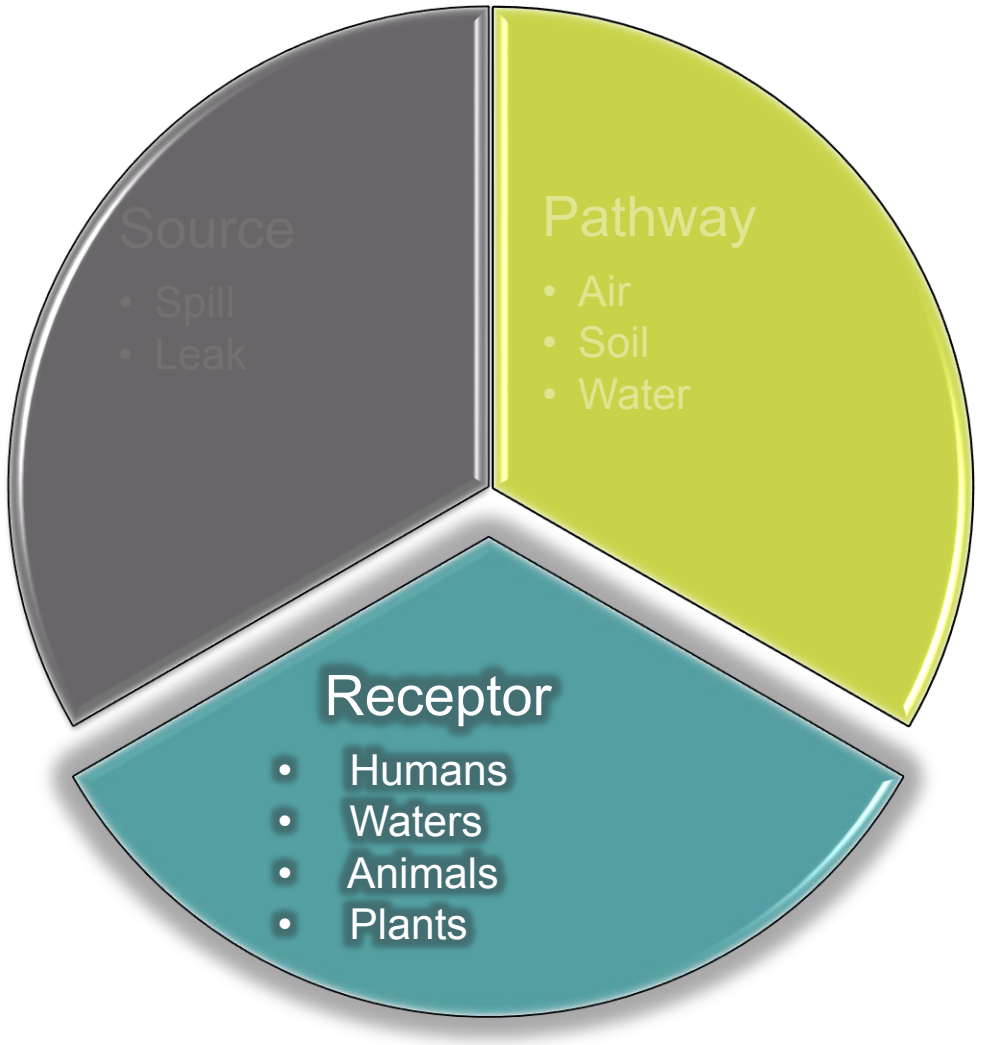
[1] Massachusetts Department of Environmental Protection, Bakken Crude Oil Spills – Response Options and Environmental Impacts.
[2] USGS, Fate and Transport of Petroleum Hydrocarbons in Soil and Ground Water at Big South Fork Nation River and Recreation Area, 2002–2003.
[3] Dr. Ben Thomas testimony to New Mexico Oil Conservation Division, Risk-Based Decision Making and Surface Water Management.

Carbon Number and Boiling Point

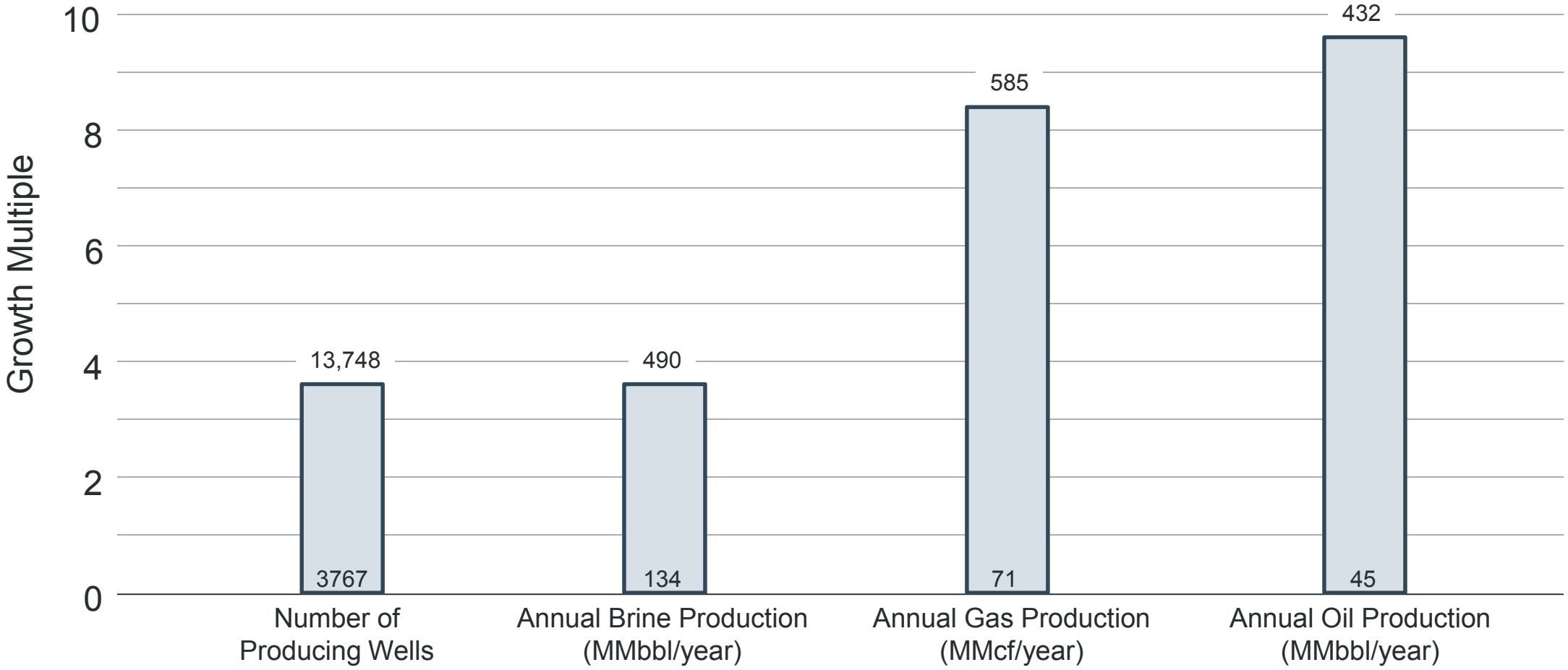


Crude Oil Releases and Risk-Based Decision Making

- Typical receptors:
  - Human (direct contact, ingestion, inhalation)
  - Waters (surface water, groundwater)
  - Animals
  - Plants

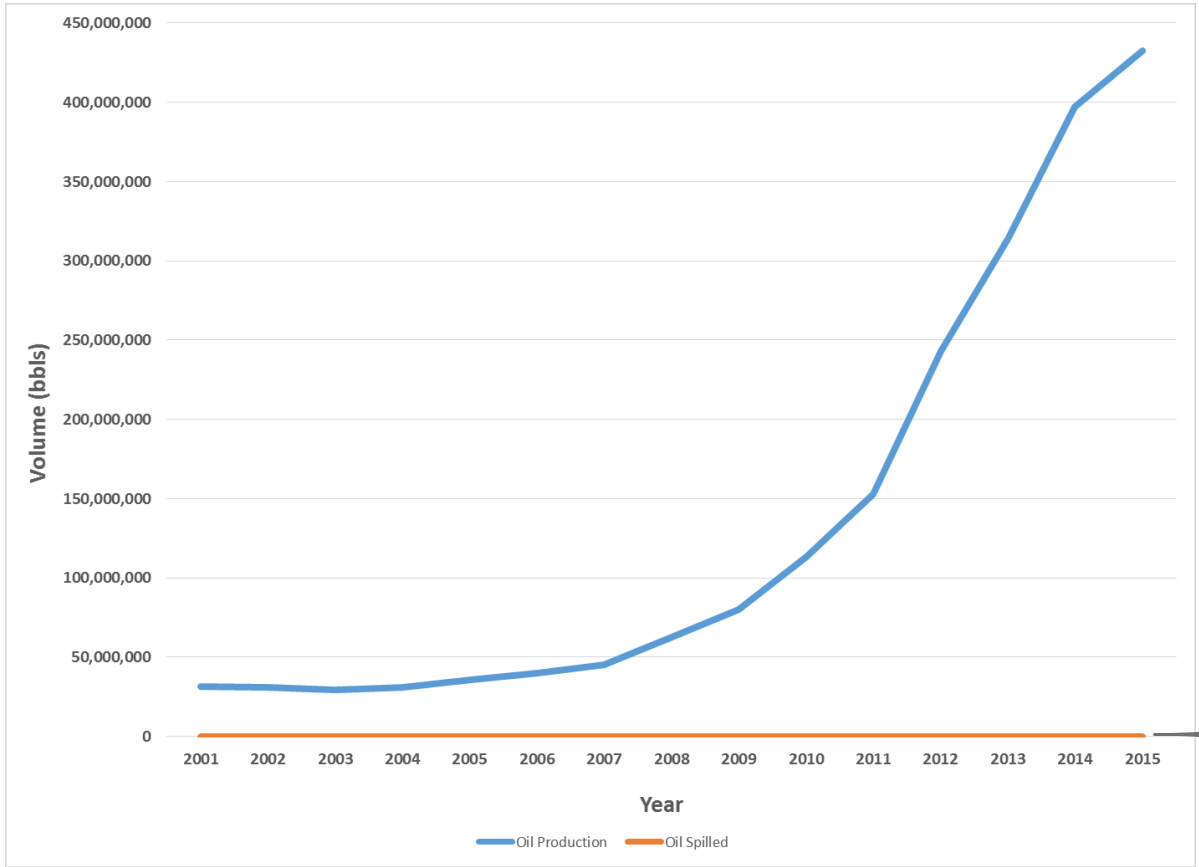


Background: Bakken Development by the Numbers 2007 vs. 2015

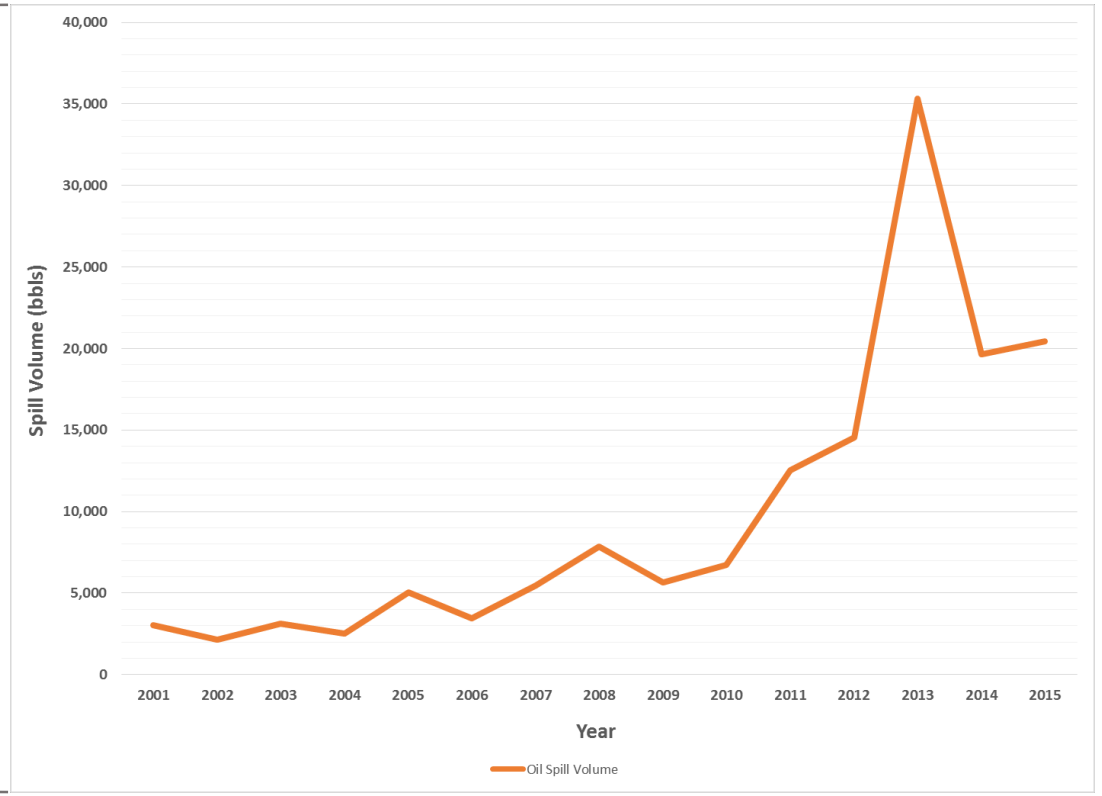


Notes: bbl = barrel
cf = cubic feet
MM = million

Crude Oil (2001–2015)

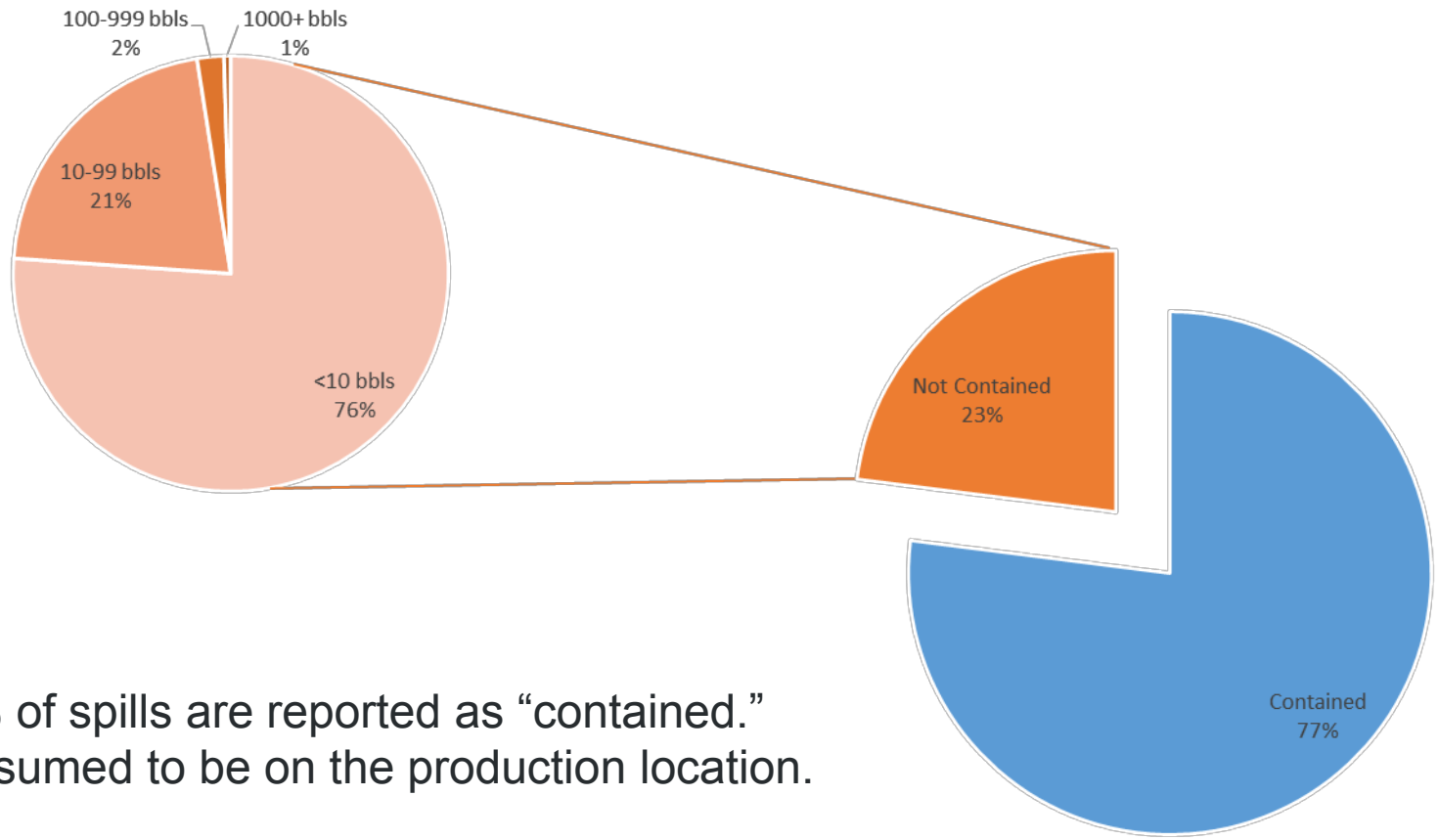


- From 2001 through 2015, roughly 6400 spills reported the release of nearly 148,000 barrels of oil.
- In 2015, approximately 20,000 barrels of oil were spilled of the approximately 432,000,000 barrels of oil produced.



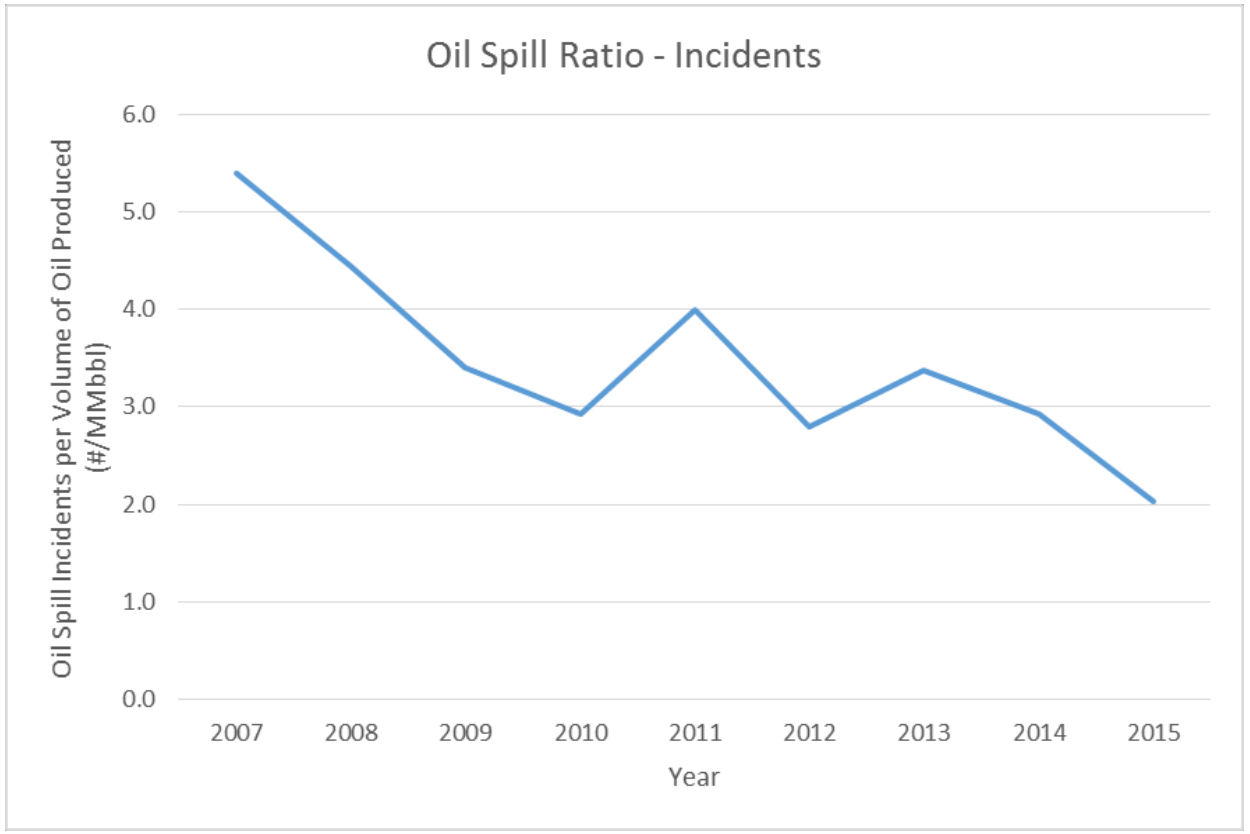
- On average, 0.009% of the oil volume produced annually is spilled.
- In other words, for every 10,000 barrels produced, 9,999 barrels are delivered to their destination and one barrel is spilled.

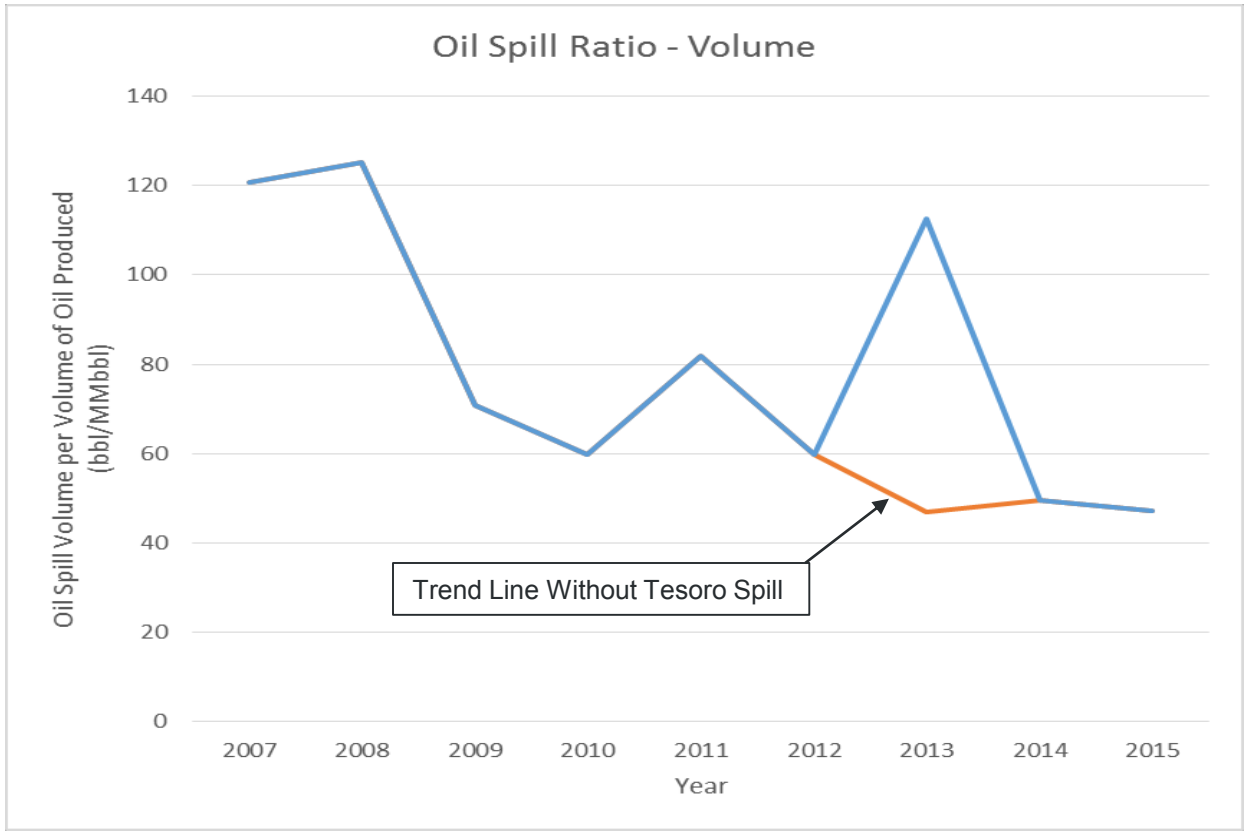
Crude Oil Spill Incidents (2015)



On average, 75% of spills are reported as “contained.”
“Contained” is assumed to be on the production location.

Crude Oil Spill Ratios

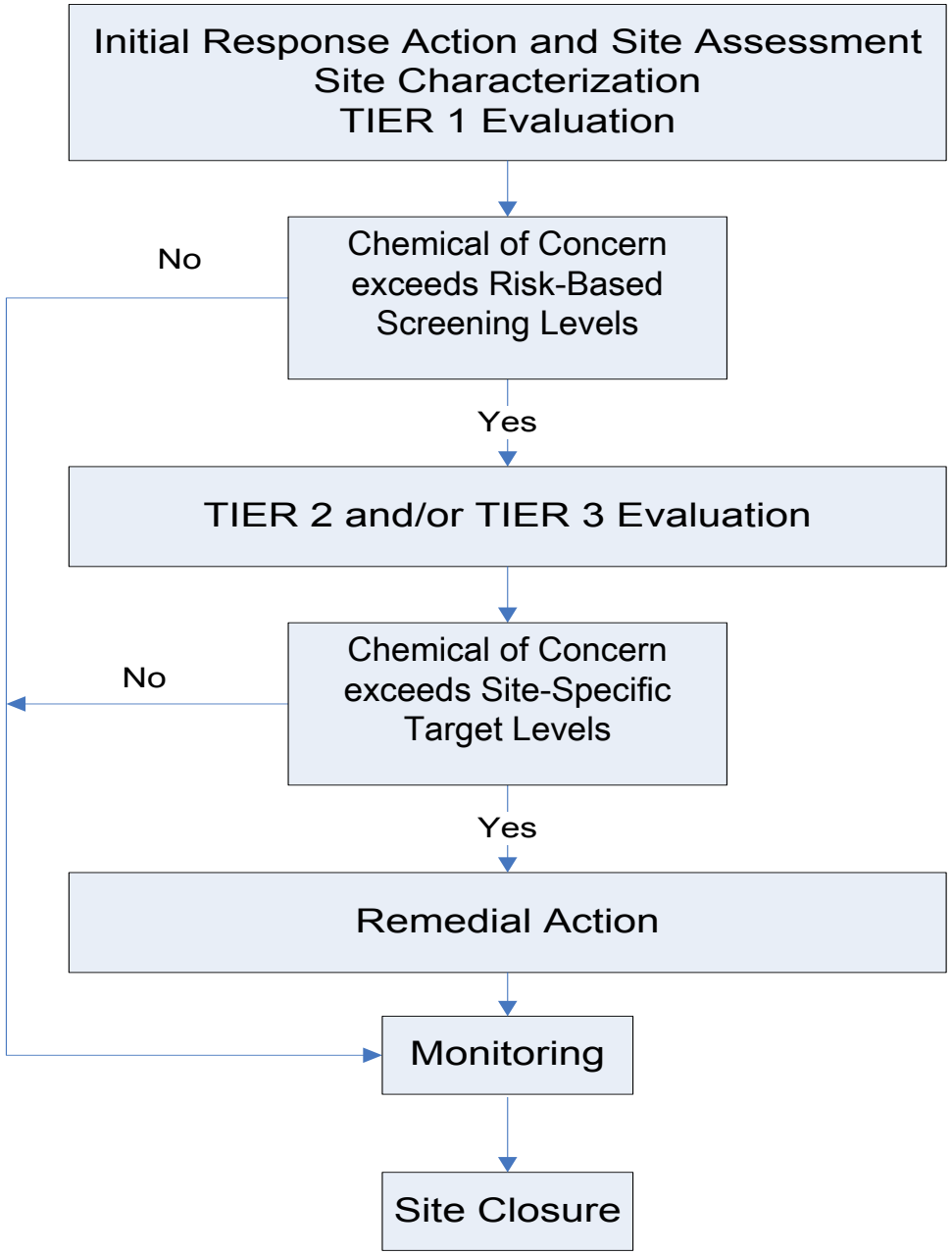




Notes: bbl = barrel
MMbbl = million barrels

Risk-Based Decision Making and Corrective Action

- Developed by American Society of Testing of Materials (ASTM)
  - ES38 – 94
  - E1739 – 95
- Adopted by U.S. Environmental Protection Agency (EPA)
- Scientific process for quantifying risks associated with exposure to chemicals in the environment.
- Decisions related to urgency of response, target cleanup levels, and remedial measures are based on current and reasonable potential risks to human health and the environment.
- Framework for many state underground storage tank regulations and some crude oil spill regulations
- Pathways
  - Air (inhalation by humans)
  - Soil (direct contact by humans, plants, animals)
  - Water (ingestion by humans, plants, animals)
- Receptors
  - Humans, animals, surface water, groundwater, plants



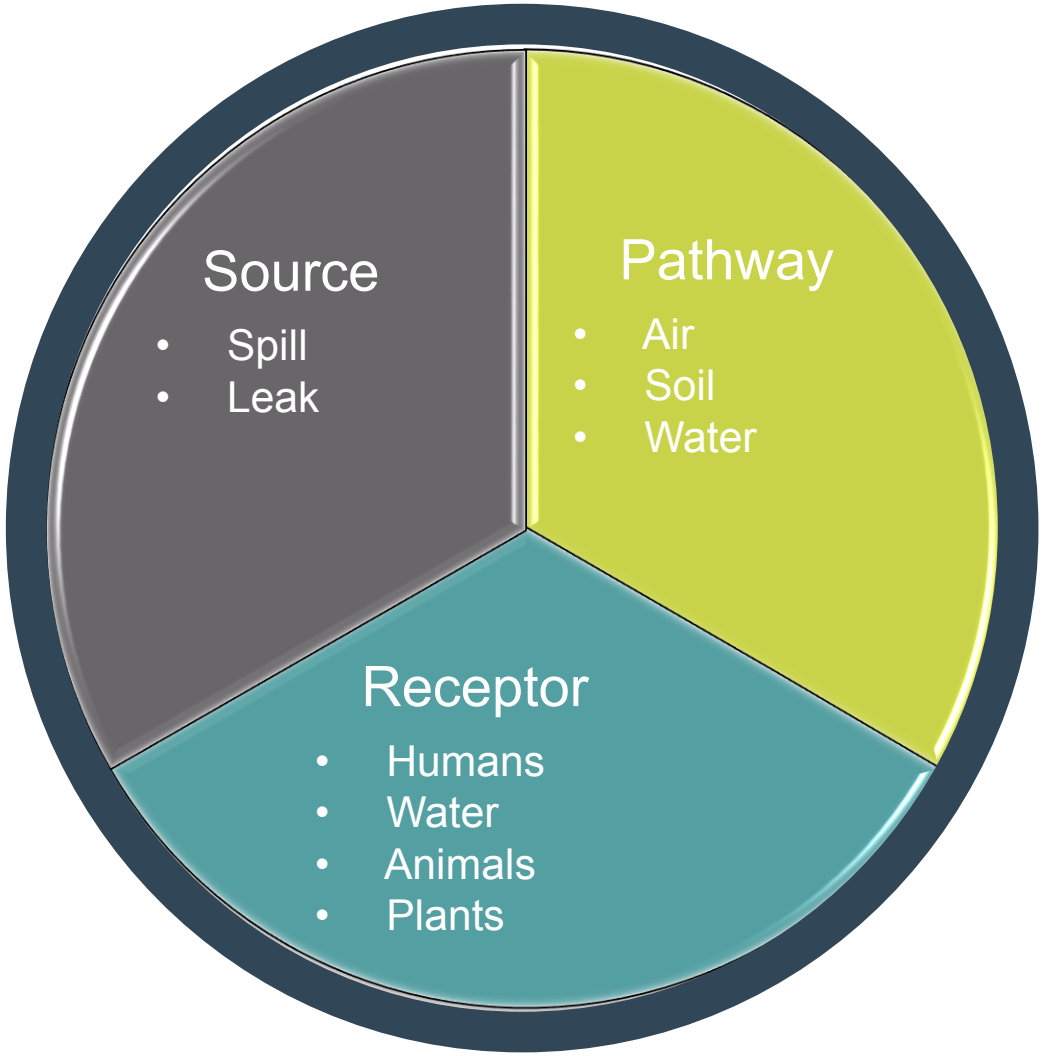
Modified from ASTM E1739 – 95

Risk-Based Corrective Action

- 2010 Internet survey of petroleum cleanup regulation performed by the Alaska Department of Environmental Conservation, Contaminated Sites Program:
  - Categorized and summarized the hydrocarbon cleanup programs for each U.S. state and Canada.
  - 35 states and Canada regulate hydrocarbon remediation of underground storage tanks under a risk-based process.
  - Risk-Based Corrective Action (RBCA) screening thresholds, and cleanup levels vary widely.

- Oklahoma and Michigan have specific (and different) screening levels and risk criteria for “upstream” crude oil releases at exploration and production sites.

For risk to exist, there must be source and a receptor linked by a pathway.



Risk-Based Decision Making Review

- Risk-based decision making is science-based, is site-specific, and focuses on how much remedial action should be performed (not how much remedial action can be performed).
- Risks to receptors associated with unrefined petroleum products are different (and in some cases lower) than refined petroleum products:
  - Partitioning behavior of crude oil
  - Remoteness of spill locations
- Understanding the chemistry of crude oil (and how it differs from refined products) as well as how the constituents of crude oil act in the environment is critical in understanding the level of risk posed by a crude oil release.

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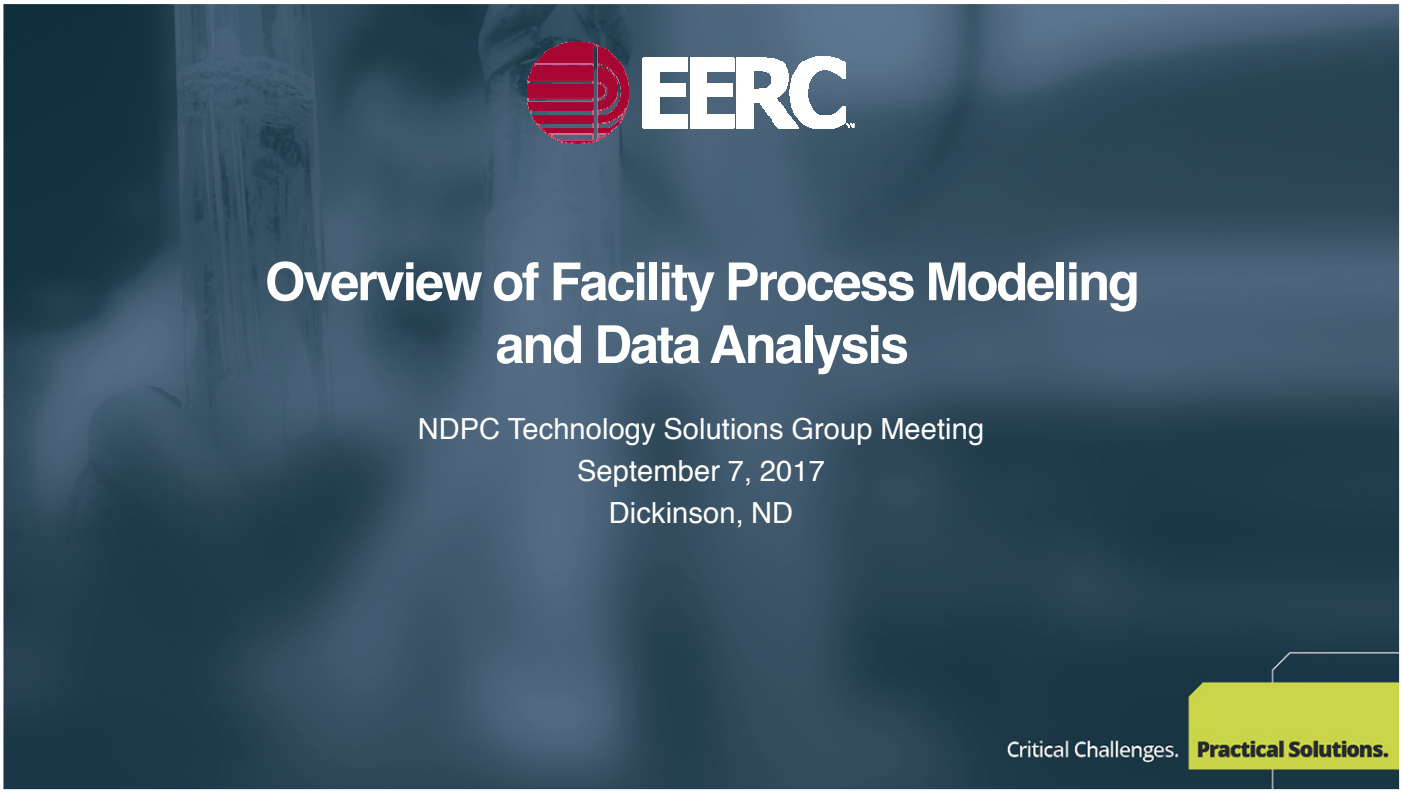
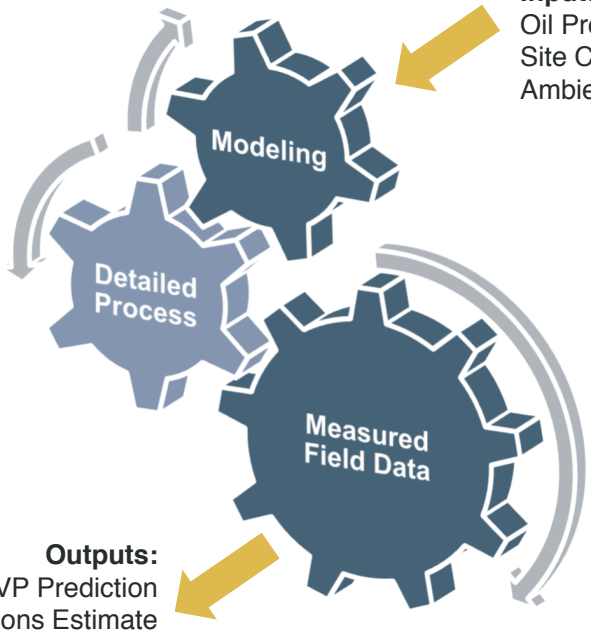
APPENDIX B

NDPC TECHNOLOGY SOLUTIONS GROUP MEETING PRESENTATION – OVERVIEW OF FACILITY PROCESS MODELING AND DATA ANALYSIS


EERC
Overview of Facility Process Modeling and Data Analysis
NDPC Technology Solutions Group Meeting
September 7, 2017
Dickinson, ND
Critical Challenges. Practical Solutions.

Background

- BPOP process modeling efforts began with fugitive emissions, i.e. predicting trends and simulating dynamic events.
- Model also applied to oil vapor pressure determination.
- Convened a crude volatility meeting in May 2017 to discuss and coordinate producer activities.
- Currently, analyzing measured field data and advising on future data collection efforts.



Inputs:
Oil Properties
Site Configuration
Ambient Conditions

Outputs:
VP Prediction
Emissions Estimate
Upset Response

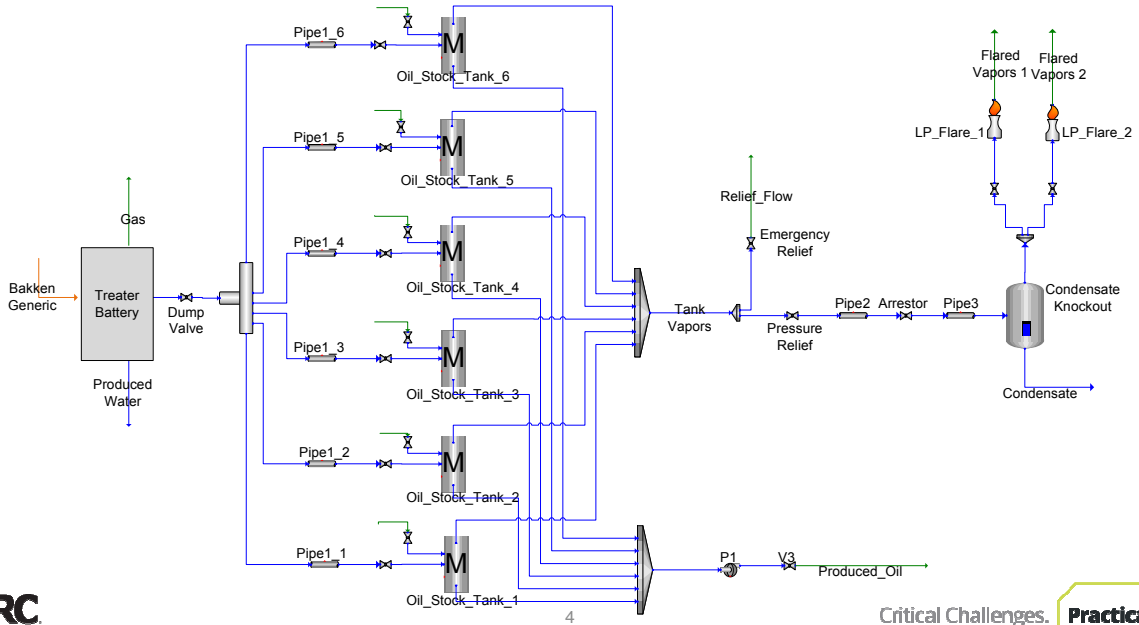
Model Summary

- Not a specific site; patterned on "common" Bakken conditions.
- **Site production rate:** 500 bbl/d/tank (3000 bbl/d/site)
- **Exposed pipe runs**
  - Treater battery to storage tanks: 3 inch sch. 40; 275 ft long.
  - Storage tank vent to flare: 6 inch sch. 40; 480 ft long.
- **Tank battery capacity:** 1.5 times daily production rate distributed among 6 tanks.
- **Flares:** low-pressure with air assist.

Bakken Production Optimization Program

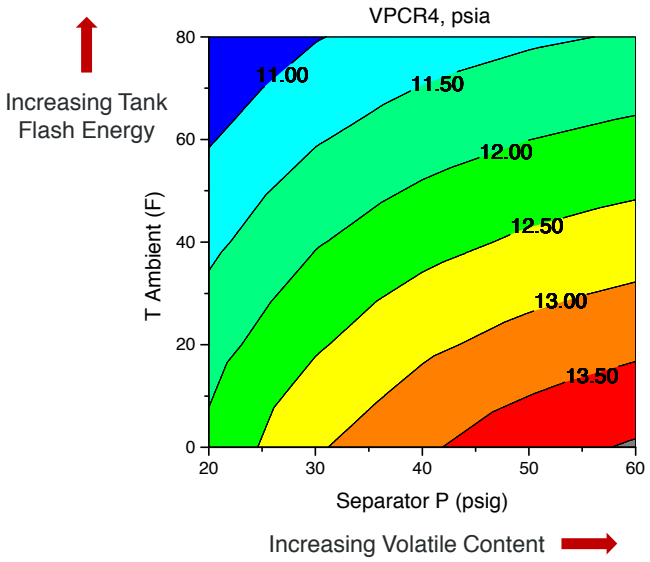
- More details available in the EERC's write-up of this work under its Bakken Production Optimization Program (BPOP).
- BPOP website: https://www.undeerc.org/Bakken/Bakken-Production-Optimization-Program.aspx
- Direct paper link: https://www.undeerc.org/Bakken/pdfs/CLM-BPOP%20Process%20ModBrief%20R4-Mar17.pdf

Process Diagram



Process Modeling Recap

- Modeling showed two key sensitivities: volatile content of oil sent to storage and the available energy for the atmospheric flash in the tanks.
- Volatile content was largely dictated by upstream treater conditions (oil makeup was not included as a parameter).
- Atmospheric flash energy was impacted by heat loss from the oil during transport to storage and within the tanks.

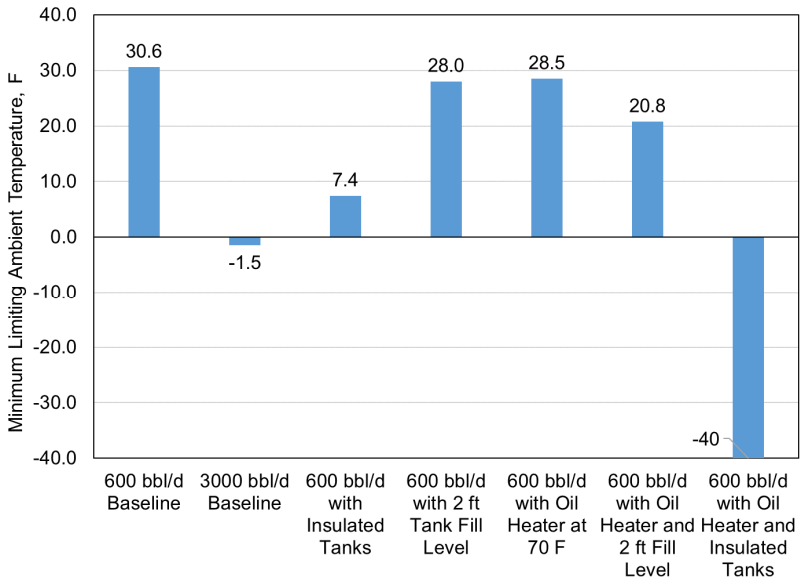


Cold Weather Modification Ranking

Different upgrade scenarios were modeled to estimate cold weather resiliency.

- Oil throughput was a significant factor for heat loss. The higher throughput site had a greater degree of cold weather protection.
- Modifying tank level and/or inline heat input resulted in only modest improvements.
- More significant improvements came with insulation and the most resilient configuration was with heating oil going to insulated tanks.

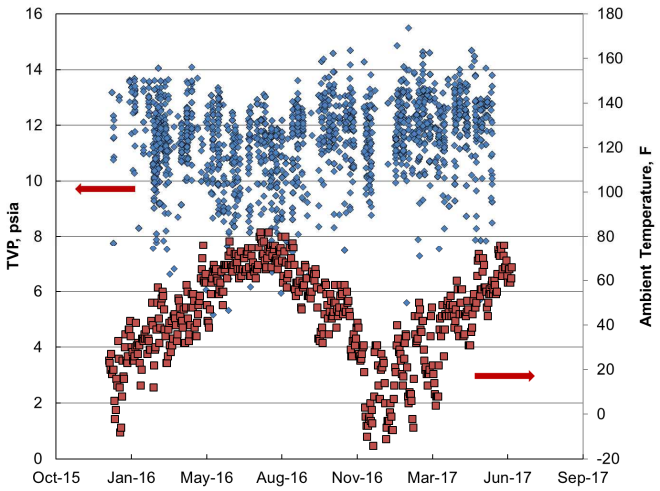
Ambient Temperatures Resulting in 13.7 psia Oil



Analysis of Historical Vapor Pressure Data

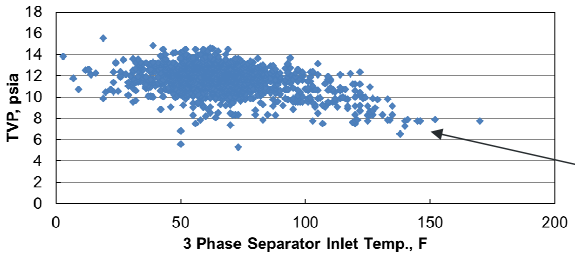
Shared Producer Data Set

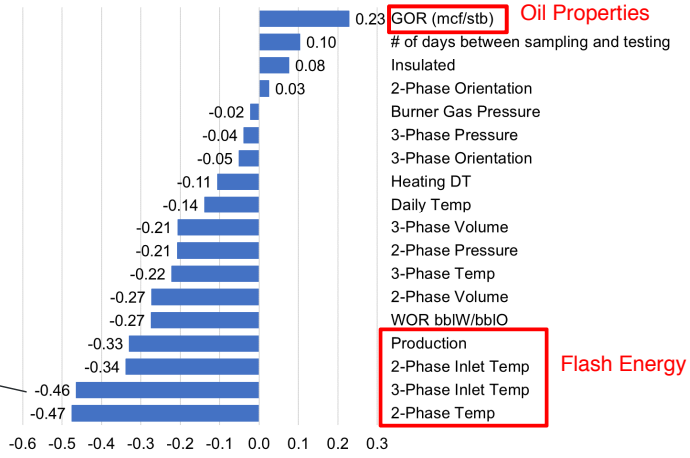
- Over 3000 individual readings covering 1.5 years.
- Consistent sampling protocol (open bottle); quarterly readings.
- Corresponding information:
  - Configuration
  - Temps. and Pressures
  - Production
  - Field



Vapor Pressure Correlation Coefficients

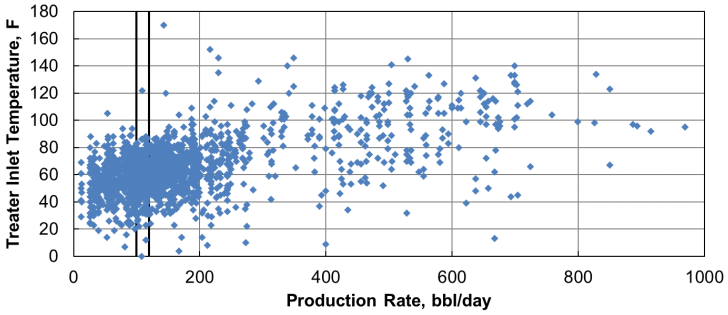
- Correlations with VP were tested for each parameter of a complete data subset, i.e. only using entries having all values populated.

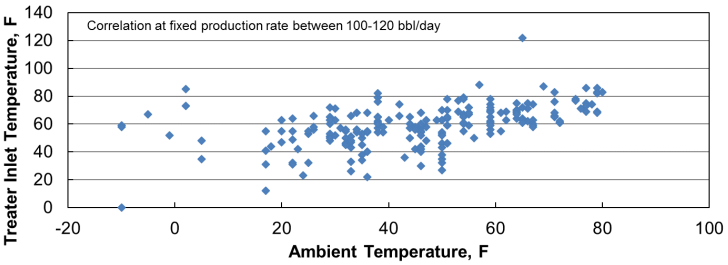




Flash Energy Correlation

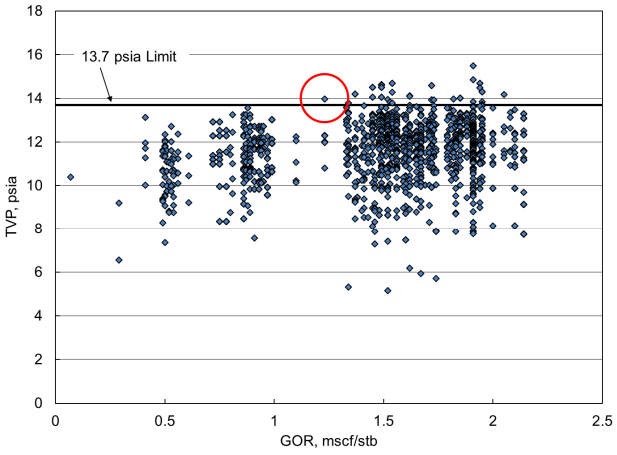
- Many loose correlations are possible; no single dominant parameter.
- Tentative associations observed between:
  - Treater inlet temperature
  - Production rate
  - Ambient temperature
- However, clearly missing are detailed geometries and real-time weather conditions.

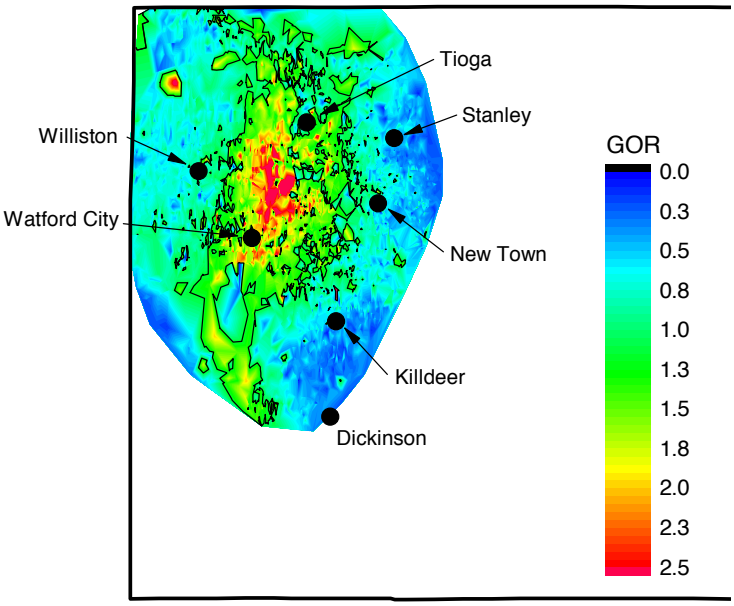




Oil Properties

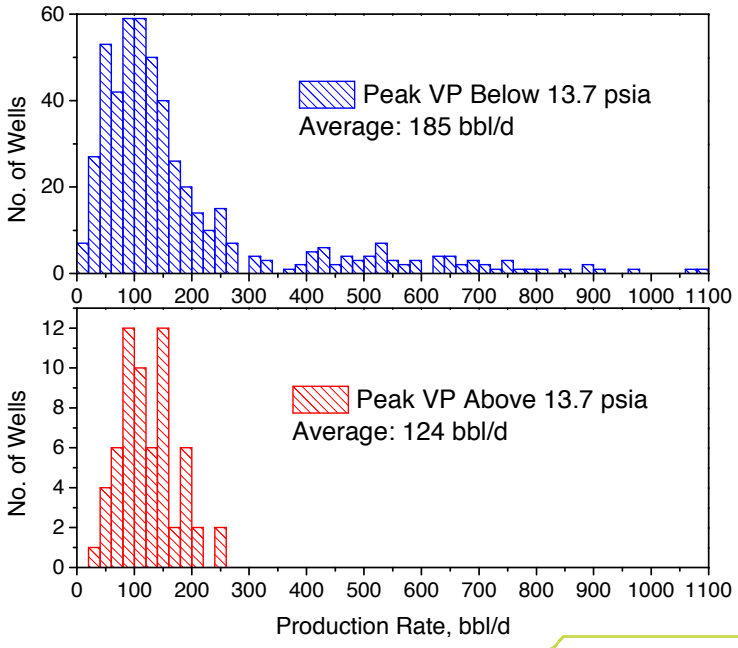
- GOR was another loose correlation factor for VP.
- GOR associated strongly with location (i.e. field). Possibly places a geographic constraint on problematic wells.





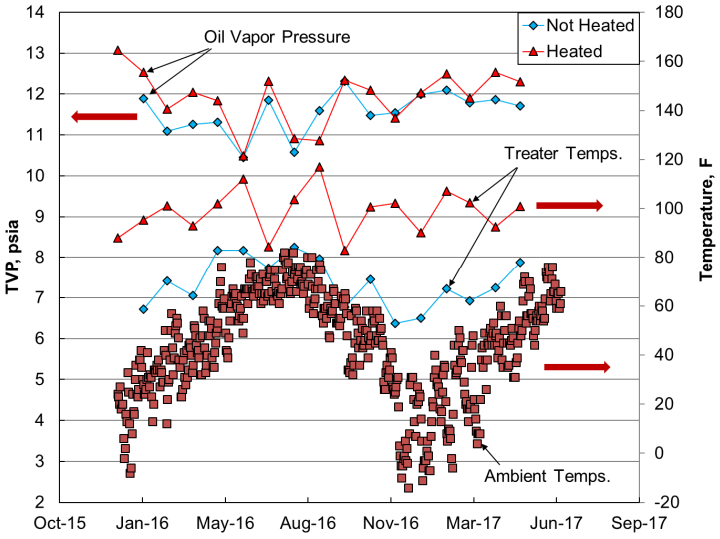
Production Rate

- Wells of most concern have lower, but not the lowest production rates.
- Peak readings above 13.7 psia were recorded for as many as 1 in 5 wells over the range of 80-160 bbl/day.
- Exceedance was non-existent for high producing wells above 260 bbl/day.
- Reduced exceedance rate at low producing wells with less than 60 bbl/day.



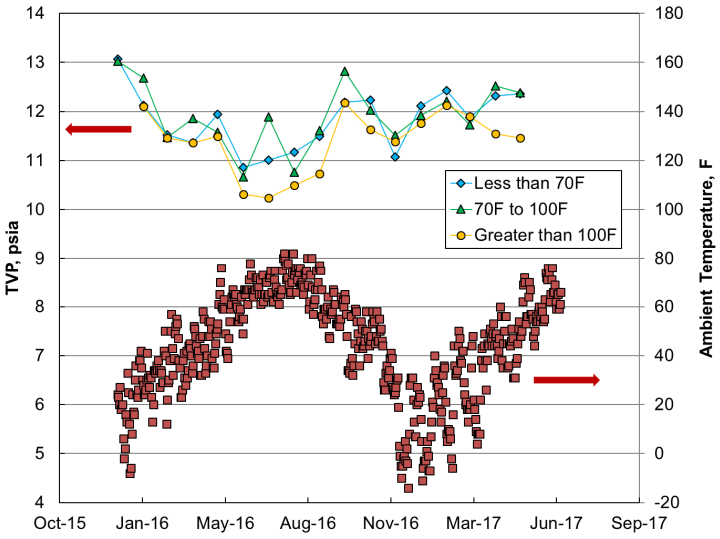
Heated vs. Unheated Treaters

- Treater data points averaged monthly.
  - Baseline configuration only: 6x20 vertical treater with 3x7.5 vertical 2 phase separator.
  - Heated data points, 958; average GOR, 1.39 mscf/bbl.
  - Unheated data points, 769; average GOR, 1.54 mscf/bbl.
- Vapor pressure with heated treater operation was 0.3 psi higher on average than for unheated.



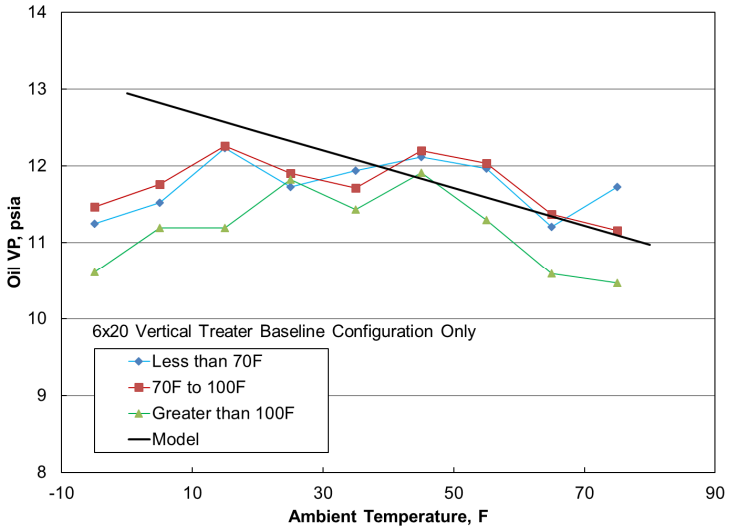
Breakdown by Treater Temperature

- Baseline configuration data averaged monthly.
- Grouping information:
  - <70° F, 627 points, 1.52 average GOR.
  - 70° F to 100° F, 705 points, 1.52 average GOR.
  - >100° F, 741 points, 1.36 GOR.
- Vapor pressure for treaters hotter than 100° F were nearly equal to those less than 70° F in winter, but were roughly 0.7 psi lower in summer.



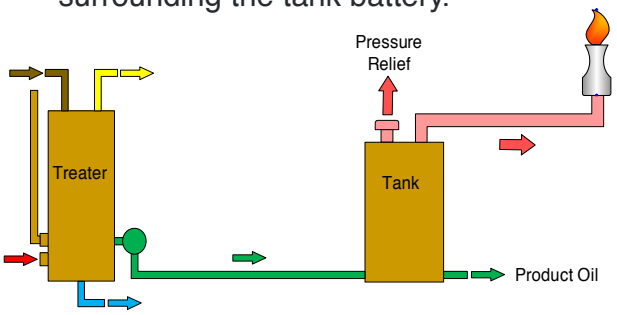
Treater Temperature Model Comparison

- VP data grouped and averaged according to the corresponding ambient temperature.
- Treaters greater than 100° F generally had lower VP averages than those 100° F or lower, although they were essentially the same in the 25° F to 45° F ambient temperature region.
- Fair agreement between averaged data and model above 45° F, but complete divergence below.



Conclusions

- Instances of similarity among trends observed in the model and measured data set. These include trends with flash energy and oil volatile content.
- However, there are also key discrepancies such as at low ambient temperatures and production rates.
- Must keep in mind that key pieces of information are missing, especially surrounding the tank battery.



Possible explanations for the missing details:

- Incomplete data set that suggests false correlations. For instance, data at temperature extremes might not be completely representative.
- Systematic bias, e.g. an introduced error from sampling.
- Potentially unidentified cold weather mechanism, e.g. tank stratification.

Next Steps

- Undertake detailed specific site evaluations to improve the model's usefulness.
- Observe tests of cold weather facility upgrades and contextualize findings.
- Report findings and conclusions to aid VP compliance.

Identified cold weather upgrades from May volatility meeting:

- Insulation and oil heating options
  - Insulated tanks
  - Insulated connection piping
  - Heat trace
  - Inline hot oiler
  - Separator recycle
- Variations of atmospheric flash vessels
  - "Tankless" configuration with VRT vessel
  - VRT or other atmospheric flash vessel added upstream of tank battery
  - Insulated and heated stock tank flash

APPENDIX C

LIBERTY RESOURCES EXHIBIT PRESENTED TO NDIC

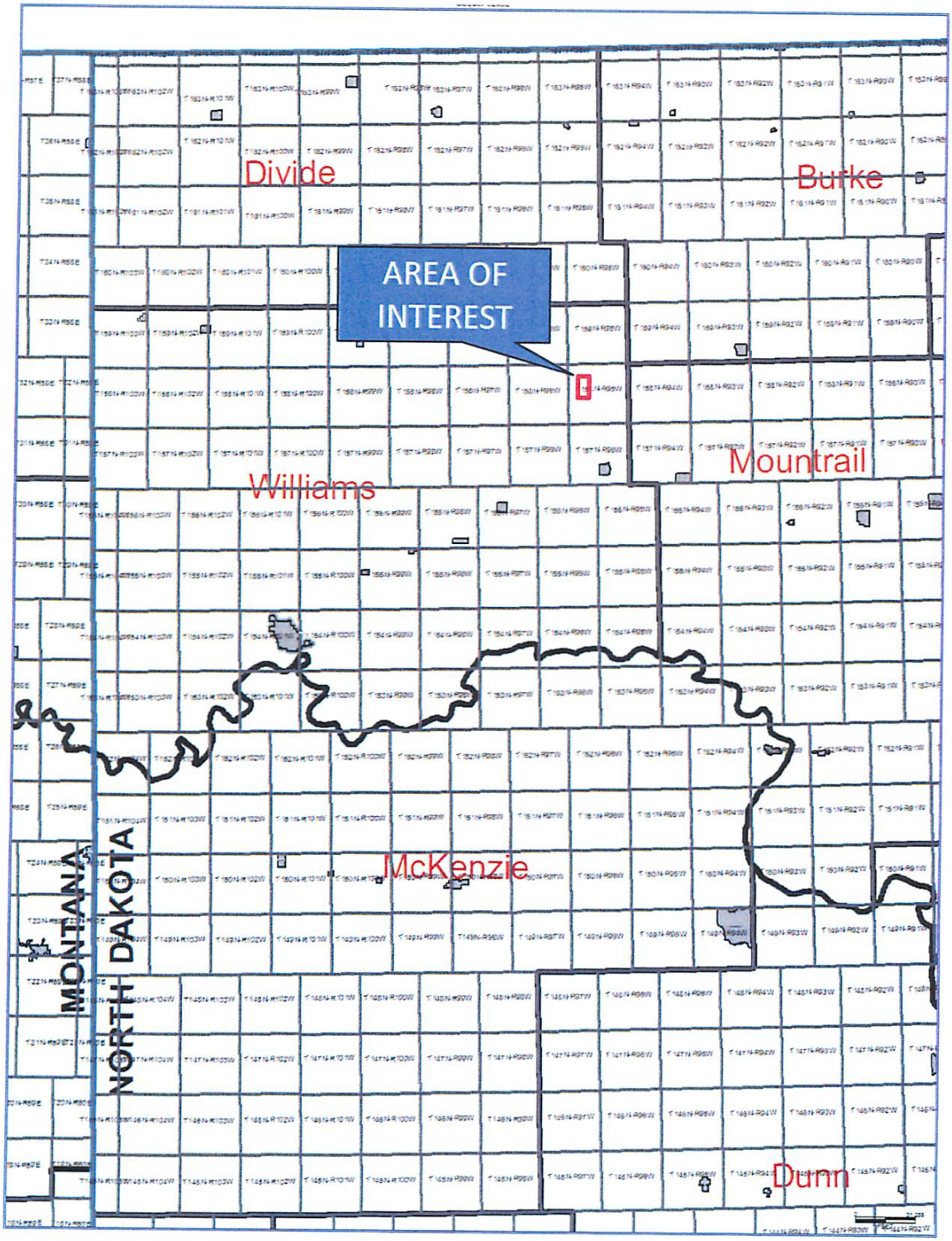
CASE No. 26035

Application of Liberty Resources Management Co., LLC for an order granting temporary authority to use numerous wells located in a spacing unit comprised of Sections 8 and 17, T.158N., R.95W., Williams County, ND, as injection wells for an enhanced oil recovery pilot operation in the McGregor-Bakken Pool, and such other relief as is appropriate.

Before the North Dakota Industrial Commission
September 21, 2017

Liberty Resources Management Company, LLC
1200 17th Street, Suite 2200
Denver, CO 80202

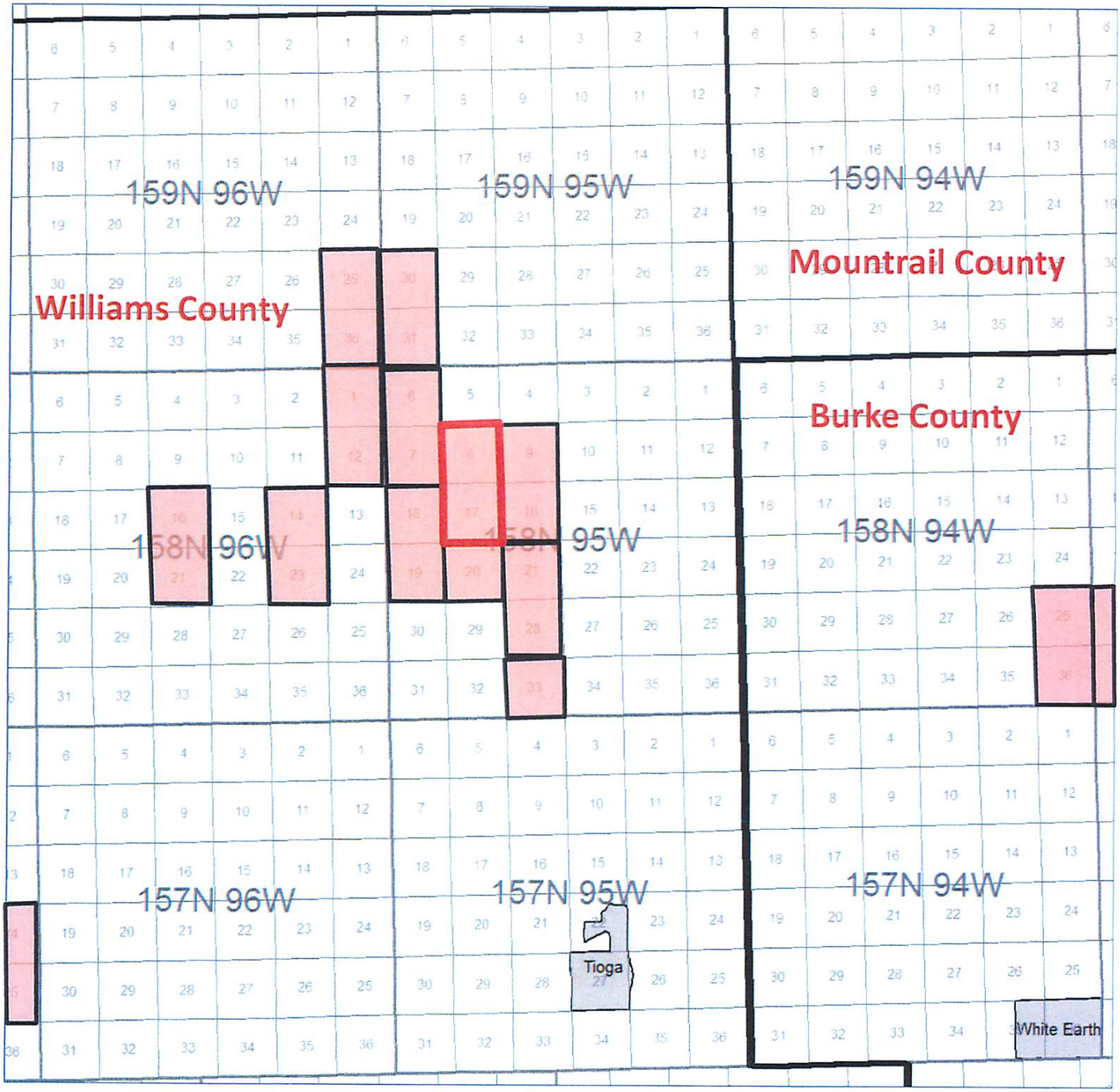
Regional Map



LIBERTY RESOURCES

Exhibit L-1
Case No. 26035

Location Map



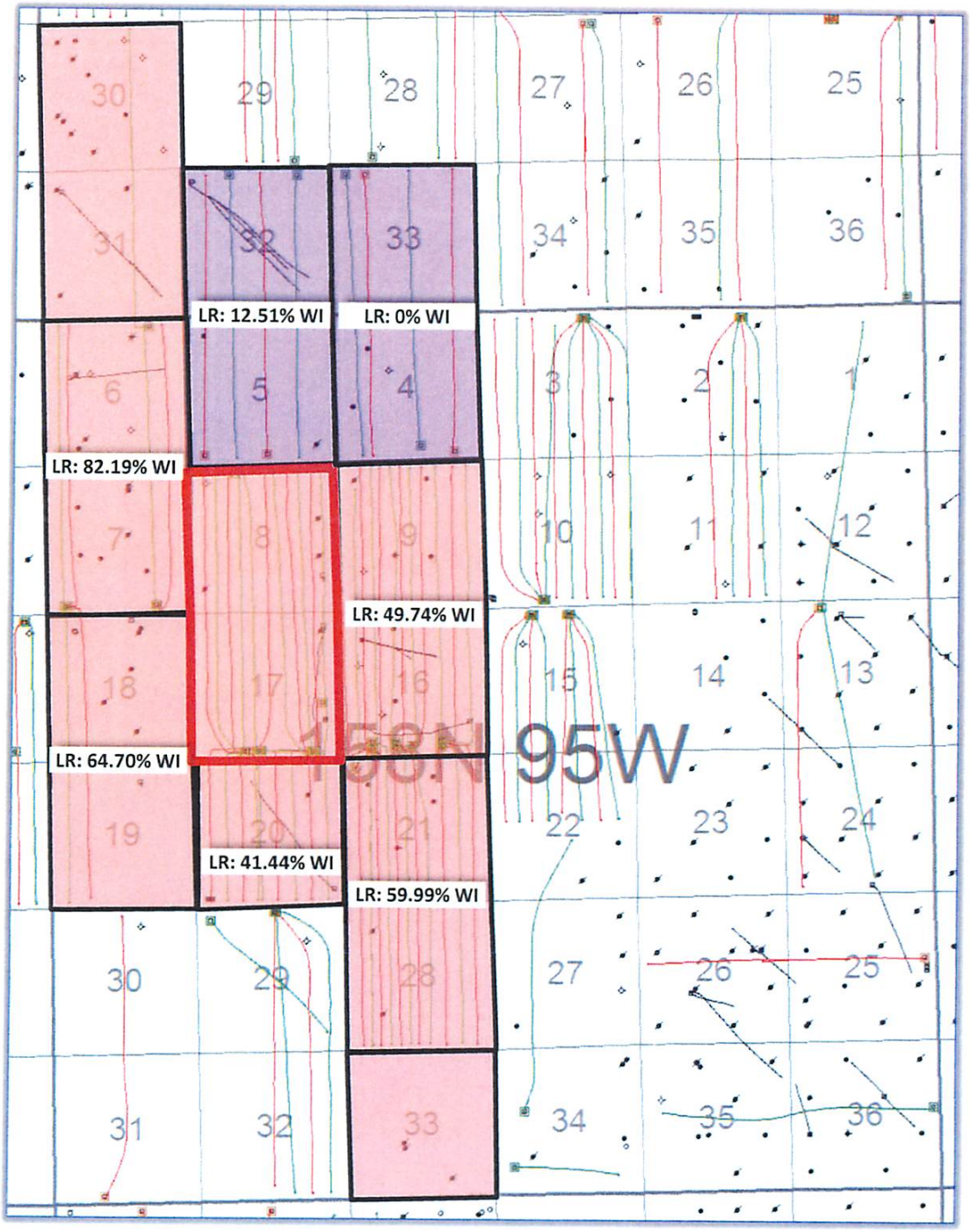
- 1280-acre Spacing Unit of Interest

- Existing Liberty Spacing Unit

LIBERTY RESOURCES

Exhibit L-2
Case No. 26035

Location Map – Offset Ownership



- 1280-acre Spacing Unit of Interest
- Existing Liberty Spacing Unit
- Murex Operated Spacing Unit
- Existing Middle Bakken Horizontal
- Existing Three Forks Horizontal

LIBERTY RESOURCES

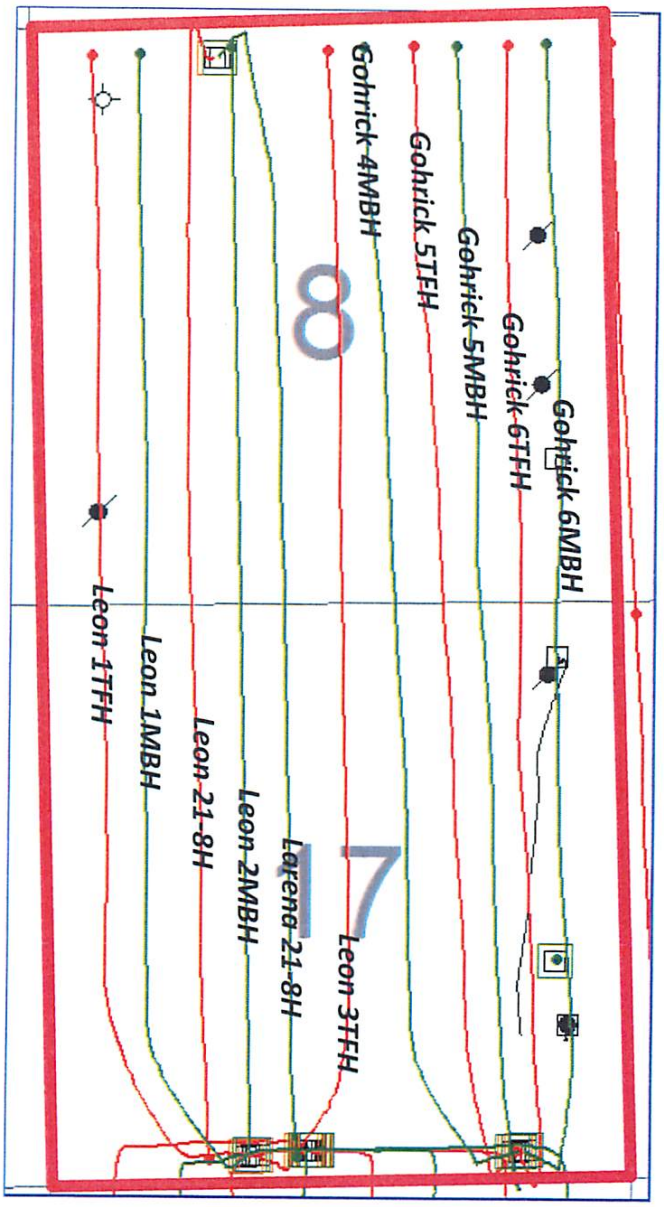
Exhibit L-3
Case No. 26035

Current 1280 Acre Spacing Unit

Township 158 North, Range 95 West, Sections 8 & 17

Williams County, North Dakota

Containing 1280 Acres



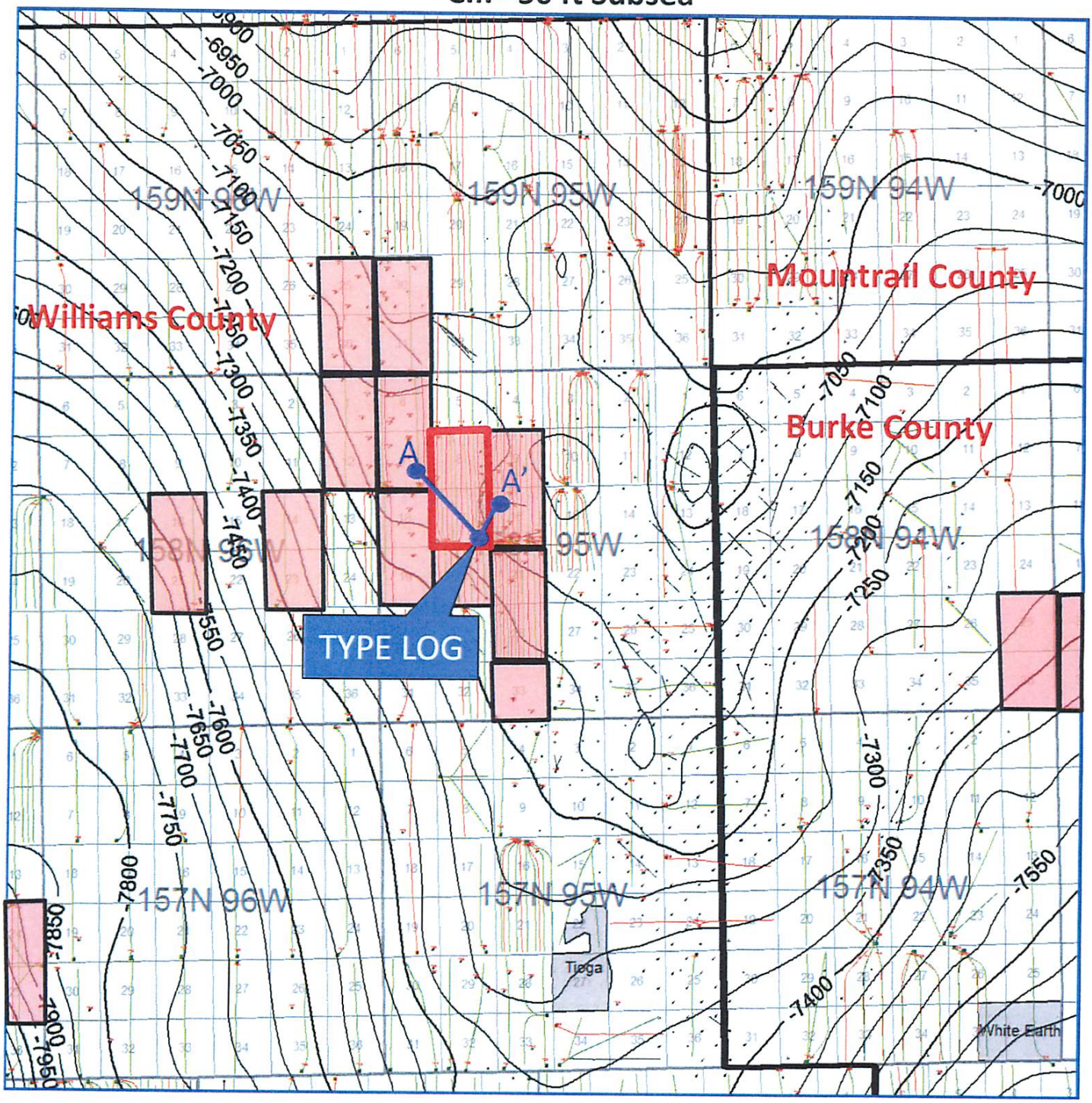
- Existing Middle Bakken Horizontal
- Existing Three Forks Horizontal
- 1280-acre Spacing Unit

Working Interest Summary (does not reflect any carried interests):
Liberty Resources Bakken Operating, LLC= 27.36%
Others= 72.64%

LIBERTY RESOURCES

Exhibit L-4
Case No. 26035

Geologic Structure Map
Top Middle Bakken
C.I.= 50 ft Subsea

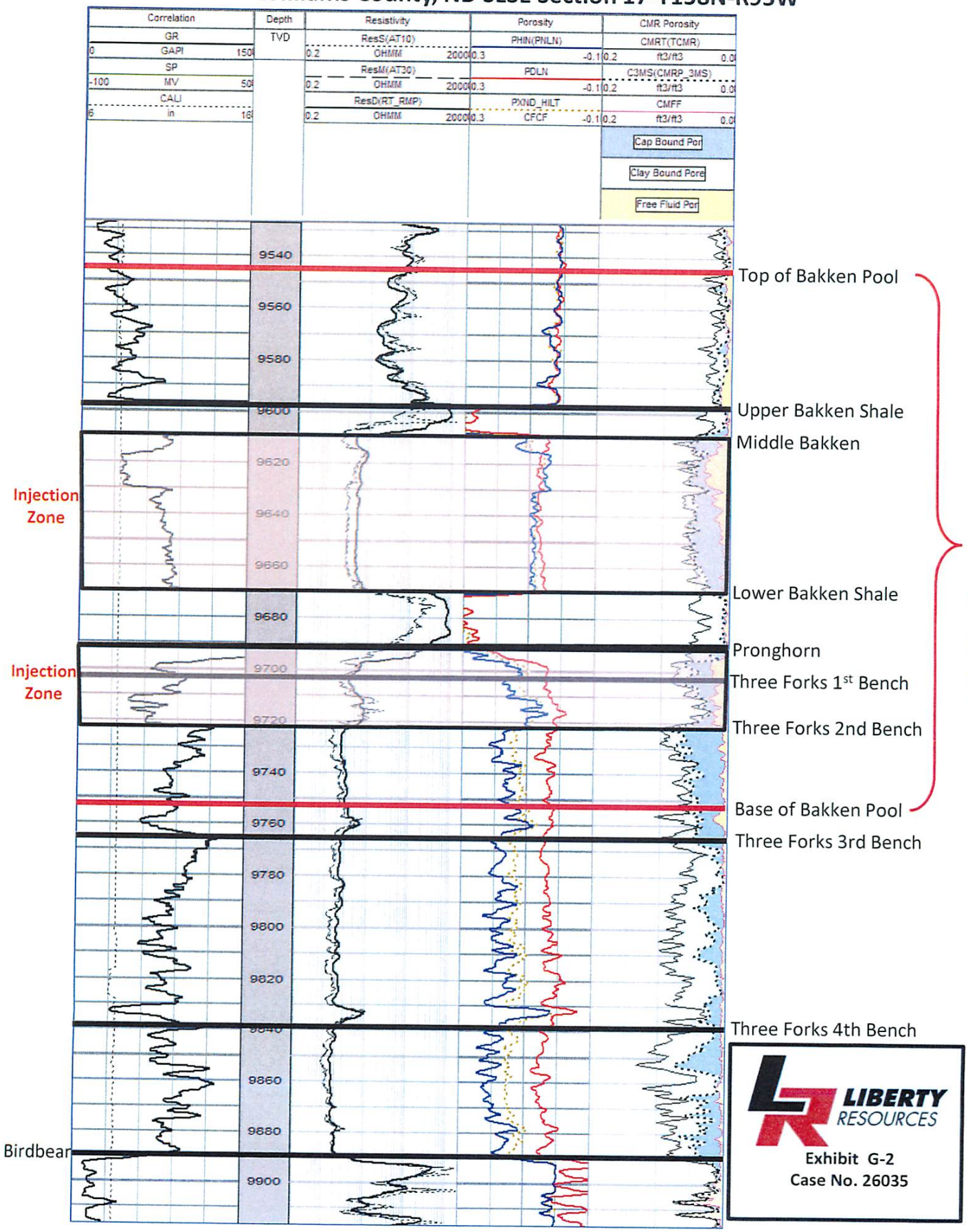


- Existing Liberty Resources Spacing Unit
- Existing Middle Bakken Horizontal
- Existing Three Forks Horizontal
- 1280-acre Spacing Unit of Interest

LIBERTY RESOURCES

Exhibit G-1
Case No. 26035

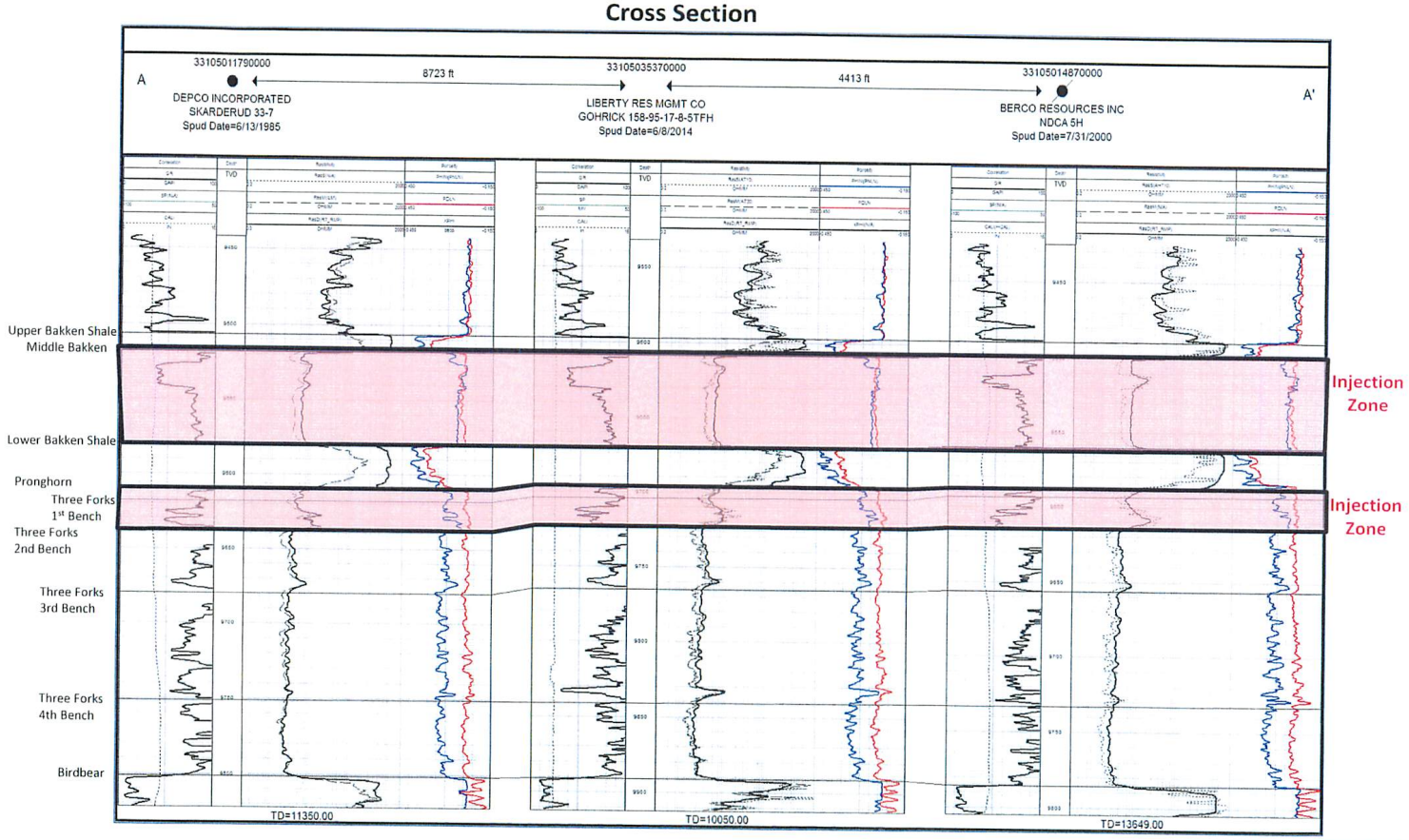
Type Log
Liberty Resources, LLC –Gohrick 158-95-17-8-5TFH
Williams County, ND SESE Section 17-T158N-R95W



LIBERTY RESOURCES

Exhibit G-2
Case No. 26035

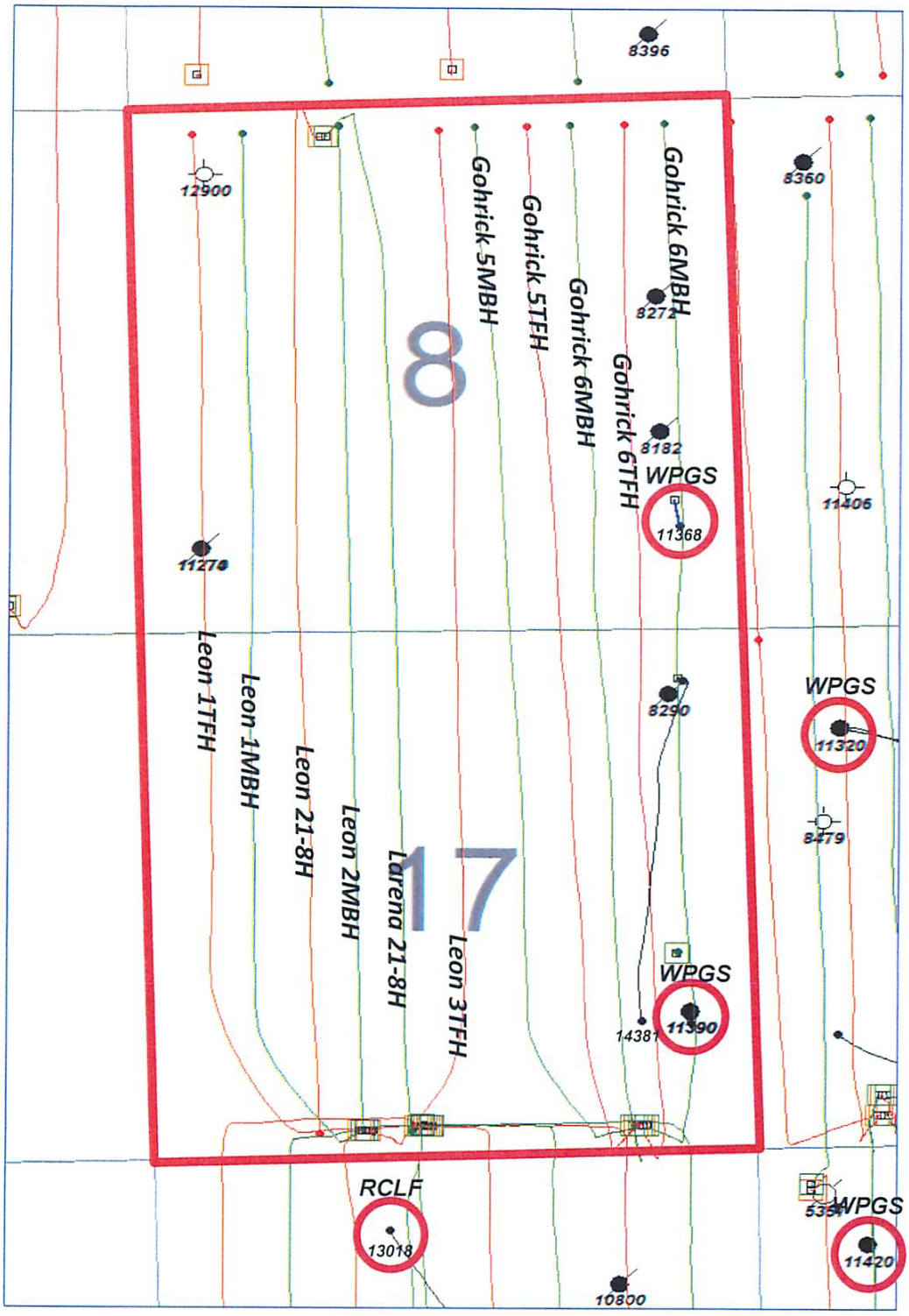
Cross Section



LIBERTY RESOURCES

Exhibit G-3
Case No. 26035

Non-Bakken Pool Offsets



- 1280-acre Spacing Unit of Interest

PROD FM
TD
- Active Producer

- Existing Middle Bakken Horizontal

- Existing Three Forks Horizontal

LIBERTY RESOURCES

Exhibit E-1
Case No. 26035

Pilot Goals

Pilot Goals

- To execute the pilot in order to determine the technical feasibility of enhancing oil recovery from the Bakken Pool by using natural gas and natural gas liquids as an immiscible or miscible injectant.
- To utilize a fully developed Bakken Pool DSU to evaluate and optimize injection methods for the purpose of enhanced oil recovery.
- To evaluate the effectiveness of various rich gas mixtures to mobilize oil in the Bakken petroleum system

Source of Injection Gas

- Lease gas will be used as injection gas and sourced from wells collocated on a multi-well drill site.

Anticipated Injection Rates

- A total of up to 3MMscfd; injected into either one or more than one wells simultaneously

Maximum Allowable Surface Injection Pressure

- 5,000psi as constrained by wellhead and flowline MAOP

Proposed Injection Period

- 2 year period inclusive of all wells in the pilot

Proposed Injection Volume

- Cumulative injection volume – 2,500 MMscf
- Maximum instantaneous estimated volume in the reservoir – 360 MMscf

Surveillance Plan

- Oil, gas, and water rates will be monitored continuously from Liberty Operated Wells
    - Oil and Water are measured using Coriolis meter, Gas is measured using orifice plate equipped with Electronic Flow Metering.
    - Data is gathered by a Scada system and is collected every 5 minutes
- The two wellbores immediately adjacent to the injector well will be equipped with gas chromatograph, or daily samples will be taken for GC
- The injection well will be equipped with bottom hole pressure gauges. Gauge data will be retrieved at the end of the injection cycle.
- The four wellbores immediately adjacent the injector, two to the east and two to the west, will be equipped with bottom hole pressure gauges. Gauge data will be retrieved every two weeks at minimum.
- The offset operator to the north has been contacted, and has agreed to provide operational information.

LIBERTY RESOURCES

Exhibit E-2
Case No. 26035

Pilot Estimated Cost Summary

Compression Cost – Provided at no cost to Liberty or our working interest partners through a strategic technical partnership

Lease Fuel Use – Estimated at 55 Mscfd, $2,100 Gross/month

Bottom Hole Pressure Monitoring - $4,000 - $10,000/month ($2,000/well per month)

Gas Chromatograph – $9,100/month

Total Estimated Compressor Installation and Start-up Cost - $12,000-$15,000/well

Average Incremental Operating Expense per Well - $2,700/month

LIBERTY RESOURCES

Exhibit E-2
Case No. 26035

Stomping Horse Bakken Rich Gas EOR Project

Stomping Horse Bakken Rich Gas EOR Project –

Goals, Hypothesis, Experimental Design, and Potential Applications to Future Commercial Bakken EOR Operations

Summary Overview

Prepared by

Energy & Environmental Research Center
Grand Forks, North Dakota

Prepared for

Liberty Resources Management Company

September 11, 2017

LIBERTY RESOURCES

Exhibit E-3A
Case No. 26035

Stomping Horse Bakken Rich Gas EOR Project

Introduction

The associated gas from Bakken oil production operations is typically a mixture dominated by methane with a significant amount of ethane and other hydrocarbons. This gas mixture is commonly referred to as "rich gas." The results of recent preliminary laboratory investigations at the Energy & Environmental Research Center (EERC) suggest that rich gas may be used to mobilize oil from Bakken rocks and thus could be a viable injection fluid for enhanced oil recovery (EOR) operations (Hawthorne and others, 2017). An analysis of historical pilot-scale EOR tests in the Bakken has shown that keeping the injected fluid in the target reservoir long enough for it to mobilize incremental oil (e.g. "conformance") is a significant challenge for EOR operations in tight oil reservoirs (Hoffman and Evans, 2016; Sorensen and Hamling, 2016). Previous EERC research efforts also indicate that cyclic multiwell huff 'n' puff (CMWHP), which includes a sequence of alternating injection, shut-in (soak), and production using three or more wells, may be an effective EOR scheme for Bakken reservoirs (Sorensen and others, 2014).

Liberty Resources Management Company (Liberty), in partnership with the EERC, the North Dakota Industrial Commission (NDIC), and the U.S. Department of Energy, is planning to conduct field-based activities to determine the feasibility of using rich gas injection, with conformance managed by a CMWHP scheme, for EOR operations in hydraulically fractured horizontal wells in the Bakken. It is anticipated that the scientific understanding gained from these research activities will ultimately lead to commercial deployment of rich gas EOR in the Bakken and Three Forks formations in North Dakota.

Liberty has identified their integrated oilfield complex in Williams County, North Dakota, referred to as the Stomping Horse Complex, as an ideal site for the rich gas EOR test. The Stomping Horse Complex includes oil production wells, produced fluid and rich gas-handling and processing facilities, produced water disposal wells, associated infrastructure, and a supervisory control and data acquisition (SCADA) system for managing all aspects of the complex. The integrated components of the Stomping Horse site make it an optimal location for conducting a pilot-scale rich gas EOR test in a Bakken reservoir. However, the composition of the rich gas stream is known to vary substantially between different parts of the Stomping Horse complex (e.g., wellhead vs. gas plant), and it is believed that those compositions may also change over time as a function of reservoir depletion. The site-specific geologic characteristics of the reservoir will also dictate the specific design elements of EOR schemes and reservoir surveillance plans. It is clear there are knowledge gaps with respect to how different gas compositions can affect the performance of an EOR operation. There is also uncertainty about how the hydraulically fractured nature of producing Bakken reservoirs can be accounted for and incorporated into a successful EOR scheme. A multidisciplinary scientific approach to a pilot field test can fill those knowledge gaps and lead to commercial implementation of rich gas EOR not only at the Stomping Horse complex, but throughout the Bakken play.

Goals

The overarching ultimate goal of the pilot-scale EOR test is to develop fundamental data that will provide a technical and economic foundation for the design and operation of a future commercial-scale rich gas-driven EOR operation. Specific research objectives related to this goal are as follows:

- Determine the effectiveness of CMWHP as an injection/production scheme that can maintain conformance of the working fluid within the reservoir.

LIBERTY RESOURCES

Exhibit E-3B
Case No. 26035

Stomping Horse Bakken Rich Gas EOR Project

- 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.

Hypothesis

A series of EERC laboratory experiments have demonstrated that CO_2, ethane, methane, and mixtures of ethane and methane can permeate the rocks of the Middle Member and Shale Members of the Bakken Formation and cause an increase in oil mobility (Hawthorne and others, 2014; Hawthorne and others, 2016). However, past pilot-scale injection tests using CO_2, rich gas, water, and combinations thereof, into horizontal Bakken wells have shown little to no effect on oil mobilization (Hoffman and Evans, 2016; Sorensen and Hamling, 2016). This is most likely due to poor injection conformance caused by fractures in the reservoir system serving as fast flow pathways that disperse the injected fluid, thereby minimizing its contact time with the matrix in which stranded oil resides. With respect to the potential for EOR in the Bakken, there is clearly a gap in what laboratory-scale experiments and modeling suggest may be possible and what the application of "conventional" approaches to EOR in the field has shown to be possible. In an effort to close this knowledge gap, Liberty and the EERC intend to conduct a set of field-based experimental activities to test a two-pronged hypothesis; 1) that CMWHP using rich gas as the working fluid can be an effective means of conformance control in a hydraulically fractured tight oil reservoir and 2) injected rich gas can interact with the in-place fluids, resulting in subsequent mobilization of hydrocarbons and improvements in ultimate recovery.

Experimental Design

The experimental activities will be based on a pilot-scale field test of rich gas injection into a Bakken petroleum system reservoir at Liberty's Stomping Horse Complex. Liberty efforts in the test will include designing and operating the compression/injection/production scheme, supplying rich gas to the injection locations, and conducting reservoir surveillance in the test wells and offset wells. EERC efforts in the test will include providing modeling support to Liberty, conducting laboratory-based studies of oil–rich gas interactions on site-specific samples of oil and rock, working with Liberty to design a test monitoring program, and assisting Liberty in interpretation and evaluation of results. Specific aspects of the field test will include, but are not necessarily limited to, the following:

- Fluid samples will be collected from the reservoir and the rich gas source (i.e. County Line Gas Plant) and analyzed before any injection activities. Those data will be used to generate insight on baseline reservoir characteristics and to help determine post injection effects of rich gas on key reservoir characteristics (e.g., oil and gas composition).

Stomping Horse Bakken Rich Gas EOR Project

- Small scale injectivity tests using water have been conducted on representative wells in the area to determine injection pressures and rates and estimate gas injection performance in the subject wells. This information is being incorporated into the project design.

- A final design for the primary CMWHP test will be developed, including maps and diagrams to illustrate key design elements of the test, and detailed operational procedures for the baseline reservoir characterization, rich gas injection, and monitoring elements of the field test.

- The delivery, compression, and injection of rich gas will be conducted at selected wells in the Leon-Gohrick drill spacing unit. It is anticipated that approximately 2,500 mmcf of rich gas will be injected over the course of the primary CMWHP test. The primary test will include injection of rich gas into four wells in the Middle Bakken and three wells in the Three Forks.

- Fluid samples and detailed reservoir pressure and temperature data will be collected and analyzed during and after the primary CMWHP test. Those data will be used to rapidly generate insight regarding injection conformance and to determine the effects of rich gas on reservoir dynamics and oil mobility.

- The EERC methods used in previous laboratory-based evaluations of rich gas/oil interaction and hydrocarbon extraction will be applied to samples from the field test location. Those data will be used to provide insight on the mechanisms controlling the movement of fluids in the matrix which, when combined with injection/production schemes that improve conformance, will ultimately support the development of longer-term, commercial scale rich gas EOR operations.

- EERC personnel will assist with selected field-based monitoring aspects of the test. EERC efforts in the field will be focused on obtaining information and data from the injection operation that may yield insight regarding the conformance of injected rich gas in the reservoir.

In addition to addressing the stated hypothesis, the field-based experimental activities will address several associated questions including, but not necessarily limited to, the following:

- What role might the Bakken shales play in rich gas EOR?
- Can naturally occurring hydrocarbon species be used as "natural tracers" to distinguish between oil mobilized from the shales and oil mobilized from the Middle Bakken and/or Three Forks?
- What is the nature and magnitude of vertical and horizontal pressure and/or fluid communication in the Bakken Petroleum System?

The results of the field activities will support future larger-scale EOR operations in the following ways:

- Past pilot-scale field tests in the Bakken were conducted in either older (pre-2010) horizontals that used outdated completion techniques, or vertical wells. The Stomping Horse test will demonstrate how sophisticated completions in a group of newer, highly characterized, horizontal wells can be used to improve conformance.
- The Stomping Horse test will demonstrate how carefully planned and executed rich gas injection/soak/oil production operations in multiple wells can be used to maintain conformance and improve oil production.

LIBERTY RESOURCES

Exhibit E-3D
Case No. 26035

Stomping Horse Bakken Rich Gas EOR Project

- The scale of the test and the existing and planned integration of the rich gas source, infrastructure, compression, injection, production, and reservoir surveillance will yield new insight on the economics of using rich gas for EOR in the Bakken.
- The field based results will be used to history match simulations of the CMWHP tests. Results of those simulation and history matching exercises can be used to improve injection conformance and directly inform the design of future commercial-scale operations.
- The laboratory and modeling work that has been done under this program to date (Hawthorne and others, 2013; Hawthorne and others, 2014; Jin and others, 2016) indicates that solubility and diffusion of working fluids are primary mechanisms controlling oil mobility in Bakken rocks. The combination of laboratory-, field-, and modeling-based activities under this project will provide new insight regarding the role that solubility and diffusion of rich gas may play in mobilizing oil from within the matrix of the Bakken. That information will be instrumental to designing future larger-scale and longer-term rich gas EOR operations.
- The results may also inform the design of future completions or refracing operations, such that those operations may be designed and conducted in a way to maximize the exploitation of those mechanisms if/when a well moves into the EOR phase.
- If the pilot-scale test demonstrates that hydrocarbon species can be shown to be effective natural tracers to determine the zones from which the produced oil is coming, then those hydrocarbon species can be used in future injection tests as tracers to help determine which stages of the horizontal wellbore are being most affected by the injected working fluid.

References:

Hawthorne, S.B., Gorecki, C.D., Sorensen, J.A., Steadman, E.N., Harju, J.A., Melzer, S., 2013, Hydrocarbon mobilization mechanisms from Upper, Middle, and Lower Bakken reservoir rocks exposed to CO_2. Paper presented at the SPE Unconventional Resources Conference – Canada, Society of Petroleum Engineers, SPE 167200-MS.

Hawthorne, S.B., Gorecki, C.D., Sorensen, J.A., Miller, D.J., Melzer, L.S., Harju, J.A., 2014, Hydrocarbon mobilization mechanisms using CO_2 in an unconventional oil play. Paper presented at GHGT-12, Energy Procedia, v. 63, p. 7717-7723, Elsevier.

Hoffman, T.B., and Evans, J.G., 2016. Improved oil recovery IOR pilot projects in the Bakken Formation. Paper presented at the SPE Low Perm Symposium, SPE-180270-MS, 22 pp., Denver, Colorado, USA, May 5-6, 2016.

Jin, L., Hawthorne, S., Sorensen, J., Kurz, B., Pekot, L., Smith, S., Bosshart, N., Azenkeng, A., Gorecki, C., Harju, J., 2016. A systematic investigation of gas-based improved oil recovery technologies for the Bakken Tight Oil Formation. Paper presented at the Unconventional Resources Technology Conference (URTeC), URTeC:2433692, 15 pp., San Antonio, Texas, USA, 1-3 August, 2016.

Sorensen, J.A., and Hamling, J.A., 2016. Historical Bakken test data provide critical insights on EOR in tight oil plays. The American Oil & Gas Reporter, Vol. 59, No. 2, pp. 55-61, February, 2016.

Sorensen, J.A., Hawthorne, S.A., Smith, S.A., Braunberger, J.R., Liu, G., Klenner, R., Botnen, L.S., Steadman, E.N., Harju, J.A., and Doll, T.E., 2014, CO_2 Storage and Enhanced Bakken Recovery Research Program: Subtask 1.10 final report for U.S. Department of Energy Cooperative Agreement No. DE-FC26-08NT43291, May, 79 p.

LIBERTY RESOURCES

Exhibit E-3E
Case No. 26035

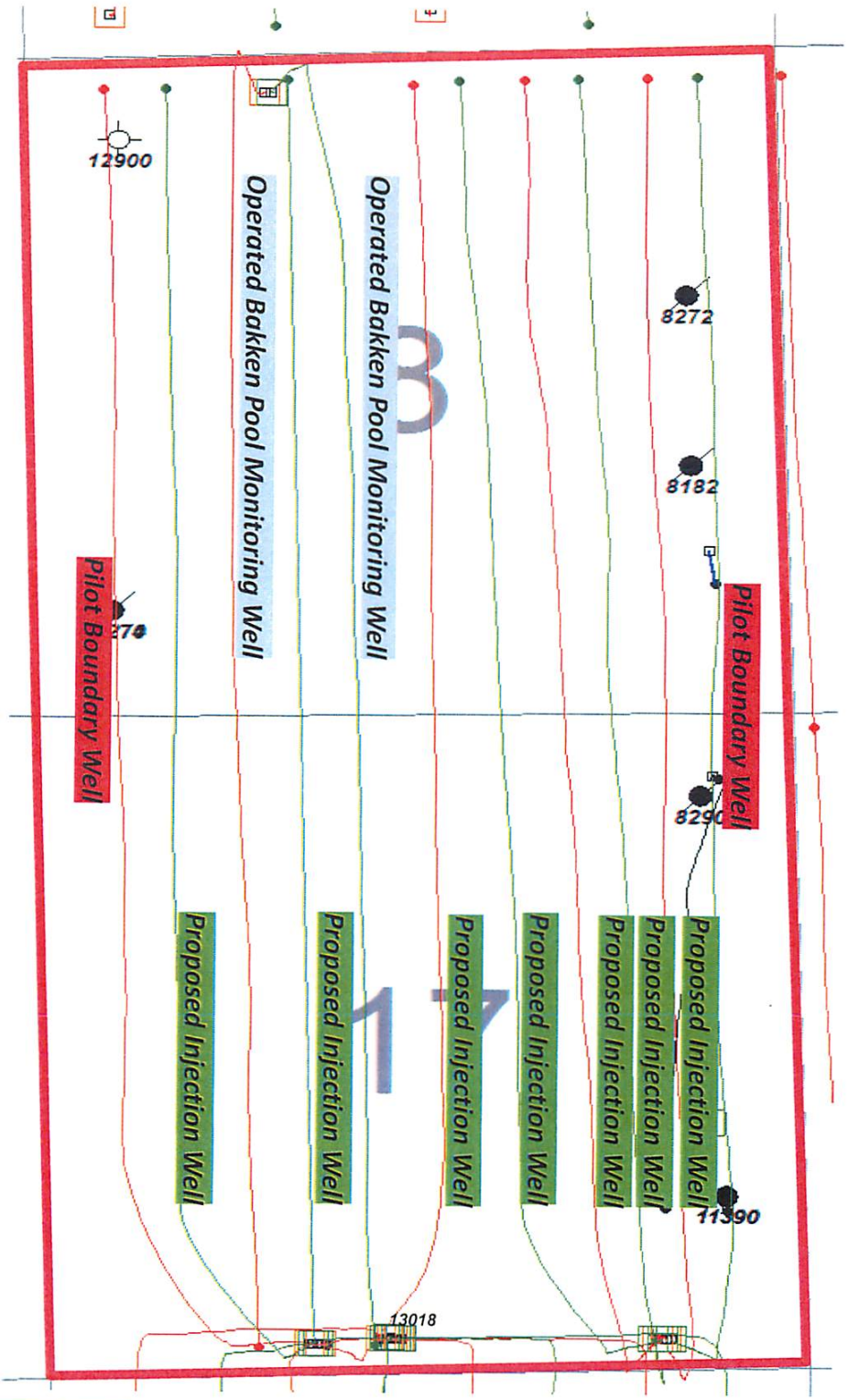
Reservoir Data

Formation	Middle Bakken	Three Forks 1st Bench (Including Pronghorn Limestone)
Thickness (ft)	61	27
Avg Porosity (%)	7.5	9.0
SoPhiH (ft)	2.70	1.20
Avg Sw (%)	40	50
Oil Gravity	45 API	45 API
BHT	240°F	240°F
Solution GOR	1,250	1,250
Gas Gravity	0.86	0.86
FVF	1.6	1.6
STOIP/1280	16,757,280	7,447,680

LIBERTY RESOURCES

Exhibit E-4
Case No. 26035

Pilot Layout & Well Nomenclature



Proposed Injection Well – Operated Bakken pool well proposed for rich gas injection during EOR pilot.

Operated Bakken Pool Monitoring Well – Operated Bakken pool well collocated in the DSU to be used for monitoring purposes only.

Pilot Boundary Well – Operated Bakken pool well to be used for monitoring purposes only in order to provide a pilot boundary on the eastern and western edges of the DSU

LIBERTY RESOURCES

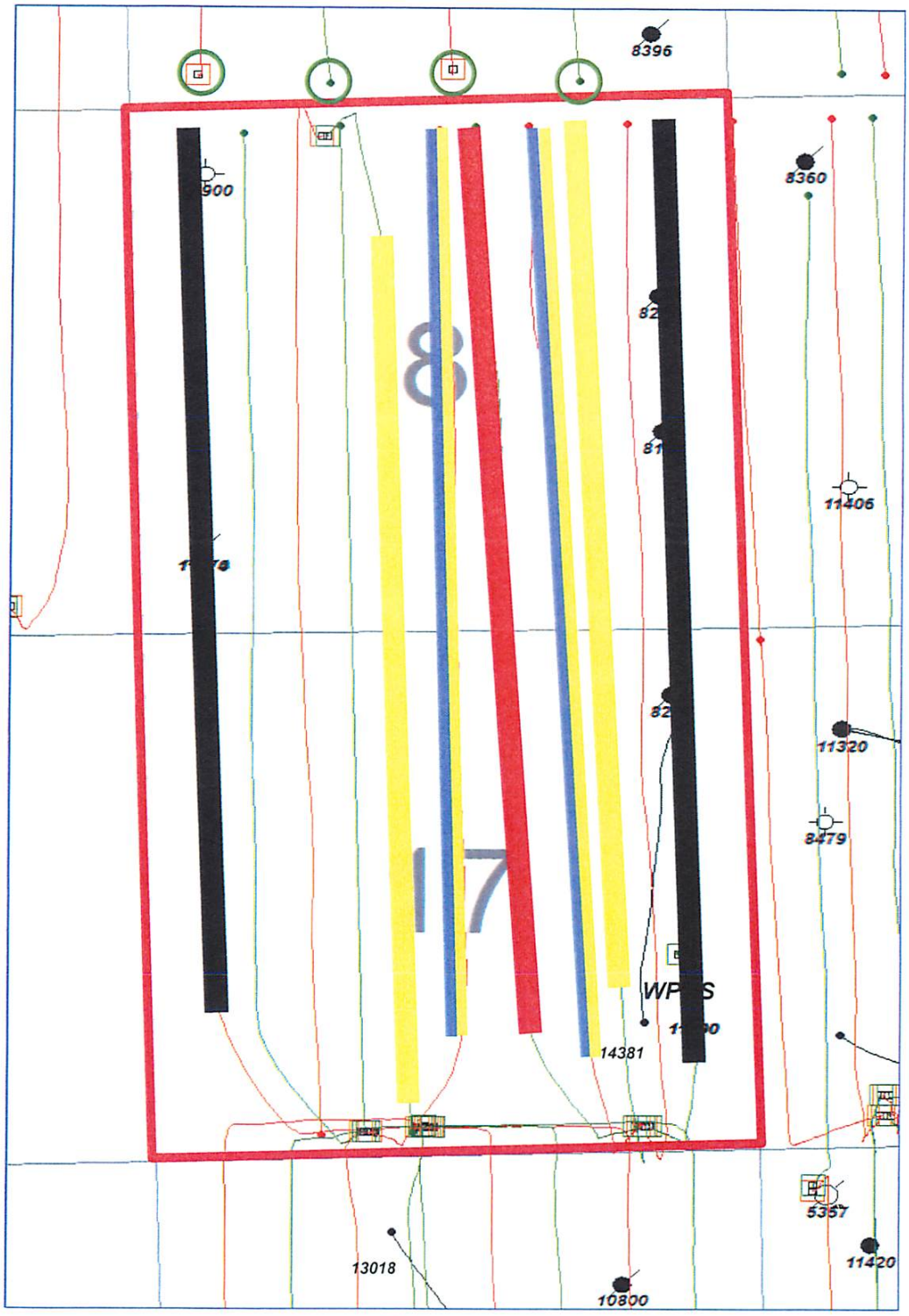
Exhibit E-5
Case No. 26035

Bakken Pool Wells

Township 158 North, Range 95 West, Sections 8 & 17

Well Name	Field	Pilot Well Type	Location	NDIC #	API #
Gohrick 158-95-17-8-4MBH	McGregor	Proposed Injection Well	SESE 17-158-95	28439	33-105-03536
Gohrick 158-95-17-8-5TFH	McGregor	Proposed Injection Well	SESE 17-158-95	28440	33-105-03537
Gohrick 158-95-17-8-5MBH	McGregor	Proposed Injection Well	SESE 17-158-95	28441	33-105-03538
Gohrick 158-95-17-8-6TFH	McGregor	Proposed Injection Well	SESE 17-158-95	28442	33-105-03539
Leon 158-95-17-8-1MBH	McGregor	Proposed Injection Well	SWSW 17-158-95	30618	33-105-03964
Leon 158-95-17-8-2MBH	McGregor	Proposed Injection Well	SWSW 17-158-95	30619	33-105-03965
Leon 158-95-17-8-3TFH	McGregor	Proposed Injection Well	SWSW 17-158-95	30620	33-105-03966
Leon 21-8H-0817-15895-TF	McGregor	Operated Bakken Pool Monitoring Well	NENW 8-158-95	24600	33-105-02935
Larena 21-8H-0817-15895-MB	McGregor	Operated Bakken Pool Monitoring Well	NENW 8-158-95	24599	33-105-02934
Gohrick 158-95-17-8-6MBH	McGregor	Pilot Boundary Well	SESE 17-158-95	28734	33-105-03592
Leon 158-95-17-8-1TFH	McGregor	Pilot Boundary Well	SWSW 17-158-95	30617	33-105-03963

Example Surveillance Plan

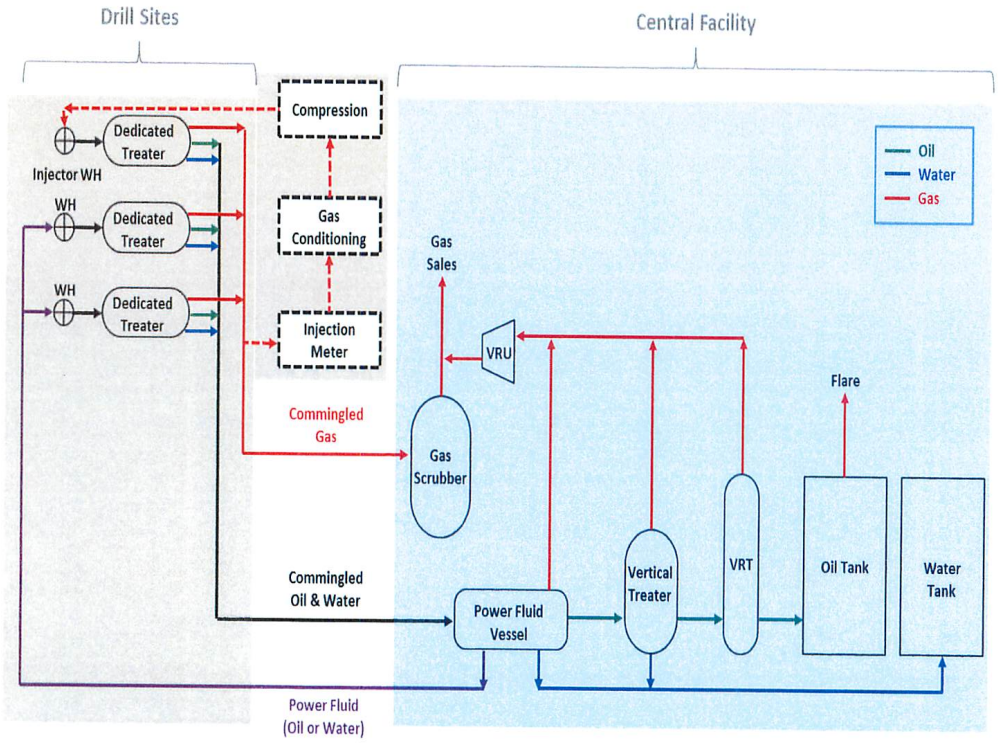


- Injector Wellbore Outline
- Monitor Well Chromatograph
- Monitor Well BHP Gauge
- Boundary Well
- Offset Operator Notification

LIBERTY RESOURCES

Exhibit E-7
Case No. 26035

Process Flow Illustration



LIBERTY RESOURCES

Exhibit E-8
Case No. 26035

Gas Composition for Proposed Injection

	Sample Information
Sample Name	Leon CTB West
Operator	Josh Engle
Company	WHAM LLC
GQ Source Number	East/West
Sample Temp	92
Sample Pressure	67
Client	Liberty Resources
Method Name	WhamLLC C6+.met
Injection Date	2016-08-12 15:17:33
Report Date	2016-08-12 10:31:43
Source Data File	2016-08-12 10-17-04 (GMT -05-00)-Rep12.dat
EZReporter Data File	Leon CTB West-20160812-103143.btu
NGA Phys. Property Data Source	GPA Standard 2145-09 (FPS)

Component Results

Component Name	Raw Amount	Norm%	Gross HV (Dry) (BTU / Ideal cu.ft.)	Gross HV (Sat.) (BTU / Ideal cu.ft.)	GPM (Dry) (Gal. / 1000 cu.ft.)	GPM (Sat) (Gal. / 1000 cu.ft.)
Hydrogen	0.0000	0.0000	0.0	0.0	0.000	0.000
Nitrogen	2.9880	2.9564	0.0	0.0	0.000	0.000
Methane	63.0570	62.3896	631.6	620.6	0.000	0.000
Carbon Dioxide	0.7650	0.7569	0.0	0.0	0.000	0.000
Ethane	19.1520	18.9493	336.1	330.3	5.092	5.002
Propane	8.9900	8.8948	224.3	220.4	2.462	2.419
i-Butane	0.9340	0.9241	30.1	29.6	0.304	0.299
n-Butane	2.8960	2.8653	93.7	92.1	0.908	0.892
i-Pentane	0.5390	0.5333	21.4	21.0	0.196	0.193
n-Pentane	0.8210	0.8123	32.6	32.1	0.296	0.291
Hexanes Plus	0.9250	0.9152	47.1	46.2	0.399	0.392
Hydrogen Sulfide	0.0028	0.0028	0.0	0.0	0.000	0.000
water	0.0000	0.0000	0.0	0.0	0.000	0.000
Total:	101.0698	100.0000	1416.9	1392.3	9.657	9.487

Results Summary

Result	Dry	Sat.
Total Normalzed Mole%	100.0000	100.0000
Pressure Base (psia)	14.730	
Gross Heating Value (BTU / Ideal cu.ft.)	1416.9	1392.3
Gross Heating Value (BTU / Real cu.ft.)	1424.1	1399.1
Relative Density (G), Real	0.8608	0.8457
Compressibility (Z) Factor	0.9950	0.9952

LIBERTY RESOURCES

Exhibit E-9
Case No. 26035

Gas Supply Wells

Injection gas supply wells for injection into wells located on ~~Leon~~ Gohrick Drill Site East:

NDIC #	Well Name	Field	API #	Location
28734	Gohrick 158-95-17-8-6MBH	McGregor	33-105-03592	SESE 17-158-95
28439	Gohrick 158-95-17-8-4MBH	McGregor	33-105-03536	SESE 17-158-95
28440	Gohrick 158-95-17-8-5TFH	McGregor	33-105-03537	SESE 17-158-95
28441	Gohrick 158-95-17-8-5MBH	McGregor	33-105-03538	SESE 17-158-95
28442	Gohrick 158-95-17-8-6TFH	McGregor	33-105-03539	SESE 17-158-95

Injection gas supply wells for injection into wells located on Leon Drill Site West:

NDIC #	Well Name	Field	API #	Location
30617	Leon 158-95-17-8-1TFH	McGregor	33-105-03963	SWSW 17-158-95
30618	Leon 158-95-17-8-1MBH	McGregor	33-105-03964	SWSW 17-158-95
30619	Leon 158-95-17-8-2MBH	McGregor	33-105-03965	SWSW 17-158-95
30620	Leon 158-95-17-8-3TFH	McGregor	33-105-03966	SWSW 17-158-95

LIBERTY RESOURCES

Exhibit E-10
Case No. 26035

Rich Gas EOR Pilot Summary

Goals

- To execute the pilot in order to determine the technical feasibility of enhanced oil recovery from the Bakken Pool by using natural gas and natural gas liquids as an immiscible or miscible injectant.
- To utilize a fully developed Bakken Pool DSU to evaluate and optimize injection methods for the purpose of enhanced oil recovery.
- To evaluate the effectiveness of various rich gas mixtures to mobilize oil in the Bakken petroleum system

Design Summary

- Utilize produced gas for cyclic injection into up to seven existing production wells within a single 1280 acre DSU to increase oil recovery.
- Monitor oil, water, and gas production rates, pressures, and fluid compositions to assess response to gas injection.
- Integrate pilot activities into ongoing operations and avoid or minimize impacts to production operations of offset operators and to surrounding land owners.
- Coordinate and collaborate with the EERC to fully utilize information from past pilots and studies and to provide useful data for advancing ongoing programs for improved oil recovery.

LIBERTY RESOURCES

Exhibit E-11
Case No. 26035

APPENDIX B-2

2018 BPOP ANNUAL REPORT

EERC
Energy & Environmental Research Center
15 North 23rd Street, Stop 9018 • Grand Forks, ND 58202-9018 • P. 701.777.5000 • F. 701.777.5181
www.undeerc.org

October 15, 2018

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

Dear Ms. Fine:

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

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

Sincerely,

Charles D. Gorecki
Director of Subsurface R&D

CDG/bjr

Attachment

BAKKEN PRODUCTION OPTIMIZATION PROGRAM 2.0

Annual Progress Report

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

Prepared for:

North Dakota Industrial Commission

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

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October 2018

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EXECUTIVE SUMMARY

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

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

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

BPOP activities in support of the rich gas EOR pilot during the first two quarters of the year were focused on laboratory studies and the development of models of Liberty's Stomping Horse reservoir and surface facilities. Laboratory experiments examined interactions between rich gas components, Bakken oil, and Bakken rocks, including minimum miscibility pressure (MMP) studies and rock extraction studies. The MMP studies showed that ethane and propane are effective at lowering MMP in Bakken crude oil. The extraction studies indicated that rich gas components can effectively mobilize oil from Bakken shale and non-shale matrix. The reservoir modeling exercises indicated that execution of a cyclic multiwell huff 'n' puff scheme for EOR can yield substantial incremental oil production. Surface facility modeling indicated rich gas EOR will not adversely affect existing infrastructure at Liberty's Stomping Horse complex facilities. BPOP EOR pilot activities in the last two quarters were largely focused on field-based activities at the Leon–Gohrick drill spacing unit in the Stomping Horse complex. Multiple rounds of baseline fluid (oil, gas, water) samples from wells in the Stomping Horse complex were collected and analyzed

over the course of 2018. Reservoir surveillance and monitoring equipment, including downhole memory gauges to record bottomhole pressure and temperature data, were also deployed. Liberty began initial injection using gas lift compressors into a Three Forks well in mid-July 2018. Subsequent injection into a neighboring Middle Bakken well was conducted in August 2018. Surface and subsurface monitoring data from those injection tests were collected and are in the process of being evaluated and interpreted.

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

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

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

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

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

INTRODUCTION

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

The goals of BPOP are to do the following:

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

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

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

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

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

ACCOMPLISHMENTS DURING REPORTING PERIOD

Enhanced Oil Recovery Task

The goal of the enhanced oil recovery (EOR) task is to develop knowledge that will support broad commercial implementation of EOR in the Bakken play. To achieve that goal, the EERC is conducting laboratory-, modeling-, and field-based investigative activities to examine the effectiveness of using rich gas for EOR. The centerpiece of this task is the rich gas EOR pilot being

conducted by Liberty Resources LLC (Liberty) at its Stomping Horse complex in Williams County, North Dakota. NDIC is providing $1,527,234 and the U.S. Department of Energy (DOE) has committed $2,000,000 to support EERC activities related to the Stomping Horse pilot. During the last quarter of the year, DOE committed an additional $1,000,000 toward laboratory-based investigations of the role that the organic-rich shales will play in rich gas-based Bakken EOR, especially with respect to gas utilization rates. The goals of the work to be conducted under the EOR task include the following:

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

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

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

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

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

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

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

Laboratory-based examinations of rich gas interactions with obtained crude oils and core/cuttings were conducted to determine the ability of various rich gas mixtures to mobilize oil in the Bakken petroleum system. Laboratory studies were conducted to determine minimum miscibility pressure (MMP) values for different rich gas components (methane, ethane, propane; alone and in mixtures) and CO_2 (for comparative purposes) in crude oil from the Stomping Horse complex as well as a Middle Bakken crude oil. A modified rising capillary–vanishing interfacial tension technique was used for the MMP studies. The results of those studies indicate that ethane and propane can effectively lower MMP of Bakken crude oil. Substantial progress was made in preparing and utilizing stable ternary gas mixtures (methane/ethane/propane) for MMP studies of rich gas mixtures that will be conducted in the coming year.

Experiments to extract hydrocarbons from Middle Bakken and Lower Bakken shale core samples from four Liberty wells were performed using pure methane, ethane, and propane. Analysis of the hydrocarbon recovery rates with the different fluids from the samples was

conducted. The results of the extraction studies indicate that rich gas can effectively mobilize oil from Bakken shale and nonshale rocks, although some rich gas components are more effective than others. The progress in the ternary gas mixture has allowed for the performance of both "miscible" phase hydrocarbon composition determinations as well as Middle Bakken and Bakken shale rock extractions with typical methane/ethane/propane mixtures of produced gas to begin. The effect of exposing Bakken crude oil to these various hydrocarbon gases on the residual crude oil's viscosity, API (American Petroleum Institute) gravity, and molecular weight distributions are also being determined.

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

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

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

Two types of reservoir simulation models were built and calibrated. First of all, at early stages of the project (during the design phase), a mechanistic single-stage model allowed gaining an understanding of the key mechanisms affecting the performance of the gas injection EOR. Secondly, a DSU scale model was constructed to capture in more detail the geologic structure,

lithofacies distribution, and initial reservoir pressure and saturation spatial distribution. The models were used to predict incremental recovery factors considering the site-specific characteristics. Operational observations and laboratory measurements have been used to inform both the mechanistic and DSU models. Field data included petrophysical properties, reservoir pressure, temperature, fluid saturations, fluid composition, and primary production records. 3-D heterogeneous geologic models were built to investigate different injection strategies with the existing hydraulically fractured horizontal wells (i.e., without proposing drilling any new wells). Sensitivity studies were performed to quantify the effects of key parameters and injected fluids. Several hypothetical scenarios were examined in detail, including different injected fluid compositions, well schedules, and targeted injection/production rates.

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

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

Refracturing Optimization Task

More than 90% of the estimated oil in place in unconventional reservoirs is not produced via primary production. While laboratory studies of EOR methods (e.g., gas injection) for unconventional reservoirs look promising, the results from pilot and field tests are inconclusive. Well refracturing (recompletion) provides an alternative to EOR methods and is one technique for improving oil recovery by counteracting the effects of suboptimal completions. Examples of suboptimal completions include undersized fracture treatments, widely spaced fracture intervals, inoperable completion failures, and damage mechanisms that cause a loss of connectivity to the reservoir. Refracturing is a recent development for the Bakken but is not a new technique, as refracturing was first implemented in the 1970s.

This study was conducted to 1) analyze the production performance of wells that have been refractured in the Bakken Formation of North Dakota, 2) investigate the economics of well refracturing and 3) evaluate the overall potential for Bakken-wide implementation of refracturing operations. Several metrics were used to evaluate refracturing performance, including changes in peak oil rate, uplift in oil production rate following refracturing, decrease in gas–oil ratio (GOR), and incremental estimated ultimate recoveries (EURs). The economic analysis focused on discounted net oil revenue, defined as the oil revenue after deducting royalties, state tax and refracturing costs, assuming an annual discount rate. The discounted net oil revenue was investigated using Monte Carlo simulation with different combinations of oil price, refracturing cost, and the low, middle, and high incremental annual oil production from the refracturing production analysis.

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

Produced Fluid Characterization Task

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

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

- Coordinated with BPOP program leads to identify key information and data needed for ongoing and planned research efforts.

- Reviewed and refined collected data/information for inclusion in the previously developed database and to identify specific data gaps/needs.

- Created a "Bakken Fluids Characterization – Data Request and Sample Acquisition Information Sheet" for distribution to potential industry partners to help facilitate access to additional data/information and sample collection access.

- Conducted a formal solicitation of produced fluids data from key industry partners as a database of information on produced water, crude oil, and associated gas is being built. These data will be integrated into the EERC-managed Bakken fluids database for support in understanding basinwide characteristics related to production and other reservoir/well statistics.

- Developed partnerships with key industry to collect fluid samples.

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

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

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

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

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

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

Reservoir Performance Modeling Task

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

A key unknown is the degree to which geologic- and engineering-related factors are correlated to oil production performance. Furthermore, among these geologic- and engineering-related factors, which ones are most significant in predicting long-term well performance? Do technological and engineering practices determine the long-term performance of a Bakken oil well? Alternatively, do geologic factors play a more significant role? This work explored these questions.

The database created for and used in this work includes 400 wells completed in the Bakken and Three Forks Formations and located across the Bakken petroleum system. Approximately 30 different factors (completion-related and geology-related) were analyzed for their effects on short-term (6-month) and long-term (60-month) production using a multivariate statistical approach.

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

Water Injection Reservoir Assessment Task

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

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

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

Brine Treatment and Storage Assessment

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

Bakken Trend Analysis

This task is focused on the evaluation of various trends related to Bakken fluids production and completion practices to better understand the potential future impacts of those trends on

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

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

Facility Process Optimization Task

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

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

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

Aromatic/Aliphatic Study Task

Data reduction is continuing on the 40 Lower and Upper Bakken shale samples as well as the additional 33 rock core samples including several Middle Bakken, Three Forks, Pronghorn, and additional Upper and Lower Bakken shales that were extracted and analyzed for their aromatic/aliphatic ratios. These samples were selected to give complete profiles (including multiple depths of single lithofacies for some wells) of multiple wells including all relevant source and reservoir rocks. An update on the aromatic/aliphatic tracer studies was posted on the BPOP members-only Web site.

All temporal crude oil samples from three producing wells that were collected from September 2017 through August 2018 were analyzed for aromatic/aliphatic ratios to determine if the relative contributions of the shales compared to the Middle Bakken to the produced crude would shift over production time. To date, no significant change in those ratios have been observed in the produced crudes, indicating that no large change in the proposition of oil produced from the Middle Bakken and adjacent shales has yet occurred.

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

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

Environmental Support Task

North Dakota Department of Health, in conjunction with North Dakota Petroleum Council and Northwest Landowners Association, established the Brine Remediation Task Force in 2014. The Brine Remediation Task Force spent approximately 2 years negotiating appropriate guidance for remediating brine spills in the oil field and resulted in a guidance document published by the North Dakota Department of Health and a more comprehensive, “companion” document published by the EERC titled North Dakota Remediation Resource Manual. The Hydrocarbon Remediation Task Force is a continuation of the Brine Remediation Task Force with a focus on hydrocarbon guidance/regulation.

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

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

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

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

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

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

In addition to participating in the Hydrocarbon Remediation Task Force, EERC staff regularly attend the North Dakota/Montana Environmental Peer Group (EPG) meetings, which are held on a quarterly basis. The EPG meetings are a convening of environmental staff of oil and gas companies operating in the Williston Basin. The intent and value in EERC staff attending these

meetings included 1) introducing and enforcing EERC's expertise to the industry when presenting to the group and 2) gathering valuable information from exchanges between industry peers.

Program Management and Development

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

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

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

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

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

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

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

MEMBERSHIP AND FINANCIAL INFORMATION

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

Table 1. BPOP – Original Budget

Sponsors	Y1 Nov 2016 to Oct 2017	Y2 Nov 2017 to Oct 2018	Y3 Nov 2018 to Oct 2019	Total
NDIC Share – Cash	$2,000,000	$2,000,000	$2,000,000	**$6,000,000**
Industry Share (Marathon) – In-Kind	$2,500,000	$3,500,000	$1,280,000	**$7,280,000**
Total	**$4,500,000**	**$5,500,000**	**$3,280,000**	**$13,280,000**

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

Table 2. BPOP Members

ConocoPhillips	Liberty Resources	Petro-Hunt
Equinor	Marathon Oil	WPX Energy
Hess Corporation	Oasis Petroleum	XTO Energy

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

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

Table 3. BPOP – Expected Budget and Expenses to Date

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

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

FUTURE ACTIVITIES

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

Enhanced Oil Recovery Task

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

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

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

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

Refracturing Optimization Task

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

Produced Fluid Characterization Task

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

refining will also be conducted to enhance the usefulness of the database with any data gaps and additional needs being identified. Specific activities to be conducted include the following:

- Continue monthly and quarterly sample collection and analysis events on established wells.

- Review and evaluate collected data as it pertains to overall production characteristics throughout the Bakken play.

- Coordinate access and sample acquisition/analysis on additional wells throughout the basin.

- Industry partnerships will continue to be developed to further understand specific needs related to Bakken production issues and practices and to expand the geographical extent of the sampling and analysis effort.

- All fluid data and associated well production information collected will be entered into the EERC-specific database to support BPOP goals. The database structure will be refined to enhance use by BPOP researchers.

- Data collection and additional sampling and analysis will continue as needed to support BPOP goals.

Reservoir Performance Modeling Task

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

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

Water Injection Reservoir Assessment Task

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

Brine Treatment and Storage Assessment

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

Bakken Trend Analysis

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

Facility Process Optimization Task

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

Aromatic/Aliphatic Study Task

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

Environmental Support Task

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

Program Management and Development

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

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

APPENDIX B-3

2019 BPOP ANNUAL REPORT

EERC
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October 15, 2019

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

Dear Ms. Fine:

Subject: Annual Progress Report for the Period of October 1, 2018 – September 30, 2019, Entitled "Bakken Production Optimization Program 2.0"; Contract No. G-040-080 EERC Fund 22010

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

Sincerely,

Charles D. Gorecki
CEO

CDG/kal

Attachment

BAKKEN PRODUCTION OPTIMIZATION PROGRAM 2.0

Annual Progress Report

(for the period October 1, 2018 – September 30, 2019)

Prepared for:

North Dakota Industrial Commission

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

The Bakken Production Optimization Program (BPOP) was established to facilitate Bakken petroleum system (BPS) oil recovery while simultaneously reducing the environmental footprint of oil and gas development. This program is administered by the Energy & Environmental Research Center (EERC), with funding from the North Dakota Industrial Commission (NDIC) Oil and Gas Research Program (OGRP) and the North Dakota petroleum industry. Through BPOP, the EERC is working closely with a consortium of industry partners and the state to address emerging opportunities and challenges related to Bakken development. As of September 30, 2019, nine partner companies support BPOP. This annual progress report presents an update of activities from October 1, 2018, through September 30, 2019.

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

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

BPOP activities in support of the rich gas EOR pilot included field-based activities at the Leon–Gohrick drill spacing unit (DSU) in the Stomping Horse complex, modeling and dynamic simulation activities to provide technical support and guidance to the design of the pilot injection/production scheme, and laboratory-based experiments to determine the permeability and sorption behavior of rich gas components in Bakken shale. Large-scale injection testing occurred in the Gohrick 5MBH, Gohrick 4-MBH, and Gohrick 6-TFH wells. Two gas tracer studies were performed, analyzed, and interpreted. Gas samples were collected and analyzed periodically from several offset wells in the DSU to determine the timing and location of gas, oil, and water breakthrough throughout the testing. Liberty is in the process of evaluating the results of the previous pilot activities and is determining a path forward with respect to potential future pilot activities. Data analytical techniques were applied to the reservoir surveillance and operational data gathered over the course of the pilot. Samples of three target shales were tested for sorption isotherm determination using a high-pressure magnetic balance.

A Bakken refracturing study expanded upon the previous investigation from August 2018 and incorporated feedback received from BPOP partners. The refracture activities have

considerably increased over the past 2 years, with a total of 124 refractures conducted in 2017 and 2018. The production performance analysis of the refractured wells investigated several metrics to evaluate refracture performance including 1) a comparison of pre- and postrefracture peak oil rates, 2) a change in daily production data following refracture operation, 3) a change in gas/oil ratio, and 4) incremental estimated ultimate recoveries (EURs) (i.e., the change in EUR between pre- and postrefracture forecasts).

An updated 2019 analysis of Bakken/Three Forks production was performed on a substantially improved and extended data set. In total, approximately 13,000 wells were included in the analyses. The study estimated historical production trends within the Williston Basin and factors that improved oil recovery.

The facility process-modeling task continued to apply process simulation to the operation of Bakken surface facilities to improve performance, reduce emissions, and, ultimately, streamline operating costs. A comprehensive assessment of operational and environmental factors influencing crude oil conditioning and resulting vapor pressure was completed. The EERC also performed a comprehensive analysis of the impacts of wellsite operating conditions and environmental factors on tank vapors. Computational modeling was conducted to assess conditions that could lead to flammable mixtures of hydrocarbon vapors in tanks and vent lines.

The aromatic/aliphatic (A/A) studies of laboratory experiments to determine A/A ratios for oil samples extracted from Upper Bakken shale, Lower Bakken shale, Middle Bakken, and Three Forks rocks from several wells throughout North Dakota continued. The final data analyses on 105 rock core samples collected in all major lithofacies from 16 wells distributed across the reservoir were completed. A peer-reviewed journal article on the rock core A/A ratios from different facies and reservoir locations is under preparation. Temporal crude oil samples continued to be collected and analyzed for A/A ratios to determine if the relative contributions of the oil from the shales compared to contributions from the Middle Bakken would shift over production time.

The environmental support task continued to focus on providing assistance to partner activities and North Dakota Petroleum Council task force work related to reducing environmental impacts and ensuring regulatory compliance. Specific topics relevant to this task include flaring mitigation, wellsite emission control and management, environmental remediation, and crude oil vapor pressure management.

Anticipated activities in the next year include ongoing collaboration with Liberty on the rich gas EOR pilot and additional laboratory- and modeling-based investigations of factors controlling EOR in the Bakken; optimization of production facilities to improve recovery while reducing cost, waste, and environmental footprint; additional data analytics and machine learning activities with a focus on trying to better elucidate the factors that affect production in smaller areas across the BPS and to assess the optimization of well completion parameters in 1280- vs. 2560-acre DSUs; produced water management efforts, with a focus on evaluating strategies to address the increasing volumes of brine that are expected to be produced in the next couple of decades; and expansion of the temporal fluids sampling efforts with the goal of better understanding how fluid and gas chemistry changes over time and spatially across the Bakken play as a function of key geological, geochemical, and operational parameters. The remainder of the activities for the next year will be determined by partner input.

INTRODUCTION

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

The goals of BPOP are to do the following:

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

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

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

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

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

ACCOMPLISHMENTS DURING REPORTING PERIOD

Enhanced Oil Recovery Task

The goal of the enhanced oil recovery (EOR) task is to develop knowledge that will support broad commercial implementation of EOR in the Bakken play. To achieve that goal, the EERC is conducting laboratory-, modeling-, and field-based investigative activities to examine the effectiveness of using rich gas for EOR. The centerpiece of this task is the rich gas EOR pilot being

conducted by Liberty Resources, LLC (Liberty) at its Stomping Horse complex in Williams County, North Dakota. NDIC is providing $1,527,234 and the U.S. Department of Energy (DOE) has committed $2,000,000 to support EERC activities related to the Stomping Horse pilot. The goals of the work to be conducted under the EOR task include the following:

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

- Determine the ability of various rich gas mixtures (methane, ethane, and propane) to mobilize oil in BPS 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 BPS.

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

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

A compressor capable of achieving wellhead pressures >4000 psi was installed at the Leon–Gohrick pad. Large-scale injection testing was initiated into the Gohrick 5MBH well on November 20, 2018, and ceased on December 23, 2018. Large-scale injection testing was initiated into the Gohrick 4-MBH well on January 17, 2019. Multiple severe weather events in February 2019 caused interruptions in the injection activities. Consistent injection was reestablished in early March 2019 and continued until May 9, 2019. A total of 74.5 MMscf was injected into the Gohrick 4-MBH well. Injection into the Gohrick 6-TFH well was initiated May 15, 2019, and ceased in early June 2019, with a total of 17.4 MMscf injected. Injection was ceased because of a constraint on rich gas availability. Liberty conducted workovers in July and August 2019 on several wells in the drill spacing unit (DSU) to address this issue.

A gas tracer study was begun shortly after the start of injection into the Gohrick 5MBH well. A second gas tracer study was also begun shortly after the start of injection in the Gohrick 4-MBH well. Data from the first tracer study, which was a gas tracer performed in late 2018, were analyzed and interpreted, as were data from the second tracer study, which included injection and monitoring of gas, oil, and water tracers. Gas samples were collected and analyzed periodically from several offset wells in the DSU to determine the timing and location of gas, oil, and water

breakthrough throughout the testing. Liberty is in the process of evaluating the results of the previous pilot activities and is determining a path forward with respect to potential future pilot activities.

Modeling and dynamic simulation activities provide technical support and guidance to the design of the pilot injection/production scheme. History-matching exercises, using the previously developed static geomodel, detailed historical operational data, and data from the summer injection testing provided by the project partner were conducted. Data analytical techniques were applied to the reservoir surveillance and operational data gathered over the course of the pilot. A material balance equation calculation was determined.

Efforts to conduct laboratory-based experiments to determine the permeability and sorption behavior of rich gas components in Bakken shale continued. Samples of three target shales were tested for sorption isotherm determination using a high-pressure magnetic balance. Isotherms from ambient to 5000 psi (345 bar) were successfully measured for methane, ethane, propane, and a mixture of those three gases on shales. Sorption isotherm data were evaluated and interpreted. 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 were conducted. The effects of pressure were examined both in terms of the mass of oil mobilized and the molecular weight selectivity shown by the different pressures.

An Expanded Study of Bakken Refracturing

This study expanded upon the previous investigation that was completed in August 2018 and incorporates feedback received from BPOP partners. Currently, all of the technical work planned under this study is complete, and a final report is drafted and in a process of internal review and revision. The main objectives were to:

- Update the compilation and review of the wells that have been refractured in the BPS, North Dakota.
- Revise the evaluation of production performance of the refractured wells.
- Analyze the impact of secondhand refracturing.
- Update the assessment of refracture economics using a decision tree modeling approach.
- Assess the potential economic impact of a broad refracturing program applied throughout the BPS.

As of May 2019, there have been 272 refractures conducted in the BPS. The refracture activities have considerably increased over the past 2 years, with a total of 124 refractures conducted in 2017 and 2018. The production performance analysis of the refractured wells investigated several metrics to evaluate refracture performance including 1) a comparison of pre- and postrefracture peak oil rates, 2) a change in daily production data following refracture operation, 3) a change in gas/oil ratio (GOR), and 4) incremental estimated ultimate recoveries (EURs) (i.e., the change in EUR between pre- and postrefracture forecasts). In addition to summarizing the results across all refractured wells, the refracturing production performances were compared between wells that were originally completed as barefoot and non-barefoot wells. Barefoot completions are believed to be understimulated during the original treatment, which

results in a greater undrained area and, therefore, larger remaining hydrocarbon volume and commensurately better postrefracture production performance.

Refracturing cannot only restore or improve production of the well that is refractured but can also improve production of offset wells located near the refractured well. In this work, 161 offset wells were identified for an evaluation for secondhand refracturing. These offset wells were located near the top 50 refractured wells with the greatest postrefracture production. The analysis of secondhand refracturing examined uplift in daily oil production rates in the offset wells that occurred around the time of the refracturing of a nearby or parent well in the DSU.

A decision tree modeling approach was used to evaluate the overall economic performance of refracturing in this expanded work. The economic analysis focused on *discounted net oil revenue* (defined as the oil revenue after deducting royalties and state tax assuming an annual discount rate) and compared the decision to refracture a well against a baseline scenario without refracturing.

Finally, a preliminary screening of the existing wells in the BPS was carried out to identify the number of wells in the BPS that meet a simple set of criteria, specifically wells that had single-stage completions, older completion dates, and barefoot completions. The economics of refracturing these identified wells was evaluated to understand the potential of a larger, basinwide refracturing program in the BPS based on the economic performance of the existing refractures.

Produced Fluid Characterization Task

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

Collaboration continued with key industry partners to obtain access to fluids (crude, water, and/or gas) sample collection from numerous wells at multiple locations and acquisition of existing compositional data to support the ongoing research efforts of individual BPOP tasks. Fluid samples from two adjacent producing Bakken wells (one stimulated and one nonstimulated) were collected for the purpose of evaluating compositional differences that may indicate possible fluid migration pathways. Other sampling on five separate wells was performed for the purpose of a temporal evaluation of compositional changes throughout the production life of newly established wells and an increased geographical distribution of data. Efforts continued to support sample collection and related fluids analysis training/education for multiple EERC field personnel. The training/education is intended to provide sample collection personnel with better insight on analytical methods and the benefits of the data to oil and gas production-related research activities.

Efforts continued on the review of existing data to identify specific data gaps and needs. Work also continued on the development of newly updated geographic information system (GIS)-based maps derived from the data to evaluate basinwide characteristics specific to the Bakken and Three Forks Formations.

Modifications and repairs were made to existing gas chromatographs to accommodate new whole oil–crude fingerprinting analytical methods. The existing instrumentation was modified and configured to run high-resolution gas chromatography (GC). The methods are being used to analyze existing crude and available core samples collected from within the Bakken in an attempt to determine oil origination and/or subsurface migration during production activities. Two standard output reports have been created for the purposes of geochemical characterization of oil and pressure, volume, temperature (PVT) calculations. Several pairs of oil samples have been fingerprinted. Star diagrams were used to compare oil samples.

Bakken/Three Forks Production Analysis Using Data Analytics and Machine Learning Task

An updated 2019 analysis of Bakken/Three Forks production was performed on a substantially improved and extended data set. In total, approximately 13,000 wells were included in the analyses. Data and information were sourced from NDIC, DrillingInfo, publications, oil and gas company websites, and personal communication with industry experts. The data set included wells from 12 different counties, 340 fields in the BPS, and 72 different operators. Most of the wells (89%) are located within the core area: the four main oil-producing counties (Williams, Mountrail, McKenzie, and Dunn). The completion year of the wells ranged from 2005 to 2019, with nearly 90% of the wells completed after 2009.

The study summarized historical production trends within the Williston Basin and estimated factors that could improve oil recovery. EUR and decline rates from the 13,000 wells were estimated and used for comparison with completion strategies to better understand the engineering-related parameters that can affect production.

The analysis also evaluated BPS brine production based on completion practice trends to better understand the potential future impacts of fluids production on surface-related infrastructure, freshwater demand, and saltwater disposal (SWD) capacity. The following volumes were calculated for the BPS: annual injection fluid volume used as a percentage of total water production and net water production (by subtracting volume of injection fluid from the volume of produced water) over the past decade (2008–2018).

Parent–child well relationships were evaluated using statistical analysis to better elucidate production behavior trends related to infill drilling. An algorithm to group wells by DSUs was created, and further analysis of production trends on a DSU level showed a correlation between EUR and the total number of wells within a DSU.

Data-mining techniques were applied to investigate completion strategy impacts on production performance at a DSU level. A subset of data used in the calculations included 5027 wells from 2175 unique DSUs located across the Bakken play. Well and completion data

were analyzed using multilevel regression models to predict 6-month oil production per DSU. The analysis demonstrated the potential of the data-mining method and quantified the relative importance of different well features.

Another approach to investigate the effect of completion parameters such as fracturing fluid volumes, proppant mass, and the number of stages on well performance was performed using a gradient boosting model. For this method, three smaller data sets (300 wells each) representing high-, medium-, and low-producing zones of the Williston Basin were included in the analysis. The results of the calculation showed that data-mining techniques could be successfully applied for the purpose of completion optimization and different production zones of the Williston Basin would benefit from the tailoring of completion strategies.

The findings of this study were presented at the BPOP Annual Meeting in August 2019.

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 report on the modeling and simulation portion of this task, entitled "Modeling and Simulation of the Inyan Kara Formation to Estimate Saltwater Disposal Potential: Final Report," is available on the BPOP partners-only website. The report will be available to the public in April 2020.

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. Additional activities focused on comparing the spreadsheet-based predictions with those estimated using the Inyan Kara reservoir model based on a simplistic SWD scenario.

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 partner input to examine in detail parameters that affect fugitive emissions and crude oil properties. Modeling results are then reduced to actionable suggestions for partner producers to consider when evaluating their operations.

A comprehensive assessment of operational and environmental factors influencing crude oil conditioning and resulting vapor pressure was completed. This work included computational modeling by EERC staff and field validation through coordination and participation with BPOP partners. 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 validated cold-weather models that were used to screen and rank design changes that could be used to ensure vapor pressure compliance during cold weather. A short technical brief entitled "Vapor Pressure Modeling of Cold Weather Modifications for Bakken Surface Facilities" and an accompanying set of presentation slides entitled "Surface Facility Vapor Pressure Modeling" were uploaded to the BPOP partners-only website. The technical brief and slides will be available to the public in April 2020.

The EERC also performed a comprehensive analysis of the impacts of wellsite operating conditions and environmental factors on tank vapors. Computational modeling was conducted to assess conditions that could lead to flammable mixtures of hydrocarbon vapors in tanks and vent lines. Field data from BPOP partners provided model validation. Results from this work have been shared with partner companies and provide a basis for facilities and operations engineers to implement engineering controls and operating practices necessary to ensure continued safe operation.

Aromatic/Aliphatic Study Task

The goal of the aromatic/aliphatic (A/A) task is to investigate and develop the use of the determination of the relative ratios of aromatic hydrocarbons to aliphatic hydrocarbons in rock cores and produced crude oil for two general applications: 1) to provide a well management tool that can determine the changes in produced crude oil contributed from the adjacent source shales to wells completed in the Middle Bakken (or Three Forks) and 2) to yield a better understanding of oil migration from the source shales to the target reservoir formations. 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.

The final data analyses on 105 rock core samples collected in all major lithofacies from 16 wells distributed across the reservoir was completed. 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. A peer-reviewed journal article on the rock core A/A ratios from different facies and reservoir locations is under preparation.

Temporal crude oil samples continued to be collected and analyzed for A/A ratios to determine if the relative contributions of the oil from the shales compared to contributions from the Middle Bakken would shift over production time. Data were presented at the BPOP Annual Meeting in August 2019.

Environmental Support Task

The environmental support task has focused on providing assistance to partner activities and North Dakota Petroleum Council (NDPC) task force work related to reducing environmental impacts and ensuring regulatory compliance. Specific topics relevant to this task include flaring mitigation, wellsite emission control and management, environmental remediation, and crude oil vapor pressure management.

During this reporting period, the EERC supported the latest efforts of the NDPC Natural Gas Capture and Infrastructure Development Task Force. An industry survey is being prepared to solicit input from Bakken operators describing activities related to flare gas mitigation. Additionally, the EERC continues to provide technical guidance to companies with wellsite-scale gas capture technologies to assist their efforts to tailor technologies and approaches to the reality of flared gas. Over the past year, the EERC traveled to speak at several meetings on the topic of gas capture. These meetings include the following:

- Presented at the Flaring Issues, Solutions and Technologies Workshop organized by the Houston Advanced Research Center held April 23, 2019, in Denver, Colorado. The slide deck presented at this meeting is attached in Appendix A.

- Spoke at the NDPC Flaring Royalties Work Group Meeting held August 21, 2019, in Bismarck, North Dakota, presenting information related to small-scale gas utilization technologies to the U.S. Bureau of Land Management. The slide deck presented at this meeting is attached in Appendix B.

- Presented at the Interstate Oil and Gas Compact Commission (IOGCC) meeting on August 26, 2019, in Medora, North Dakota. A slide deck summarizing factors influencing flaring in North Dakota was presented and is attached in Appendix C.

The EERC continues to perform analysis on a variety of technical and operational alternatives to associated gas use. As new technologies and vendors are identified, EERC staff help identify the challenges and opportunities to implementation and provide preliminary techno-economic analysis when appropriate. Results from these efforts are typically shared with individual vendors or Bakken operators in direct response to their inquiries.

In cooperation with the NDPC Remediation Task Force and stakeholders including the North Dakota Department of Environmental Quality and landowners, the EERC updated the North Dakota Remediation Resource Manual. This final document provides guidance on remediation strategies for soils impacted by produced water or hydrocarbon releases and is available on the BPOP partners-only website. The manual is available to the entire BPOP partnership for a 15-month period before the report is fully public in September 2020.

On May 8, 2019, an EERC representative attended the NDPC Technical Solutions Group (TSG) meeting in Dickinson, North Dakota, and presented an overview of the recently completed North Dakota Remediation Resource Manual. PowerPoint slides shared with TSG participants are attached in Appendix D.

Program Management and Development

The Year 3 activities were determined based on partner input. Activities will be initiated next quarter, and additional details on the goal of each area will be provided in the next quarterly report. Some funding was reserved for potential match to DOE funding opportunities to be released in 2019. A summary of the Year 3 activities is as follows:

- Improved oil recovery (IOR) activities
  - Reinjection of rich gas into parent wells – effects on offset wells
  - Refracs/IOR workshop
- Subsurface activities
  - Data analytics and trend analysis
  - Reservoir characteristics and fluids database
  - Produced water management tools and general topics
- Surface activities
  - Facilities optimization
  - Fluids characterization
- Management
  - Program oversight, document control, website upgrade, etc.

John Harju presented "Bakken Production Optimization Program 2.0 (BPOP 2.0) Update" at the NDIC Oil and Gas Research Council (OGRC) meeting on December 18, 2018. Presentation items included updates on activities including rich gas EOR with Liberty, facilities modeling, fluids characterization, a summary of upcoming Year 3 activities, an overview of the final report review process, and a report status. A copy of the presentation is provided in Appendix E.

The revision of the BPOP website was completed and went live May 3, 2019. The website can be accessed at http://undeerc.org/Bakken/Optimization/. A key feature of the revamped site is access to all free and premium products through the Search Documents feature. All products are accompanied by a public abstract. Free, publicly available products are available for download by all. Premium products are available exclusively to partners for 15 months following review, then they are released to the public.

An EERC representative attended the IOGCC 2019 annual business meeting held in Oklahoma City, Oklahoma, May 5–7, 2019. The meeting was also attended by NDPC personnel, a subset of BPOP partner companies, and NDIC representatives.

An extension of the current BPOP funding to May 31, 2020, was requested and approved. Determination of project activities through May 31, 2020, are in discussion. Preparation of a proposal to NDIC OGRP continued for the next 3 years of BPOP.

The BPOP Annual Meeting was held August 7–8, 2019, in Williston, North Dakota, with 22 external participants. Project partner, Equinor, hosted the meeting at the TrainND facilities. Presentations and discussions were largely focus on key findings and lessons learned in BPOP's

primary research areas. A brief demonstration of the BPOP website (http://undeerc.org/Bakken/Optimization/) was provided to meeting participants. Ron Ness, NDPC, provided a welcome from NDPC. The presentations, which were uploaded to the BPOP website and are available to project partners, are as follows:

- Programmatic Overview, presented by James Sorensen, EERC
- Rich Gas EOR Pilot Status – Liberty Resources Update, presented by Gordon Pospisil, Liberty
- Laboratory Studies with Rich Gas: MMP, "Miscible"-Phase Hydrocarbon Composition, and Rock Extractions, presented by Dr. Steven Hawthorne, EERC
- Modeling and Optimization of Surface Facilities, presented by Chris Martin and Chad Wocken, EERC
- Expanded Refracturing Study (including 2017 and 2018 wells), presented by Dr. Chantsalmaa Dalkhaa, EERC
- Evaluation of Produced Gas Injection, presented by Bethany Kurz, EERC
- Bakken Petroleum System (BPS) Historical Trends and Data Analytics, presented by Dr. Nicholas Azzolina and Alexander Chakhmakhchev, EERC
- Future of Bakken Resources, presented by Charles Gorecki, EERC
- Turtles and Snakes: Using Molecular Shape to Understand Oil Migration and Production in the Bakken, presented by Dr. Steven Hawthorne, EERC
- Produced Water Management and Trends, presented by Bethany Kurz, EERC
- Salt Water Disposal Performance in the Williston Basin, presented by Darren Schmidt, Equinor

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

PARTNERSHIP AND FINANCIAL INFORMATION

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

The EERC continues to seek support for this program, and to date, additional cost share has been secured from the Bakken producers listed in Table 2.

Table 1. BPOP – Original Budget

	Y1	Y2	Y3	
Sponsors	**Nov 2016 to Oct 2017**	**Nov 2017 to Oct 2018**	**Nov 2018 to Oct 2019**	**Total**
NDIC Share – Cash	$2,000,000	$2,000,000	$2,000,000	**$6,000,000**
Industry Share (Marathon) – In-Kind	$2,500,000	$3,500,000	$1,280,000	**$7,280,000**
Total	**$4,500,000**	**$5,500,000**	**$3,280,000**	**$13,280,000**

Table 2. BPOP Partners

ConocoPhillips	Liberty Resources	Petro-Hunt
Equinor	Marathon Oil	WPX Energy
Hess Corporation	Oasis Petroleum	XTO Energy

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

Table 3 presents a revised expected budget based on the additional cost share secured by the EERC. This revised budget is an increase of more than 92% over the original budget. Expenses to date are also listed in Table 3.

Table 3. BPOP – Expected Budget and Expenses to Date

Sponsors	Expected Budget	Actual Expenses as of 9/30/19	Balance
NDIC Share – Cash	$6,000,000	$4,988,002	$1,011,998
Industry Share – Cash	$1,750,000	$989,299	$760,701
Marathon – In-Kind	$12,615,401	$12,615,401	$0
Liberty – In-Kind*	$3,255,937	$3,255,937	$0
DOE – Cash	$2,000,000	$1,672,740	$327,260
Total	**$25,621,338**	**$23,521,379**	**$2,099,959**

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

FUTURE ACTIVITIES

The planned activities for the next year are described below. At this time, the flexible portion of BPOP funds for the upcoming year are being planned with partner input that will be sought via interviews with partner 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 injection tests during the winter of 2018–2019 and spring of 2019 will be evaluated. The lessons learned from those injection tests will be used to guide operation of the potential future injection tests.

Laboratory experiments to examine the sorptive capacity of Bakken shale samples for rich gas components will be completed. Rich gas flow-through tests in shale will continue.

With respect to modeling, the development of a report on the approaches, results, and key lessons learned from the modeling activities will be initiated.

An Expanded Study of Bakken Refracturing

The internal review and revision of the draft final report will be completed, and the report will be available for review by selected partners.

Produced Fluid Characterization Task

Partnerships with industry will continue 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 are expected to continue, with results supporting the ongoing compositional evaluations of each fluid and supporting the temporal evaluations and enhancing the size and usefulness of the database to the various BPOP research efforts. Data review and refining will also be conducted to enhance the usefulness of the database, with any data gaps and additional needs being identified.

Enhancement of the existing GCs and development of analytical methods to enable new whole oil–crude fingerprinting and sulfur isotope characterization will continue. These methods will be used to analyze existing crude and available core samples collected from within the Bakken to determine oil origination and/or subsurface migration during production activities.

Bakken/Three Forks Production Analysis Using Data Analytics and Machine Learning Task

Completion optimization calculations using data-mining methods will be refined and updated based on BPOP partner comments and inputs. The algorithms to define child and parent wells and to group wells by DSUs will be improved, and calculations for the production volumes on a DSU level will be updated. An evaluation of optimization parameters for 1280- versus 2560-acre DSUs will also be performed. The findings will be summarized in a final report.

Water Injection Reservoir Assessment Task

The report on the modeling and simulation portion of this task, entitled "Modeling and Simulation of the Inyan Kara Formation to Estimate Saltwater Disposal Potential: Final Report," is available on the BPOP partners-only website. The report will be available to the public in April 2020.

A simplistic spreadsheet model to evaluate the area of influence of SWD wells in the Inyan Kara was completed and is ready for partner review. A select number of BPOP partners will be asked to review the tool, after which necessary revisions will be made based on partner input before the tool is shared with the remaining BPOP partners.

Facility Process Optimization Task

The EERC will continue to engage BPOP partners to assess facility optimization needs relative to flaring mitigation, emission control, vapor pressure management, and relevant process-related issues. The EERC plans to send a representative to the next quarterly NDPC TSG meeting and will seek additional opportunities to improve the processing of crude oil, associated gas, and produced water from the well to market. A partner meeting is also being planned to discuss partner needs and priorities for production facility optimization.

Aromatic/Aliphatic Study Task

Temporal crude oil samples will continue to be collected and analyzed at appropriate time intervals. A journal article on shape-selective crude oil hydrocarbon migration will be submitted.

Environmental Support Task

The EERC plans to continue supporting the NDPC task forces working to address topics including gas capture, emission control, crude oil conditioning and vapor pressure compliance, and waste management.

Program Management and Development

Additional input on programmatic research priorities to help guide the remaining flexible portion of funding will be sought from the partners. This will help develop a scope of work for BPOP activities funding through May 31, 2020, which will be discussed with NDIC and partners. A proposal will be submitted to NDIC OGRP by November 1, 2019, requesting funding for an additional 3 years (June 1, 2020 – May 31, 2022) to continue BPOP.

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

APPENDIX A

FLARING ISSUES, SOLUTIONS AND TECHNOLOGIES WORKSHOP PRESENTATION – NORTH DAKOTA GAS CAPTURE UPDATE


EERC
UND
UNIVERSITY OF
NORTH DAKOTA
Critical Challenges. Practical Solutions.

Energy & Environmental Research Center (EERC)

NORTH DAKOTA GAS CAPTURE UPDATE

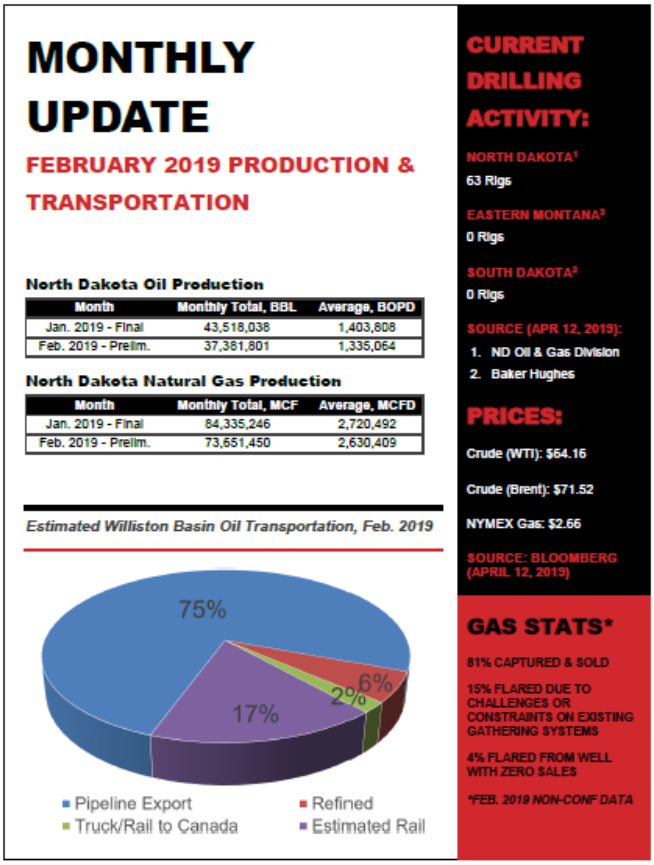
Flaring Issues, Solutions, and Technologies Workshop
Denver, CO
April 23, 2019

Chad Wocken
Principal Engineer, Fuel Group Lead

NORTH DAKOTA PRODUCTION

NORTH DAKOTA PRODUCTION DATA

63 drill rigs
15,000 producing wells
1.4 million barrels crude oil per day
2.7 billion cubic feet associated gas per day



MONTHLY UPDATE

FEBRUARY 2019 PRODUCTION & TRANSPORTATION

North Dakota Oil Production

Month	Monthly Total, BBL	Average, BOPD
Jan. 2019 - Final	43,518,038	1,403,808
Feb. 2019 - Prelim.	37,381,801	1,335,064

North Dakota Natural Gas Production

Month	Monthly Total, MCF	Average, MCFD
Jan. 2019 - Final	84,335,246	2,720,492
Feb. 2019 - Prelim.	73,651,450	2,630,409

Estimated Williston Basin Oil Transportation, Feb. 2019

CURRENT DRILLING ACTIVITY:

NORTH DAKOTA[1]
63 Rigs

EASTERN MONTANA[2]
0 Rigs

SOUTH DAKOTA[2]
0 Rigs

SOURCE (APR 12, 2019):
1. ND Oil & Gas Division
2. Baker Hughes

PRICES:

Crude (WTI): $64.16

Crude (Brent): $71.52

NYMEX Gas: $2.66

SOURCE: BLOOMBERG (APRIL 12, 2019)

GAS STATS*

81% CAPTURED & SOLD

15% FLARED DUE TO CHALLENGES OR CONSTRAINTS ON EXISTING GATHERING SYSTEMS

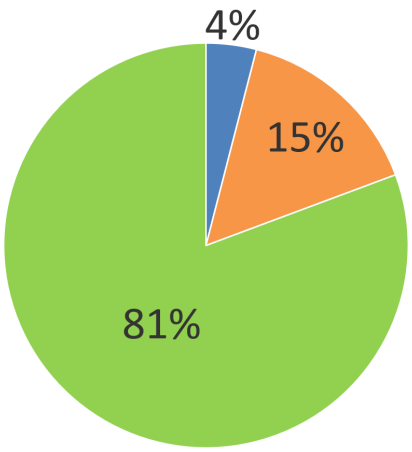
4% FLARED FROM WELL WITH ZERO SALES

*FEB. 2019 NON-CONF DATA

EERC | UND UNIVERSITY OF NORTH DAKOTA

https://ndpipelines.files.wordpress.com/2019/04/ndpa-monthly-update-apr-12-2019.pdf

Solving the Flaring Challenge



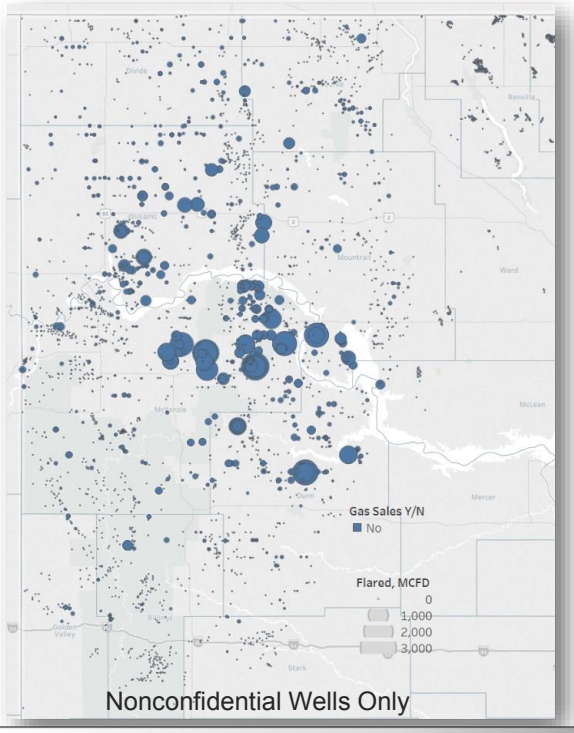
Statewide

GREEN – % of gas captured and sold
Blue – % flared from zero sales wells
Orange – % flared from wells with at least one Mcf sold.

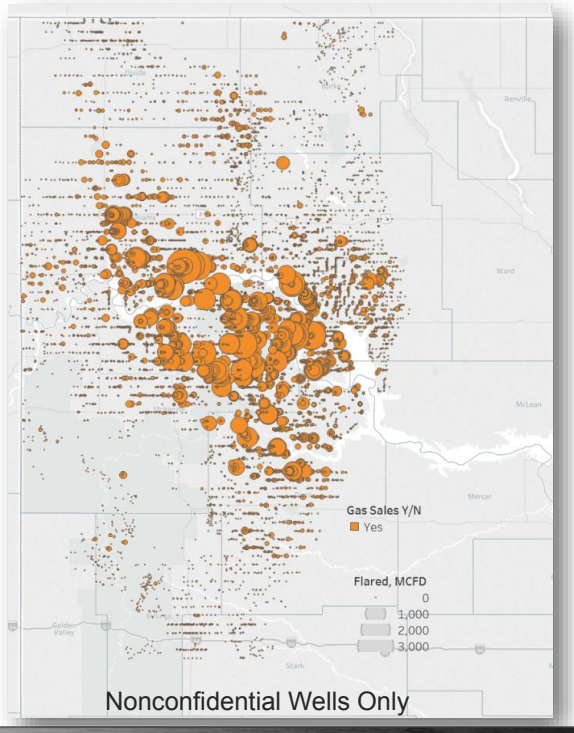
Simple Terms
Blue – Lack of pipelines
Orange – Challenges on existing infrastructure

Feb. 2019 Data – Nonconfidential Wells

Flaring by Category – July 2018



Nonconfidential Wells Only



Nonconfidential Wells Only

NORTH DAKOTA GAS CAPTURE POLICY
INDUSTRIAL COMMISSION ORDER 24665

ORDER 24665 – VERSION 112018

- Gas capture rule adopted in 2014, input from multiple stakeholders
- Order 24665 revised in November 2018
- Gas capture targets:
  - November 1, 2018: 88% capture (12% flaring)
  - November 1, 2020: 91% capture (9% flaring)
- Gas production forecast must be submitted to midstream gathering companies
- Gas capture plan developed for increased density drilling and production
- If capture targets are not met, production restrictions:
  - 200 bpd provided 60% of monthly produced gas is captured.
  - 100 bpd if capture is below 60% of monthly produced gas.
- Compliance based on state, county, field, or well.

GAS CAPTURE OPTIONS

Associated Gas Not Included in Flared Volume

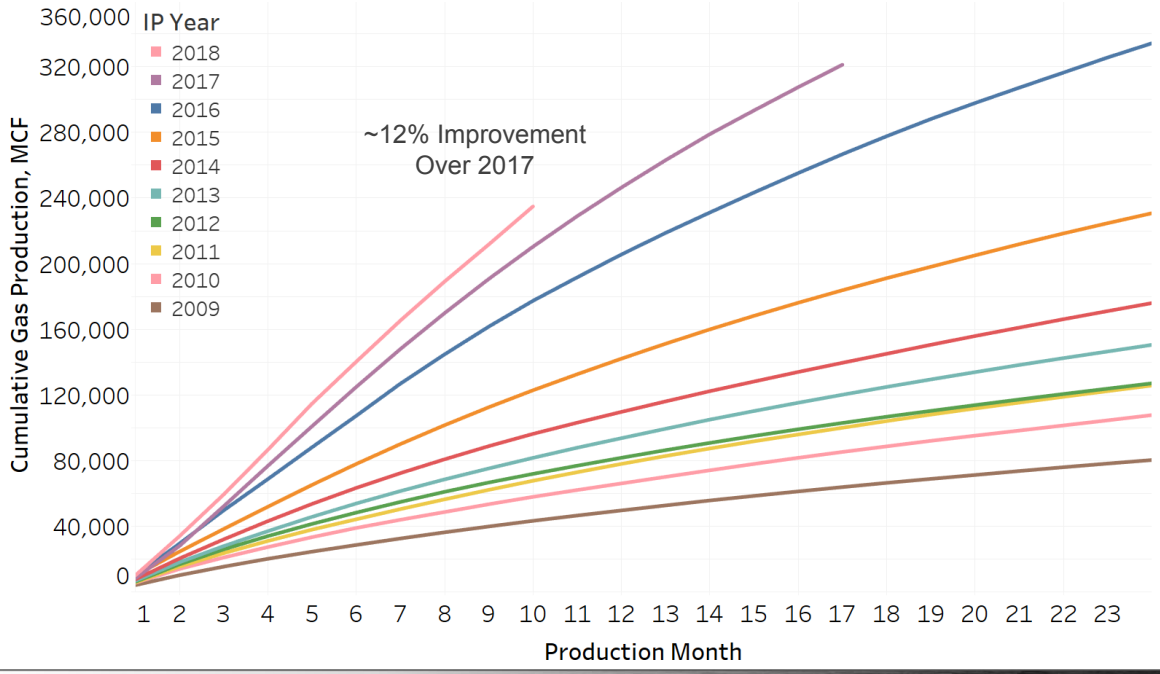
- Gas produced during the first 60-day initial production period
- Gas transported to processing facility via gathering pipelines
- Gas placed into geologic storage or used for enhanced oil recovery
- Gas used in a beneficial manner:
  - Electrical generation
  - Natural gas liquid recovery
  - Compressed or liquefied gas for use as a fuel elsewhere
  - Processed or converted into another chemical or fuel
  - Technology that reduces the volume or intensity of the flare by more than 60%
- Credits for gas captured in excess of the gas capture goal or LNG/CNG utilization

GAS CAPTURE: A MOVING TARGET

FACTORS INFLUENCING FLARING IN NORTH DAKOTA TODAY

- Continued increase in associated gas production
  - Ten fold increase from 2008 to 2018
- Rapid production decline curve
- Transience of flared gas and dynamic gathering system operating conditions:
  - High initial production (IP) can overwhelm gas gathering during first months of production
  - High natural gas liquid (NGL) content, 8–12 gallons NGL/Mcf
  - Location and rate of production is constantly changing
- Approximately 20% of flared gas occurs from stranded wells
- Economics challenging for small-scale gas use
  - Inexpensive coal-generated electricity
  - Low NGL and ethane value, and large distance to market (transportation cost)
  - Small regional market for transportation fuel CNG/LNG

INCREASING GAS PRODUCTION



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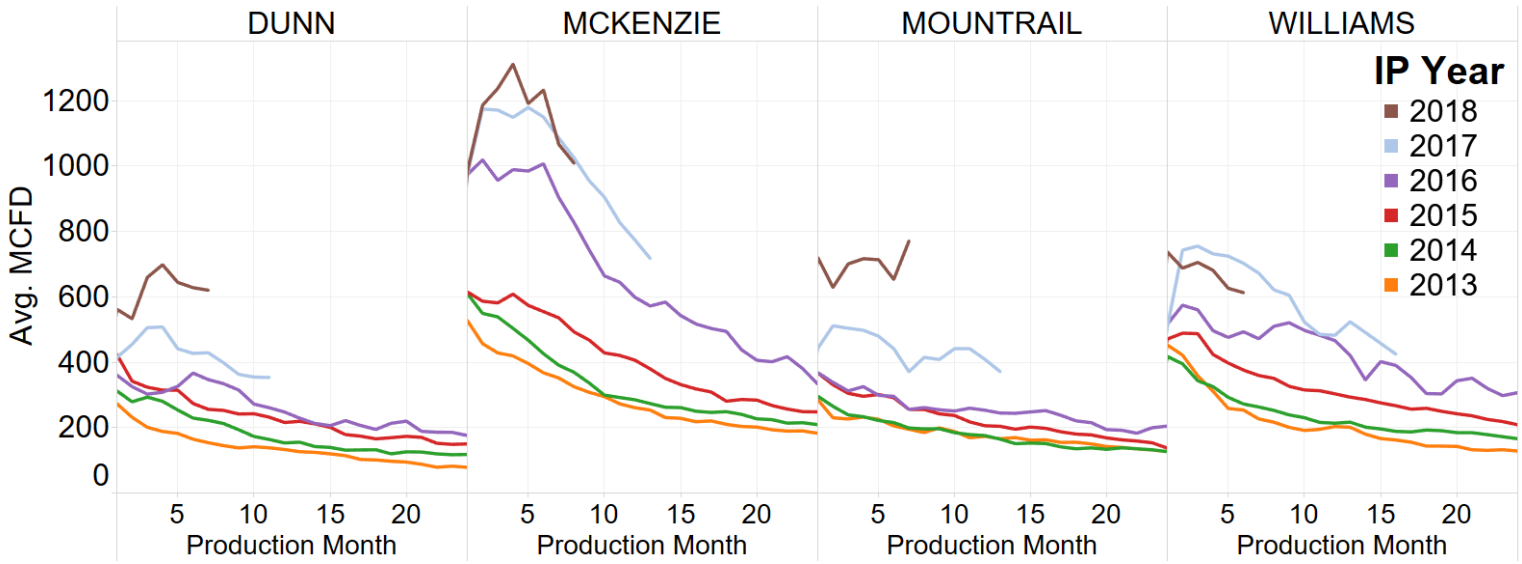
RAPID PRODUCTION DECLINE



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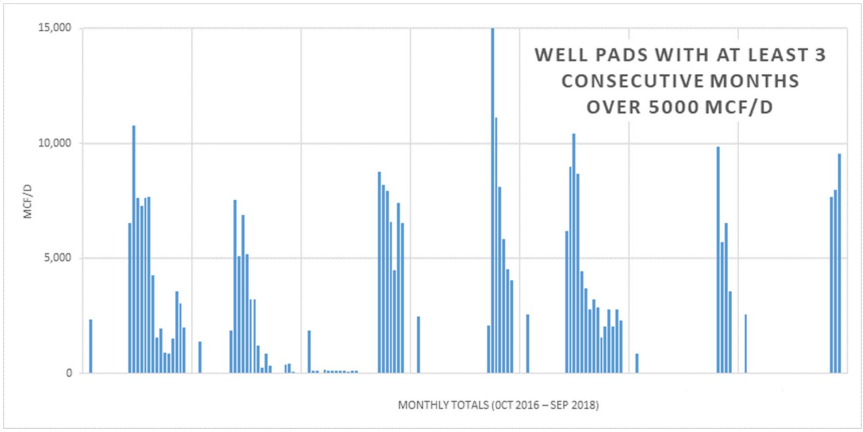
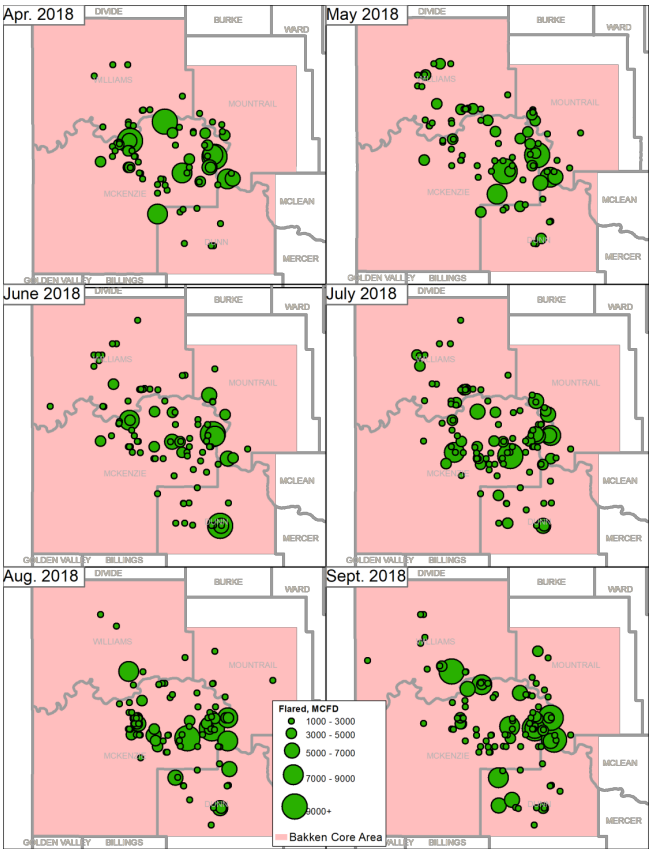
TRANSIENT FLARE

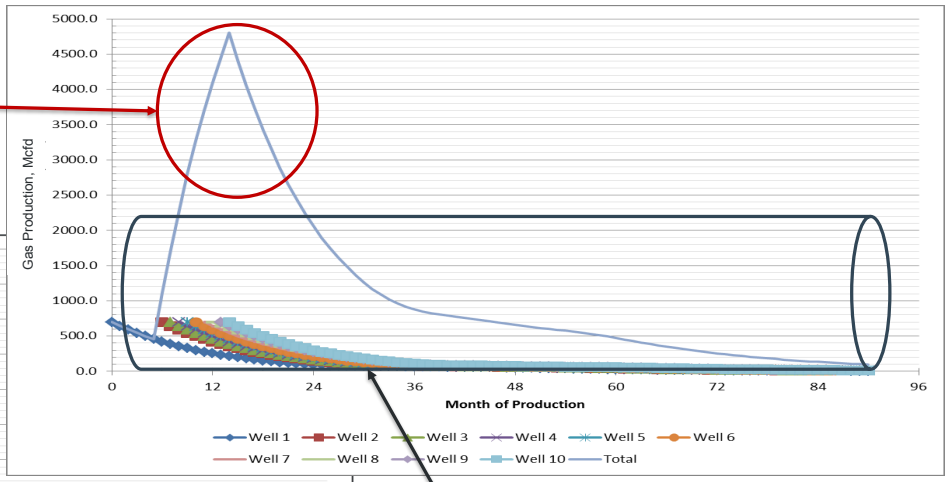
- Large flares (>1000 Mcfd) don't remain in the same place for long

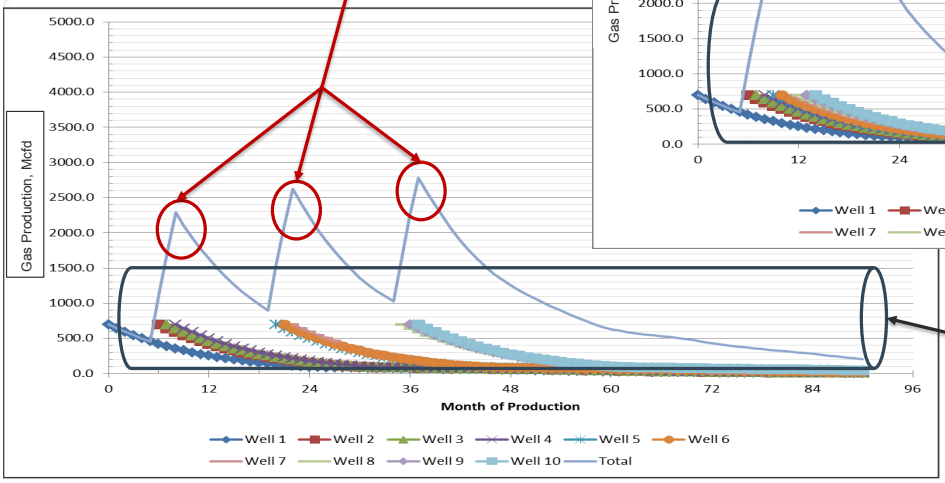




FLOWBACK STRATEGY AND PRODUCTION DECLINE FROM A TEN-WELL PAD

How do you shave the flare peak?





How do you “right-size” gathering infrastructure?

Critical Challenges. Practical Solutions.

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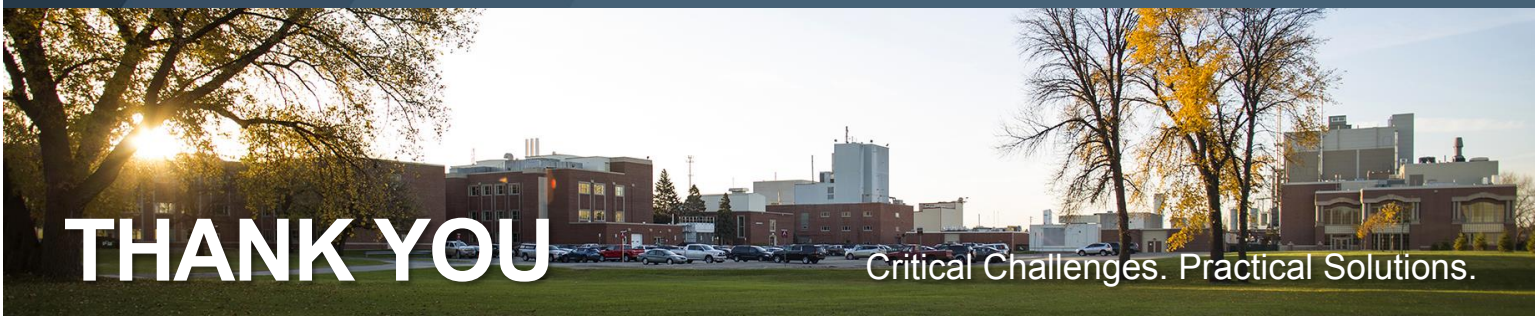

APPENDIX B

NDPC FLARING WORK GROUP MEETING WITH THE U.S. BUREAU OF LAND MANAGEMENT PRESENTATION – REMOTE CAPTURE OPPORTUNITIES AND CHALLENGES


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REMOTE CAPTURE OPPORTUNITIES AND CHALLENGES

Bismarck, ND
August 22, 2019

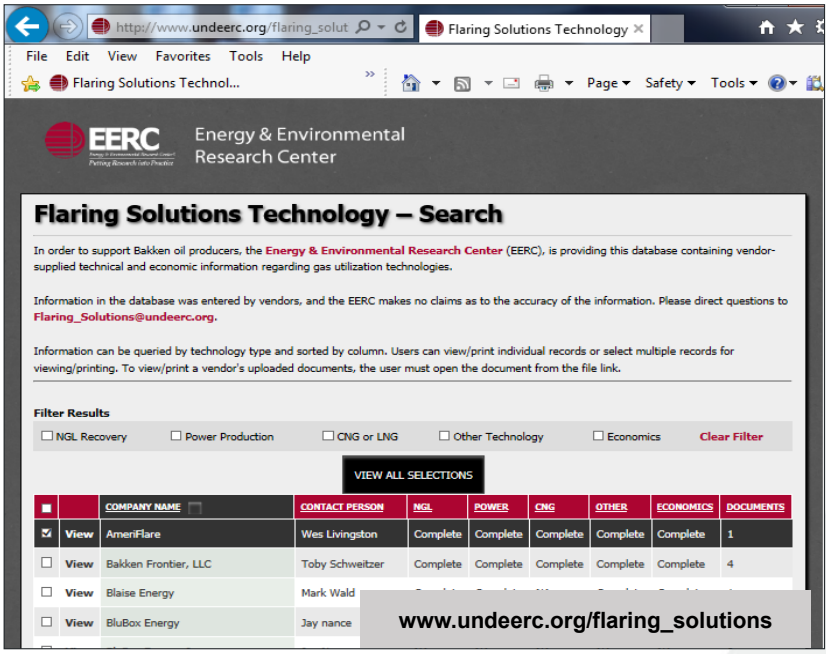
Chad Wocken
Principal Engineer, Fuels and Renewable Energy Lead

EERC REMOTE CAPTURE DATABASE

As of August 2019, the EERC's Flaring Solutions database contained 33 companies with technologies in the following categories:

- NGL recovery
- Power production
- CNG or LNG production
- Gas conversion to chemicals or fuels

Approximately 50% of these companies have had units deployed at some point in time.



www.undeerc.org/flaring_solutions

Natural Gas Liquid Recovery Economics

Key Challenge: Low NGL and ethane value, and large distance to market (transportation cost)

	2014	Current
Total gas treated[1]	1000 mcfd	1000 mcfd
NGL Recovery[2]	3 gal/mcf	3 gal/mcf
NGL Value[3] (net back)	$1/gal	<$0.20/gal
Annual costs[4] (lease, mobilization, royalty)	$687,600	$569,520
Annual NGL Revenue[5]	$984,400	$196,800
Net Profit[6] (Loss)	$296,400	($372,720)

Assumptions:

[1] Larger systems have few locations where 100% capacity achievable. Smaller systems suffer from economy of scale.

[2] Higher recovery efficiency typically results in higher ethane content and value deduction.

[3] NGL over supply and cost of transport can create a significant discount to benchmark prices.

[4] Annual costs ranging from $0.75-2.00/mcfd capacity ($22,500/mo. - $60,000/mo); three mobilizations/yr at $60k each; and royalty of 15% on NGLs sold.

[5] Annual NGL revenue assumes 90% capacity factor

[6] NGL recovery systems provide challenged economics under the best conditions.

POWER PRODUCTION IMPACT ON FLARING

Key Challenge: Inexpensive coal-generated electricity

Over 250 Natural Gas Generators Deployed in North Dakota

- Predominantly site power applications (100 kW to 5 MW).
- 52,000 kW electrical capacity fueled with 15 MMcfd (2% of flared volume).

Considerations

- Provides fuel cost savings over diesel when grid power is unavailable.
- Gas quantity to satisfy on-site electrical demand is small, <5% of gas produced on site.
- NGL recovery upstream of gas generation can improve engine performance, but reliability of combined system is critical to ensuring power for production equipment.
- Expansion of grid infrastructure is expected to displace on-site generation.
- Low price for power makes economics of grid-interconnect challenging at the wellsite.
- A small market exists for CNG delivered for power (drilling rigs, completions equipment).

TRANSPORTATION FUEL - CNG/LNG

Key Challenge: Small regional market for transportation fuel (compressed natural gas [CNG]/liquefied natural gas [LNG])

Possible Impact With 500,000-mile/day Fleet.

- 50,000 gallons diesel/day vs. 5600 Mcf gas/day.
- $94,800/day fuel savings over diesel (assumes $2/gal diesel, $1/Mcf gas).
- <1% reduction in overall flared volume for each 500,000 mile/day fleet.

Considerations

- Fuel cost savings compared to diesel.
- Transportation engines require high-purity methane, not easily achievable at small scale.
- Very little infrastructure (refueling stations, fleets) to support natural gas transportation fuel.
- Investment in infrastructure requires confidence in long term market conditions.

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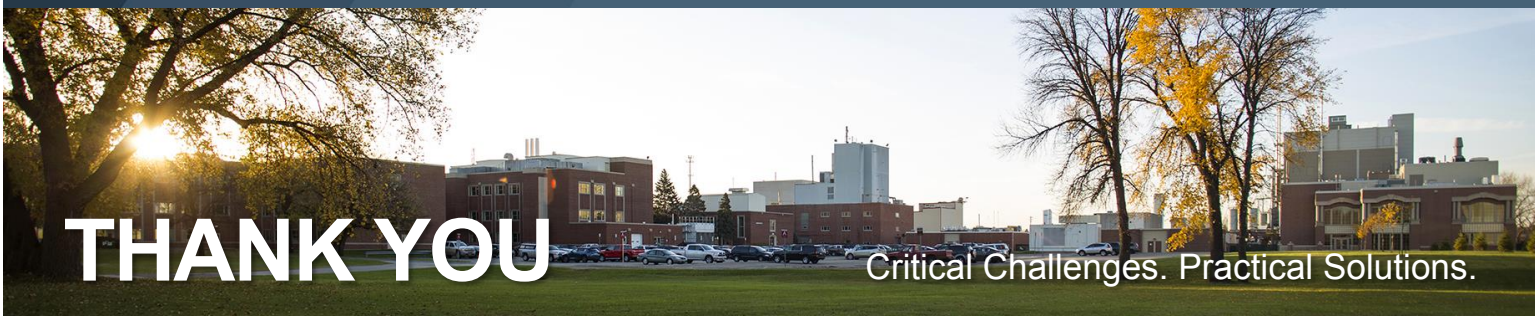

APPENDIX C

INTERSTATE OIL AND GAS COMPACT COMMISSION 2019 ANNUAL CONFERENCE – NORTH DAKOTA GAS CAPTURE UPDATE


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Critical Challenges. Practical Solutions.

Energy & Environmental Research Center (EERC)

NORTH DAKOTA GAS CAPTURE UPDATE

Interstate Oil and Gas Compact Commission
2019 Annual Conference

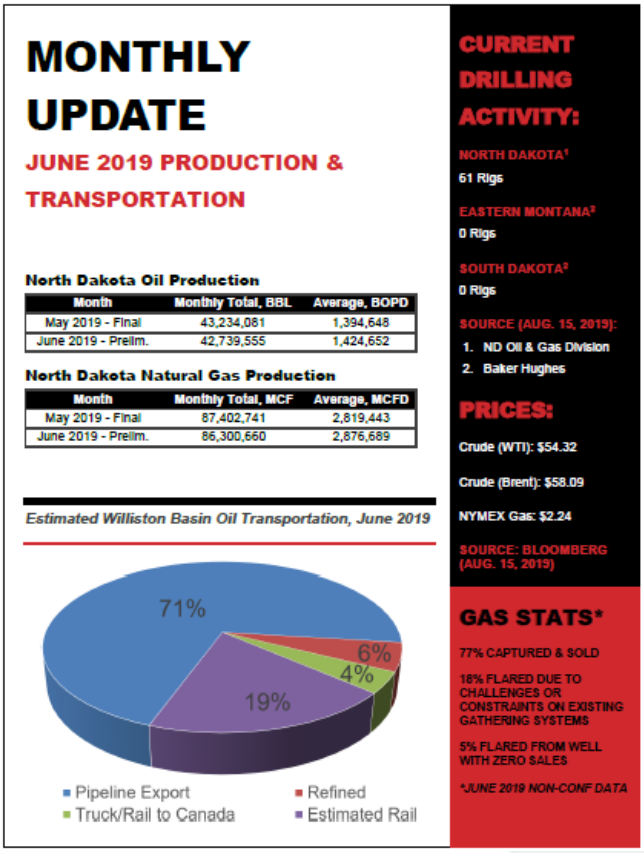
August 26, 2019

Chad Wocken
Principal Engineer, Fuel Group Lead

NORTH DAKOTA PRODUCTION

NORTH DAKOTA PRODUCTION DATA

61 drill rigs
15,700 producing wells
1.4 million barrels crude oil per day
2.9 billion cubic feet associated gas per day



MONTHLY UPDATE

JUNE 2019 PRODUCTION & TRANSPORTATION

North Dakota Oil Production

Month	Monthly Total, BBL	Average, BOPD
May 2019 - Final	43,234,081	1,394,648
June 2019 - Prelim.	42,739,555	1,424,652

North Dakota Natural Gas Production

Month	Monthly Total, MCF	Average, MCFD
May 2019 - Final	87,402,741	2,819,443
June 2019 - Prelim.	86,300,660	2,876,689

Estimated Williston Basin Oil Transportation, June 2019

CURRENT DRILLING ACTIVITY:

NORTH DAKOTA[1]
61 Rigs

EASTERN MONTANA[2]
0 Rigs

SOUTH DAKOTA[2]
0 Rigs

SOURCE (AUG. 15, 2019):
1. ND Oil & Gas Division
2. Baker Hughes

PRICES:

Crude (WTI): $54.32

Crude (Brent): $58.09

NYMEX Gas: $2.24

SOURCE: BLOOMBERG (AUG. 15, 2019)

GAS STATS*

77% CAPTURED & SOLD

18% FLARED DUE TO CHALLENGES OR CONSTRAINTS ON EXISTING GATHERING SYSTEMS

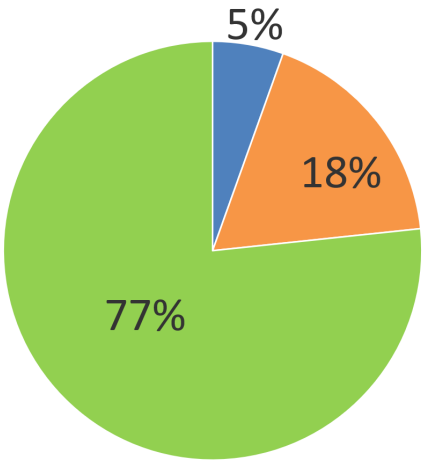
5% FLARED FROM WELL WITH ZERO SALES

*JUNE 2019 NON-CONF DATA

EERC | UND UNIVERSITY OF NORTH DAKOTA

https://ndpipelines.files.wordpress.com/2019/08/ndpa-monthly-update-aug-15-2019.pdf

Solving the Flaring Challenge



Statewide

GREEN – % of gas captured and sold
Blue – % flared from zero sales wells
Orange – % flared from wells with at least one mcf sold

Simple Terms
Blue – Lack of pipelines
Orange – Challenges on existing infrastructure

June 2019 Data – Non-Confidential Wells

WHY DO WE FLARE GAS?

FACTORS INFLUENCING FLARING IN NORTH DAKOTA TODAY

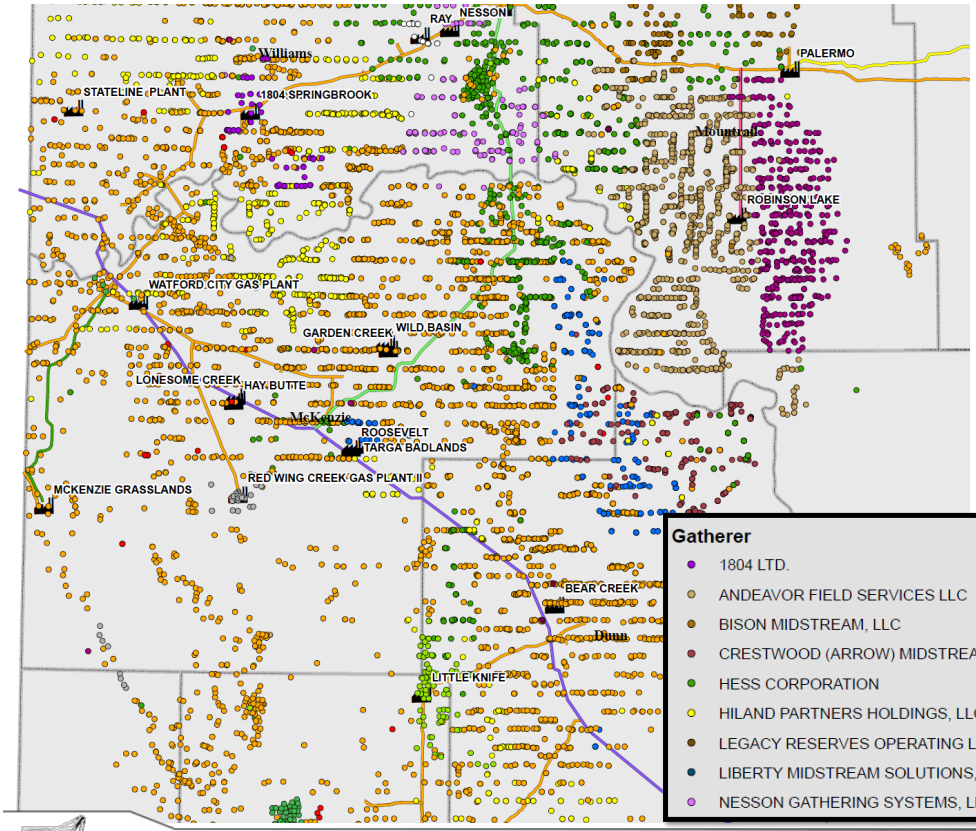
- No gas gathering pipeline and infrastructure
  - Currently 22% of flared gas in ND is due to stranded production
  - Pipeline is planned, but delayed (permitting, right-of-way approval, weather)

- Maintenance or process disruption
  - Short duration
  - Can be unplanned
  - High natural gas liquid (NGL) content, 8–12 gallons NGL/Mcf

- Gas gathering capacity constraints
  - Pipelines and gas plants take more time than wells
  - High initial production (IP) can exceed capacity during first months of production
  - Location and rate of production is constantly changing

TECHNOLOGIES TO MITIGATE FLARING

Natural Gas Gathering Network



Gatherer

- 1804 LTD.
- ANDEAVOR FIELD SERVICES LLC
- BISON MIDSTREAM, LLC
- CRESTWOOD (ARROW) MIDSTREAM
- HESS CORPORATION
- HILAND PARTNERS HOLDINGS, LLC
- LEGACY RESERVES OPERATING LP
- LIBERTY MIDSTREAM SOLUTIONS, LLC
- NESSON GATHERING SYSTEMS, LLC
- NEXTERA
- ONEOK ROCKIES MIDSTREAM
- OTHER
- PECAN PIPELINE (NORTH DAKOTA) INC
- PETRO-HUNT, L.L.C.
- TARGA BADLANDS LLC
- TRUE OIL LLC
- USG MIDSTREAM BAKKEN I LLC
- WESTERN GAS PROCESSORS
- WHITING OIL AND GAS CORPORATION

Gas Plant

PIPELINE

- Alliance
- Aux Sable
- Bear Paw
- Hess
- Northern Border
- Whiting
- WBIP

EERC REMOTE CAPTURE DATABASE

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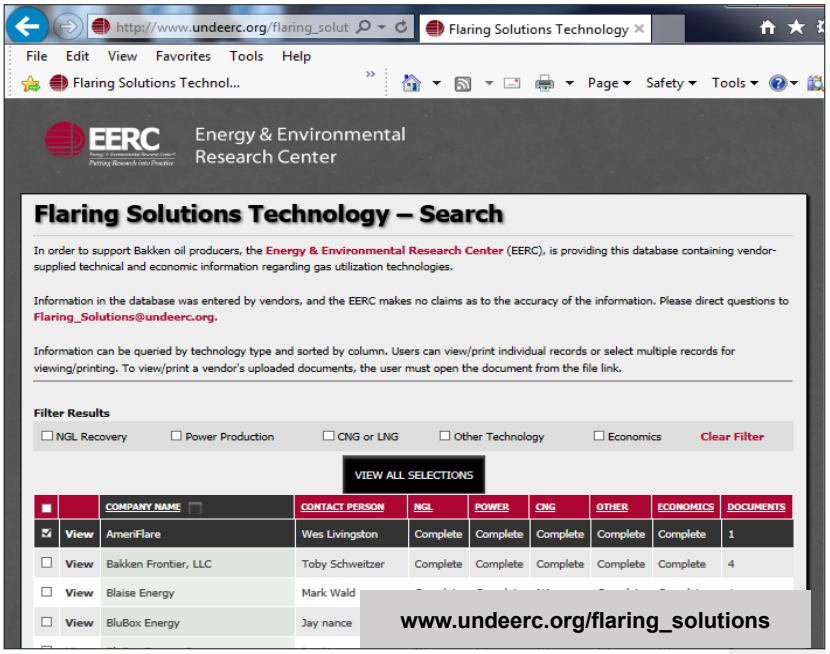

www.undeerc.org/flaring_solutions

NGL RECOVERY

- Multiple operating principles; 300–5000 Mcfd input capacity
  - Joule–Thomson cooling
  - Mechanical refrigeration
  - Membrane- or sorbent-based separation
- Recovery efficiency of 2–4 gallons NGL/Mcf gas observed in field operations
  - 30%–50% volume reduction, up to 60% reduction in energy content
  - NGLs recovered, stored as a pressurized liquid, and sold
- Residue gas available for power, or CNG/LNG delivery; excess residue gas flared

Considerations

- Commercially available, mobile, capable of remote operation
- Extract highest-value hydrocarbons, reducing residue gas Btu content
- Increases product storage and truck traffic at production site

POWER PRODUCTION

- Well site power
  - Generators sized from 100 kW to 5 MW
  - 1 MW power requires approximately 300 Mcfd gas
- Power for drilling rigs and well completions
  - Stranded gas can fuel generators used to power drilling and completions equipment
  - Bi-fuel (diesel and natural gas) and dedicated gas generators
- Companies with mobile data centers seeking low cost electricity
  - Mobilize skid mounted electrical generators and computing equipment
  - Scale of 1-10 MW power demand possible at a well site

Considerations

- Provides fuel cost savings over diesel when grid power is unavailable
- Expansion of grid infrastructure is expected to displace on-site gas generation
- Low price for power makes economics of grid-interconnect challenging at the wellsite

TRANSPORTATION FUEL
CNG/LNG

Possible impact with 500,000-mile/day fleet

- 50,000 gallons diesel/day vs. 5600 Mcf gas/day
- $90,000/day fuel savings over diesel (at $2/gal diesel, $2/Mcf gas)
- <1% reduction in overall flared volume for each 500,000 mile/day fleet

Considerations

- Fuel cost savings compared to diesel
- Transportation engines require high-purity methane, not easily achievable at small scale.
- Very little infrastructure (refueling stations, fleets) to support natural gas transportation fuel.
- Refueling infrastructure and fleet investment needed

GAS CONVERSION TO FUELS OR CHEMICALS

Small-scale conversion platforms capable of producing synthetic crude, alcohols, or ammonia-based fertilizer

- Nominal gas use of 25,000 Mcfd for 2500-bbl/day production
- Represents approximately 4% reduction in overall flared volume

Considerations

- Improved value on energy basis
- Product selection based on regional markets, cost to transport
- Scale selected to match gas supply and product demand
- 2500-bbl/day production requires aggregation of gas from multiple production locations
- Plant footprint, operational staffing, and permitting need to be addressed for remote operation
- Process needs to be tolerant of variable gas quality and quantity

OPPORTUNITIES FOR IMPROVEMENT

Additional gas gathering infrastructure
- 28,000 miles of pipe installed since 2008, more planned

Additional regional demand for gas and NGL
- Transportation fleet conversions
- Investment in petrochemical manufacture, gas conversion to higher value chemicals and fuels

Advancements in small scale gas use technologies
- Increased efficiency

Gas injection into geologic formations
- Gas storage
- Enhanced oil recovery from conventional reservoirs
- Pressure maintenance within the Bakken

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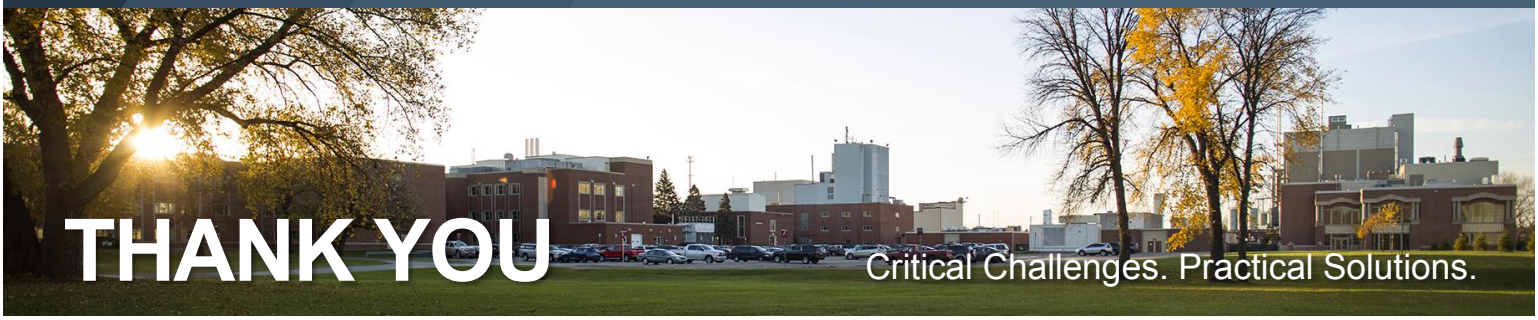


APPENDIX D

NDPC TECHNICAL SOLUTIONS GROUP PRESENTATION – NORTH DAKOTA REMEDIATION RESOURCE MANUAL

Energy & Environmental Research Center (EERC)

NORTH DAKOTA PETROLEUM COUNCIL TECHNOLOGY SOLUTIONS GROUP

Q2 – 2019 Meeting
Dickinson, ND
May 8, 2019

Chad Wocken
Principal Engineer

NORTH DAKOTA
REMEDIATION RESOURCE MANUAL

BACKGROUND

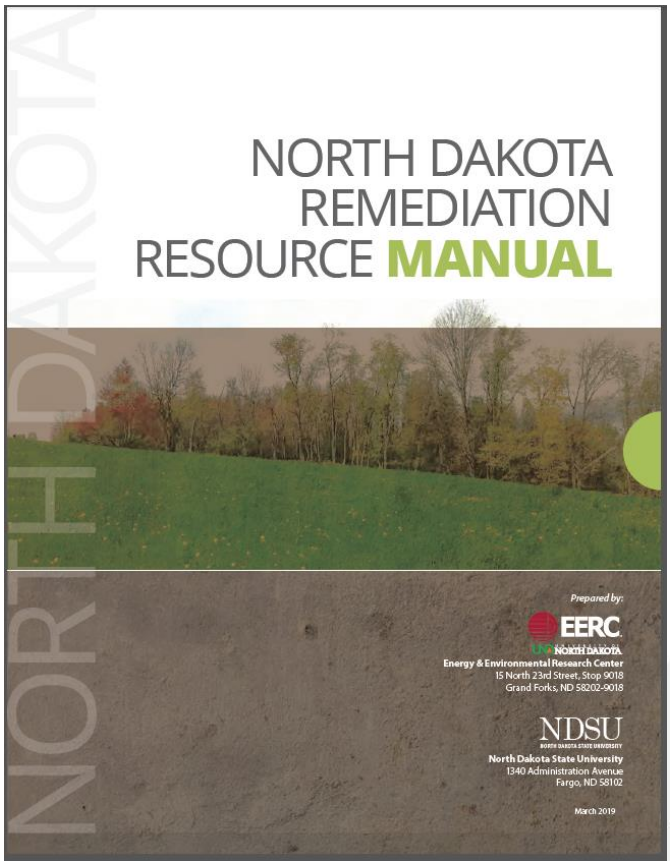
- Technical resource, not a prescriptive must-do document
  - Remediation techniques
  - Remediation decision-making process
- Suited for wide-ranging audience
  - Seasoned professional as a technical resource
  - Entry-level professional as an introductory training and educational resource
  - Non-professionals as an educational tool

- Collaboration of regulators, government, industry, and landowners
  - North Dakota Department of Health
  - North Dakota Department of Mineral Resources
  - North Dakota Department of Agriculture
  - North Dakota Petroleum Council (Kari Cutting)
    - Continental Resources (Stacy Aguirre and Todd Senescall)
    - Oasis Petroleum (Dustin Anderson)
    - Whiting Petroleum (Rafe Espinosa)
    - XTO Energy (Tim Hazen and Karen Pratt)
  - Northwest Landowners Association

OUTLINE

- Overview of regulations
- Spill Reporting
- Impact of Crude Oil and Brine Spills on Soil
- Spill and Site Assessment
- Risk Assessment
- Data Interpretation
- Remediation Options – Hydrocarbons
- Remediation Options – Brine Impacts
- Post Remediation Monitoring and Site Closure

http://www.undeerc.org/Bakken/Optimization/default.aspx



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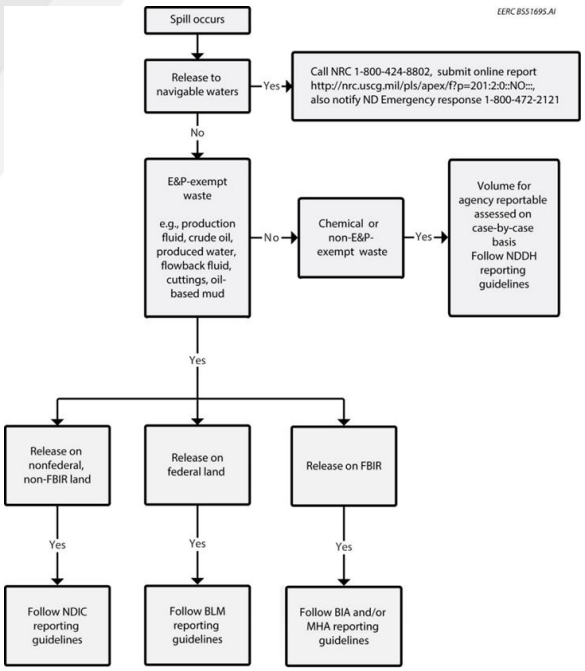
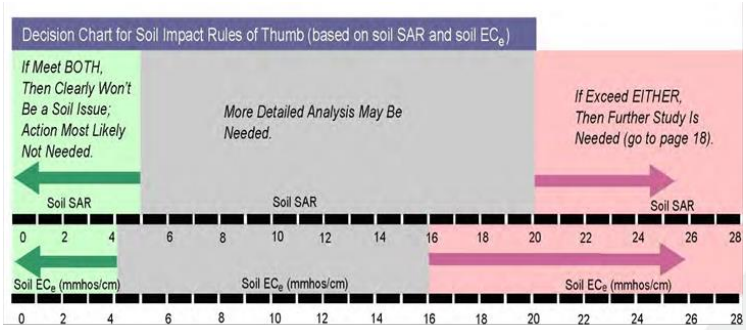
MANUAL CONTENT



Left: Decision tree for spill reporting and action

Bottom: Decision chart for brine impacted soils based on sodium absorption ratio (SAR) and conductivity.



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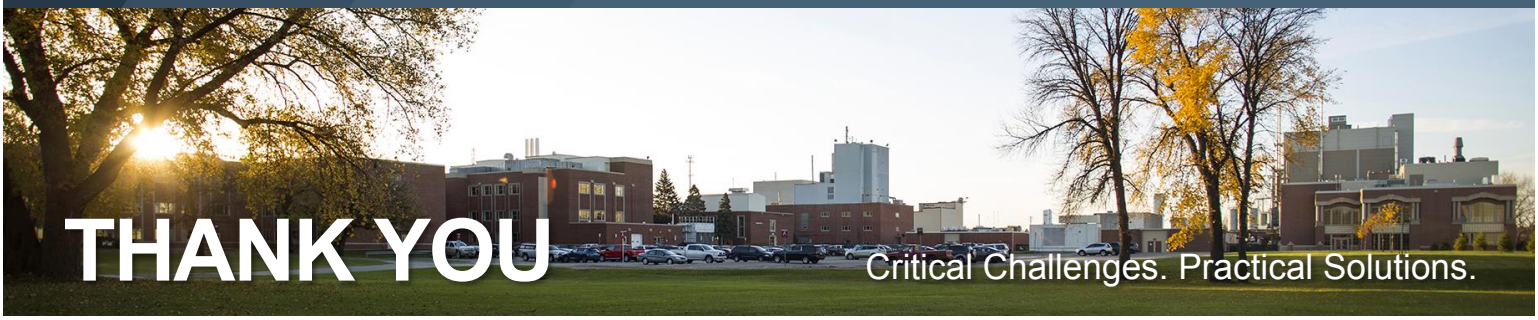


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APPENDIX E

BPOP 2.0 UPDATE TO OGRC DECEMBER 2018

Energy & Environmental Research Center (EERC)

BAKKEN PRODUCTION OPTIMIZATION PROGRAM 2.0 (BPOP 2.0) UPDATE

Presented to Oil & Gas Research Council
Bismarck, North Dakota
December 18, 2018

Charles Gorecki
Director of Subsurface R&D

AGENDA

- Rich Gas Enhanced Oil Recovery (EOR) with Liberty Resources
- Facilities Modeling
- Fluids Characterization
- Year 3 Activities
- Final Report Review Process
- Report Status

RICH GAS EOR – HIGHLIGHTS

- **Lab studies of rich gas interactions with fluids and rocks**
  - The richer the gas, the lower the MMP.
- **Iterative modeling of surface and subsurface components**
  - Rich gas EOR predicted to not adversely affect surface facility operations.
  - Predicted incremental oil recovery >25%.
- **Pilot performance assessment**
  - Summer pilot tests (July–September) injected 24.6 MMscf into two wells over three injection periods.
  - Fall–winter pilot tests started November 20 and are ongoing. Injection into four wells planned at max. rate of ~2 MMscfd at wellhead pressure ~4000 psi.
  - Results are being analyzed and interpreted, models updated.

RICH GAS EOR – NEXT STEPS

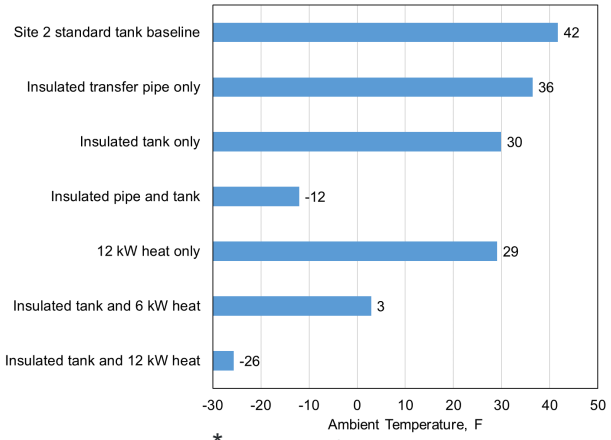
- Rich gas injection anticipated to continue through the winter and spring.
- Fluid samples representing the reservoir and the surface processing facilities will continue to be collected to determine effects of rich gas injection on both.
- Laboratory experiments to determine the sorptive capacity of Bakken shale for rich gas components will be conducted.

FACILITIES MODELING

- **Impact**: Apply process-modeling tools to address Bakken-specific issues arising at production facilities.
  - Crude quality and shrinkage
  - Emissions
  - Safety
- **Products:** Whitepapers and presentations that address specific needs, including:
  - Tank battery emissions.
  - Wintertime crude vapor pressure limits.
- **Next Steps**
  - Continued participation in information exchange forums (TSG and others).
  - Develop new calculators as site configurations evolve.

Cold Weather Modification Ranking *

Minimum ambient temperature threshold for 13.7 psia oil.



* Illustration of single hypothetical scenario

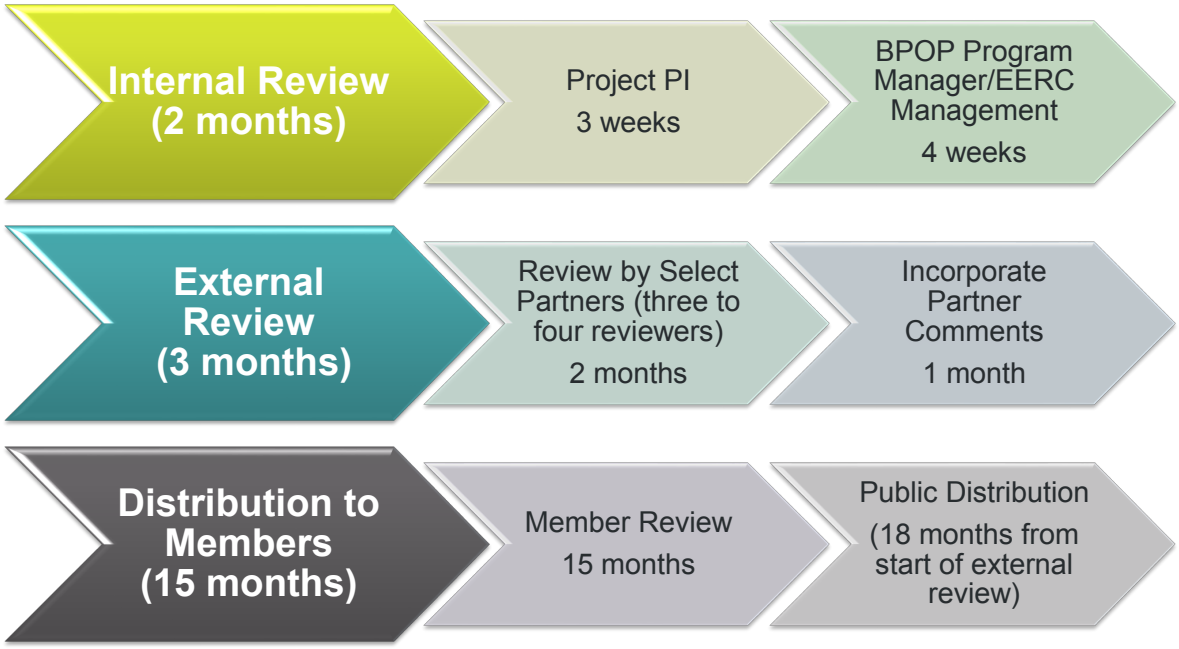
FLUIDS CHARACTERIZATION

- Coordinated with program leads to identify key information and data needed for ongoing and planned research efforts.
- Developed partnerships with key industry entities to obtain access to fluids data and information and site access for additional sample collection efforts.
- Supported a BPOP industry member conducting a rich gas injection EOR demonstration through periodic sampling and analysis of fluids potentially impacted through the EOR activity.
- Coordinated with a BPOP industry member, and initiated sampling and analysis activities on a stimulated and nonstimulated well for evaluating compositional differences that may indicate possible fluid migration pathways and possible sources of produced water in typical stimulated Bakken wells.

BPOP YEAR 3 ACTIVITIES – SUMMARY

- Improved oil recovery (IOR) encompasses any subsurface action that supplements the initial recovery profile of an oil well, including fluids injection for pressure maintenance, EOR, new stimulations, etc.
  - Reinjection of rich gas into parent wells – effects on offset wells
  - Refracs/IOR Workshop
- Subsurface activities
  - Data analytics and trend analysis
  - Reservoir characteristics and fluids database
  - Produced water management tools and general topics
- Surface activities
  - Facilities optimization
  - Fluids characterization
- Management
  - Program oversight, document control, Web site, etc.
- Reserve for possible U.S. Department of Energy match

BPOP 2.0 PRODUCT REVIEW PROCESS



BPOP 2.0 PRODUCTS

Title	Status
Process Modeling of Wellsite Production Operations	Public
Modeling and Simulation of the Inyan Kara Formation to Estimate Saltwater Disposal Potential	Partners only through April 2020
Bakken Refracturing Data Analysis	Under partner review; partners only through July 2020
Bakken Production Evaluation Using Multivariate Statistical Analysis	Under partner review; partners only through July 2020
Vapor Pressure Modeling of Cold Weather Modifications for Bakken Surface Facilities	Partners only through April 2020
BakkenSMART Fugitive Emissions Fact Sheet	Public
BakkenSMART Hydraulic Fracturing Fact Sheet	Public

QUESTIONS?

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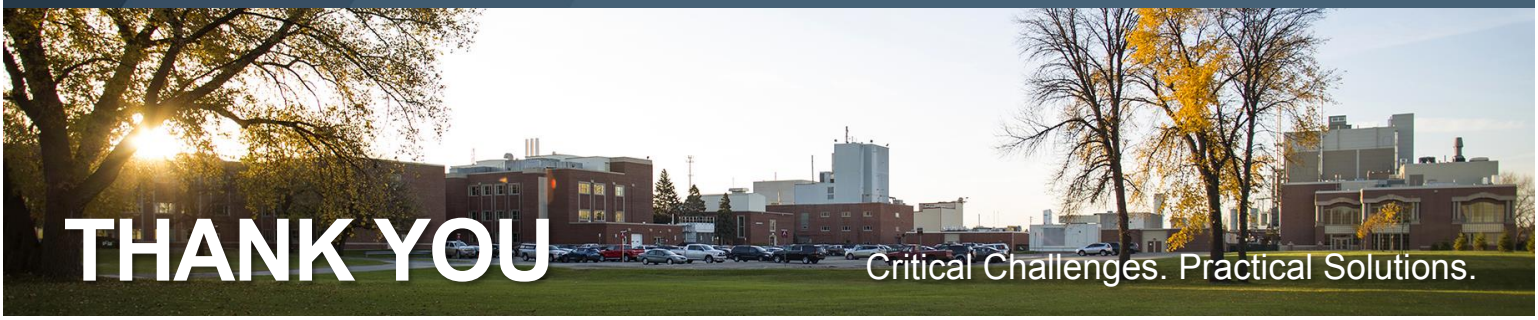

APPENDIX C

RESUMES OF KEY PERSONNEL

CHARLES D. GORECKI
CEO
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, North Dakota 58202-9018 USA
701.777.5355 (phone), 701.777.5181 (fax), cgorecki@undeerc.org

Principal Areas of Expertise
Mr. Gorecki's principal areas of interest and expertise include carbon capture, storage, and utilization; enhanced oil recovery (EOR); unconventional oil and gas research; oil and gas industry technologies; clean coal technologies; and energy and water sustainability.

Qualifications
B.S., Geological Engineering, University of North Dakota, 2007.

Professional Experience
August 2019–Present: CEO, EERC, UND. Mr. Gorecki leads a multidisciplinary science, engineering, and support team of 220 people who focus on research and development (R&D) leading to demonstration and commercialization of innovative energy and environmental technologies. The EERC, with its long tradition of fossil fuel-related R&D, has broadened its scope to include a wide array of strategic energy and environmental issues. Mr. Gorecki oversees efforts to address these issues through strategic initiatives focused on clean coal technologies; oil and gas industry technologies; carbon capture, utilization, and storage (CCUS); energy and water sustainability; air toxics and fine particulate control; water management strategies; global climate change; waste utilization, hydrogen technologies; and contaminant cleanup.

2015–July 2019: Director of Subsurface R&D, EERC, UND. Mr. Gorecki was responsible for developing and managing programs and projects focused on conventional, unconventional, and enhanced oil and gas production; geologic storage of CO_2; geothermal; and other energy and environmental research. In this role, he served as Program Manager for the Plains CO_2 Reduction (PCOR) Partnership and the Bakken Production Optimization Program, two major collaborative industry–government programs. Mr. Gorecki also managed or oversaw projects related to the entire CCUS value chain and conventional and unconventional oil and gas recovery.

2011–2015: Senior Research Manager, EERC, UND. Mr. Gorecki was manager of the PCOR Partnership and technical lead for the Bell Creek CO_2 EOR field demonstration. He led geologic modeling and simulation efforts for the EERC as well as national and international efforts associated with the nexus of water and CCS. Mr. Gorecki led efforts focused on developing storage capacity estimates and methodologies for deep saline formations (DSFs) and hydrocarbon reservoirs. In addition, he led and worked on detailed site characterization, modeling, risk assessment, and monitoring activities for both EOR projects and CO_2 storage operations in DSFs. Mr. Gorecki participated in several expert review committees and was involved in developing a methodology for estimating CO_2 storage capacity in DSFs, oil and gas reservoirs, and shale formations for the U.S. Department of Energy (DOE).

2010–2011: Research Manager, EERC, UND. Mr. Gorecki led modeling and monitoring and Water Working Group tasks for Phase III of the PCOR Partnership Program. He led the EERC's geologic modeling efforts, coordinating a multidisciplinary team to develop detailed geologic models and run

predictive simulations for CO_2 storage, CO_2 EOR, and unconventional oil and gas plays. Mr. Gorecki was also the facilitator of the RCSP Water Working Group, where he led discussion on the nexus of water and CCS.

2007–2010: Research Engineer, EERC, UND. Mr. Gorecki worked with the PCOR Partnership to develop models to describe the behavior of CO_2 prior to injection into saline formations and oil fields. He led a joint venture funded by the IEA Greenhouse Gas R&D Programme and DOE to develop storage capacity/resource coefficients to determine CO_2 storage capacity/resource estimates in saline formations. As a result of this work, he served on the expert review panel for the U.S. Geological Survey's CO_2 Capacity Methodology; advised and helped to develop methodologies for the North American Energy Working Group's CO_2 storage capacity efforts between the United States, Canada, and Mexico; and advised the DOE National Energy Technology Laboratory on the third edition of the Carbon Sequestration Atlas of the United States and Canada.

Professional Memberships

American Association of Petroleum Geologists, 2009–Present
Society of Petroleum Engineers, 2007–Present
Member of European Association of Geoscientists and Engineers, 2014–Present

Selected Publications

Mr. Gorecki has authored and coauthored many papers and given presentations on a variety of topics associated with CO_2 EOR and CO_2 storage in the United States and throughout the world, including the following:

Jin, L., Pekot, L.J., Hawthorne, S.B., Salako, O., Peterson, K.J., Bosshart, N.W., Jiang, T., Hamling, J.A., Wildgust, N., and Gorecki, C.D., 2018, Evaluation of recycle gas injection on CO_2 enhanced oil recovery and associated storage performance: International Journal of Greenhouse Gas Control, v.75, p. 151–161.

Jin, L., Sorensen, J.A., Hawthorne, S.B., Smith, S.A., Pekot, L.J., Bosshart, N.W., Burton-Kelly, M.E., Miller, D.J., Grabanski, C.B., Gorecki, C.D., Steadman, E.N., and Harju, J.A., 2018, Improving oil recovery by use of carbon dioxide in the Bakken unconventional system—a laboratory investigation: SPE Reservoir Evaluation & Engineering, v. 20, no. 3, p. 602–612.

Peck, W.D., Azzolina, N.A., Ge, J., Bosshart, N.W., Burton-Kelly, M.E., Gorecki, C.D., Gorz, A.J., Ayash, S.C., Nakles, D.V., and Melzer, L.S., 2018, Quantifying CO_2 storage efficiency factors in hydrocarbon reservoirs—a detailed look at CO_2 enhanced oil recovery: International Journal of Greenhouse Gas Control, v. 69, p. 41–51.

Jin, L., Hawthorne, S.B., Sorensen, J.A., Pekot, L.J., Kurz, B.A., Smith, S.A., Heebink, L.V., Herdegen, V., Bosshart, N.W., Torres, J., Dalkhaa, C., Peterson, K.J., Gorecki, C.D., Steadman, E.N., and Harju, J.A., 2017, Advancing CO_2 enhanced oil recovery and storage in unconventional oil play—experimental studies on Bakken shales: Applied Energy, v. 208, p. 171–183.

Azzolina, N.A., Peck, W.D., Hamling, J.A., Gorecki, C.D., Ayash, S.C., Doll, T.E., Nakles, D.V., and Melzer, L.S., 2016, How green is my oil? a detailed look at greenhouse gas accounting for CO_2-enhanced oil recovery (CO_2-EOR) sites: International Journal of Greenhouse Gas Control, v. 51, p. 369–379.

Levine, J.S., Fukai, I., Soeder, D.J., Bromhal, G., Dilmore, R.M., Guthrie, G.D., Rodosta, T.D., Sanguinito, S., Frailey, S., Gorecki, C.D., Peck, W.D., and Goodman, A.L., 2016, U.S. DOE NETL methodology for estimating the prospective CO_2 storage resource of shales at the national and regional scale: International Journal of Greenhouse Gas Control, v. 51, p. 81–94.

Ge, J., Bosshart, N.W., Pekot, J.J., Kurz, B.A., Gorecki, C.D., He, J., and Oster, B.S., 2018, Modeling and simulation of the Inyan Kara Formation to estimate saltwater disposal potential—final report: Final report for the North Dakota Industrial Commission, North Dakota Oil and Gas Research Program, and

members of the Bakken Production Optimization Program Consortium (BPOP 2.0), EERC Publication 2018-EERC-04-16, Grand Forks, North Dakota, Energy & Environmental Research Center, April.

Gorecki, C.D., Sorensen, J.A., Kurz, B.A., Wocken, C.A., Harju, J.A., Kalk, B.P., Dalkhaa, C., Hawthorne, S.B., Heebink, L.V., Kurz, M.C., Martin, C.L., Romuld, L., Stevens, B.G., and Torres, J.A., 2018, Bakken Production Optimization Program 2.0: Annual progress report (October 1, 2017 – September 30, 2018) for North Dakota Industrial Commission Contract No. G-040-080, Grand Forks, North Dakota, Energy & Environmental Research Center, October.

Kurz, B.A., Jiang, T., Wocken, C.A., Peck, W.D., Schlasner, S.M., Oster, B.S., Bosshart, N.W., McRae, T.A., Gorecki, C.D., Harju, J.A., and Steadman, E.N., 2018, Evaluation of subsurface produced gas injection: Final report for North Dakota Industrial Commission Contract No. G-000-004, EERC Publication 2018-EERC-12-03, Grand Forks, North Dakota, Energy & Environmental Research Center, December.

Sorensen, J.A., Hawthorne, S.B., Jin, L., Bosshart, N.W., Torres, J.A., Azzolina, N.A., Kurz, B.A., Smith, S.A., Jacobson, L.L., Doll, T.E., Gorecki, C.D., Harju, J.A., and Steadman, E.N., 2018, Bakken CO_2 Storage and Enhanced Recovery Program – phase II: Final report for U.S. Department of Energy National Energy Technology Laboratory Cooperative Agreement No. DE-FC26-08NT43291, XTO Energy, Hess Corporation, Marathon Oil Company, Continental Resources, and North Dakota Industrial Commission - Oil & Gas Research Program; Grand Forks, North Dakota, Energy & Environmental Research Center, April.

JOHN A. HARJU
Vice President for Strategic Partnerships
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, North Dakota 58202-9018 USA
701.777.5157 (phone), 701.777.5181 (fax), jharju@undeerc.org

Principal Areas of Expertise

Mr. Harju's principal areas of interest and expertise include carbon sequestration, enhanced oil recovery, unconventional oil and gas development, waste management, geochemistry, technology development, hydrology, and analytical chemistry, especially as applied to the upstream oil and gas industry.

Qualifications

B.S., Geology, University of North Dakota, 1986. Postgraduate coursework in Management, Economics, Marketing, Education, Climatology, Weathering and Soils, Geochemistry, Geochemical Modeling, Hydrogeochemistry, Hydrogeology, Contaminant Hydrogeology, Advanced Physical Hydrogeology, and Geostatistics.

Professional Experience

2002–Present: EERC, UND.

July 2015–Present: Vice President for Strategic Partnerships. Mr. Harju leads efforts to build and grow dynamic working relationships with industry, government, and research entities globally in support of the EERC's mission to provide practical, pioneering solutions to the world's energy and environmental challenges. He represents the EERC regionally, nationally, and internationally in advancing its core research priorities: coal utilization and emissions, carbon management, oil and gas, alternative fuels and renewable energy, and energy–water.

2003–June 2015: Associate Director for Research. Mr. Harju led a team of scientists and engineers building industry–government–academic partnerships to carry out research, development, demonstration, and commercialization of energy and environmental technologies.

2002–2003: Senior Research Advisor. Mr. Harju developed, marketed, managed, and disseminated research programs focused on the environmental and health effects of power and natural resource production, contaminant cleanup, water management, and analytical techniques.

2017–Present: Adjunct Lecturer, Department of Petroleum Engineering, UND.

1999–2002: Vice President, Crystal Solutions, LLC, Laramie, WY. Mr. Harju's firm was involved in commercial E&P produced water management, regulatory permitting and compliance, and environmental impact monitoring and analysis.

1997–2002: Gas Research Institute (GRI) (now Gas Technology Institute [GTI]), Chicago, IL.

2000–2002: Principal Scientist, Produced Water Management. Mr. Harju developed and deployed produced water management technologies and methodologies for cost-effective and environmentally responsible management of oil and gas produced water.

1998–2000: Program Team Leader, Soil, Water, and Waste. Mr. Harju managed projects and programs related to the development of environmental technologies and informational products related to the North American oil and gas industry; formulated RFPs, reviewed proposals, and formulated contracts; performed technology transfer activities; and supervised staff and contractors. He served as Manager of the Environmentally Acceptable Endpoints project, a multiyear program focused on rigorous determination of appropriate cleanup levels for hydrocarbons and other energy-derived contaminants in soils. He led GRI/GTI involvement with industry environmental consortia and organizations, such as PERF, SPE, AGA, IPEC, and API.

1997–1998: Principal Technology Manager (1997–1998) and Associate Technology Manager (1997), Soil and Water Quality.

1988–1996: EERC, UND.
1994–1996: Senior Research Manager, Oil and Gas Group. Mr. Harju served as:
- Program Manager for assessment of the environmental transport and fate of oil- and gas-derived contaminants, focused on mercury and sweetening and dehydration processes.
- Project Manager for field demonstration of innovative produced water treatment technology using freeze crystallization and evaporation at oil and gas industry site.
- Program Manager for environmental transport and fate assessment of MEA and its degradation compounds at Canadian sour gas-processing site.
- Program Manager for demonstration of unique design for oil and gas surface impoundments.
- Director of the National Mine Land Reclamation Center for the Western Region.
- Co-PI on project exploring feasibility of underground coal gasification in southern Thailand.
- Consultant to an International Atomic Energy Agency program entitled "Solid Wastes and Disposal Methods Associated with Electricity Generation Fuel Chains."

1988–1994: Research Manager (1994), Hydrogeologist (1990–1994), Research Specialist (1989–1990), and Laboratory Technician (1988–1989).

Professional Memberships
National Coal Council (appointed 2018)
National Petroleum Council (appointed 2010)
Mainstream Investors, LLC, Board of Governors (2014–present)
DOE Unconventional Resources Technology Advisory Committee (2012–2014)
Interstate Oil and Gas Compact Commission (appointed 2010)
Rocky Mountain Association of Geologists

Selected Publications
Has authored or coauthored more than 100 professional publications and nearly 300 technical presentations, including the following:

Jin, L., Sorensen, J.A., Hawthorne, S.B., Smith, S.A., Pekot, L.J., Bosshart, N.W., Burton-Kelly, M.E., Miller, D.J., Grabanski, C.B., Gorecki, C.D., Steadman, E.N., and Harju, J.A., 2018, Improving oil recovery by use of carbon dioxide in the Bakken unconventional system—a laboratory investigation: SPE Reservoir Evaluation & Engineering, v. 20, no. 3, p. 602–612.

Schnacke, J.G., Harju, J.A., Hamling, J.A., Sorensen, J.A., and Wildgust, N., 2018, Carbon capture boosting oil recovery: The American Oil & Gas Reporter, v. 61, no. 9, p. 95–99.

Harju, J.A., 2018, The Bakken Optimization Program 2.0 Update: Presented to the North Dakota Oil & Gas Research Council, Bismarck, North Dakota, May 2, 2018.

Harju, J.A., 2017, The Bakken Production Optimization Program – achievements to date and a look forward: Presented to the North Dakota Oil & Gas Research Council, Bismarck, North Dakota, January 12, 2017.

Harju, J.A., Wocken, C.A., Stevens, B.G., Almlie, J.C., and Schlasner, S.M., 2012, End-use technology study – an assessment of alternative uses for associated gas: Presentation for the North Dakota Pipeline Authority Natural Gas End-Use Technology Study Webinar, November 5, 2012.

Kurz, B.A., Jiang, T., Wocken, C.A., Peck, W.D., Schlasner, S.M., Oster, B.S., Bosshart, N.W., McRae, T.A., Gorecki, C.D., Harju, J.A., and Steadman, E.N., 2018, Evaluation of subsurface produced gas injection: Final report for North Dakota Industrial Commission Contract No. G-000-004, EERC Publication 2018-EERC-12-03, Grand Forks, North Dakota, Energy & Environmental Research Center, December.

Gorecki, C.D., Sorensen, J.A., Kurz, B.A., Wocken, C.A., Harju, J.A., Kalk, B.P., Dalkhaa, C., Hawthorne, S.B., Heebink, L.V., Kurz, M.C., Martin, C.L., Romuld, L., Stevens, B.G., and Torres, J.A., 2018, Bakken Production Optimization Program 2.0: Annual progress report (October 1, 2017 – September 30, 2018) for North Dakota Industrial Commission Contract No. G-040-080, Grand Forks, North Dakota, Energy & Environmental Research Center, October.

Sorensen, J.A., Hawthorne, S.B., Jin, L., Bosshart, N.W., Torres, J.A., Azzolina, N.A., Kurz, B.A., Smith, S.A., Jacobson, L.L., Doll, T.E., Gorecki, C.D., Harju, J.A., and Steadman, E.N., 2018, Bakken CO_2 Storage and Enhanced Recovery Program – phase II: Final report for U.S. Department of Energy National Energy Technology Laboratory Cooperative Agreement No. DE-FC26-08NT43291, XTO Energy, Hess Corporation, Marathon Oil Company, Continental Resources, and North Dakota Industrial Commission - Oil & Gas Research Program; Grand Forks, North Dakota, Energy & Environmental Research Center, April.

Energy & Environmental Research Center, 2017, Bakken Production Optimization Program: Final report Years 1–3 (2013–2016) for North Dakota Industrial Commission Contract No. G-030-060, Grand Forks, North Dakota, Energy & Environmental Research Center, January.

Energy & Environmental Research Center, 2015, Liquids gathering pipelines—a comprehensive analysis: Report for the North Dakota Industrial Commission and the North Dakota Legislative Energy Development and Transmission Committee, Grand Forks, North Dakota, Energy & Environmental Research Center, December.

Sorensen, J.A., Hawthorne, S.B., Smith, S.A., Braunberger, J.R., Liu, G., Klenner, R.C.L., Botnen, L.S., Steadman, E.N., Harju, J.A., and Doll, T.E., 2014, CO_2 Storage and Enhanced Bakken Recovery Research Program: Final report (May 1, 2013 – May 31, 2013) for North Dakota Industrial Commission, EERC Publication 2014-EERC-06-23, Continental Resources, Inc., EERC Publication 2014-EERC-06-24, and Marathon Oil Company, EERC Publication 2014-EERC-06-25, Grand Forks, North Dakota, Energy & Environmental Research Center, June.

LOREAL V. HEEBINK
Senior Project Management Specialist
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, North Dakota 58202-9018 USA
701.777.5116 (phone), 701.777.5181 (fax), lheebink@undeerc.org

Principal Areas of Expertise

Ms. Heebink's principal areas of interest and expertise include assisting in the planning, development, and management of projects related to core assessment, carbon storage and/or CO_2-based enhanced oil recovery (EOR), and beneficial use of wastes and data management and interpretation. She is responsible for progress reporting under the U.S. Department of Energy's Plains CO_2 Reduction (PCOR) Partnership, the Bakken Production Optimization Program (BPOP), and other projects. She develops management and tracking systems for projects and groups at the EERC.

Qualifications

B.S., Chemistry, Magna Cum Laude, University of North Dakota, 2000.
A.S., Chemistry, Summa Cum Laude, Minot State University–Bottineau, Bottineau, North Dakota, 1997.
Certification: Smartsheet Solution Certified User

Professional Experience

2015–Present: Senior Project Management Specialist, EERC, UND. Ms. Heebink is responsible for assisting in the planning, development, and management of projects related to core assessment, carbon storage and/or CO_2-based EOR, and beneficial use of oilfield wastes. She is responsible for progress reporting under DOE's PCOR Partnership, BPOP, and other projects. Her duties continue to include tracking project activities and deliverables, assisting in the workflow management of the Applied Geology Laboratory, technical report writing, data management and interpretation, data sheet generation, and database development and maintenance.

2012–2015: Research Chemist, EERC, UND. Ms. Heebink's responsibilities were focused on assisting in the workflow management of the Applied Geology Laboratory, technical report writing, data management and interpretation, and data sheet generation. Additional activities included database development and maintenance, beneficial use evaluations, Karl Fischer titrations, helium porosimetry, 3-D scanning for bulk volume, Dean–Stark and Soxhlet extraction techniques, and investigation of carbon dioxide mineralization materials.

2000–2012: Research Chemist, Coal Combustion Product Research, EERC, UND. Ms. Heebink's responsibilities included research focused primarily on the environmental impacts of CCP use and disposal, ultratrace mercury analysis, data interpretation and management, and sample inventory management. She managed the research efforts of the Coal Ash Resources Research Consortium® (CARRC®) from 2010–2012 and other CCP research at the EERC. She also managed several research projects concurrently and was responsible for the technical oversight and fund management of these projects. Areas of interest and expertise included ash chemistry, leaching procedures, ultratrace mercury analysis with a double-gold amalgamation atomic fluorescence apparatus, and database development and maintenance.

1997–1999: Stockroom Assistant, Department of Chemistry, UND. Ms. Heebink's responsibilities included preparing solutions weekly for classroom laboratories, assisting students and instructors with chemicals, and organization of the stockroom.

Selected Publications

Azenkeng, A.; Mibeck, B.A.F.; Eylands, K.E.; Butler, S.K.; Kurz, B.A.; Heebink, L.V. Advanced Characterization of Unconventional Oil and Gas Reservoirs to Enhance CO_2 Storage Resource Estimates – Organic Structure and Porosity of Organic-Rich Shales. Presented at Mastering the Subsurface Through Technology Innovation, Partnerships & Collaboration: Carbon Storage & Oil & Natural Gas Technologies Review Meeting, Pittsburgh, PA, Aug 1–3, 2017.

Jin, L.; Hawthorne, S.B.; Sorensen, J.A.; Pekot, L.J.; Kurz, B.A.; Smith, S.A.; Heebink, L.V.; Herdegen, V.; Bosshart, N.W.; Torres, J.; Dalkhaa, C.; Peterson, K.J.; Gorecki, C.D.; Steadman, E.N.; Harju, J.A., Advancing CO_2 Enhanced Oil Recovery and Storage in Unconventional Oil Play—Experimental Studies on Bakken Shales. *Applied Energy* **2017,** *208*, 171–183.

Jin, L.; Hawthorne, S.B.; Sorensen, J.A.; Pekot, L.J.; Kurz, B.A.; Smith, S.A.; Heebink, L.V.; Bosshart, N.W.; Torres, J.A.; Dalkhaa, C.; Gorecki, C.D.; Steadman, E.N.; Harju, J.A. Extraction of Oil from the Bakken Shales with Supercritical CO_2. Paper presented at the 2017 Unconventional Resources Technology Conference, Austin, TX, July 24–26, 2017; URTeC Paper No. 2671596.

Wildgust, N.; Gorecki, C.D.; Ayash, S.C.; Peck, W.D.; Hamling, J.A.; Sorensen, J.A.; Daly, D.J.; Jensen, M.D.; Klapperich, R.J.; Heebink, L.V.; Pekot, L.J.; Steadman, E.N.; Harju, J.A. Demonstration of Secure CO_2 Geological Storage Associated with Enhanced Oil Recovery in the PCOR Partnership Region. Presented at the Carbon Management Technology Conference 2017, Houston, TX, July 17–20, 2017.

Azenkeng, A.; Kurz, B.A.; Mibeck, B.A.F.; Smith, S.A.; Butler, S.K.; Eylands, K.E.; Beddoe, C.J.; Heebink, L.V.; Gorecki, C.D. *Subtask 1.1 – Advanced Characterization of Unconventional Oil and Gas Reservoirs to Enhance CO_2 Storage Resources Estimates*; Final Report for U.S. Department of Energy National Energy Technology Laboratory Cooperative Agreement No. DE-F0024233; EERC Publication 2019-EERC-04-07; Energy & Environmental Research Center: Grand Forks, ND, April 2019.

Gorecki, C.D.; Sorensen, J.A.; Kurz, B.A.; Wocken, C.A.; Harju, J.A.; Dalkhaa, C.; Hawthorne, S.B.; Heebink, L.V.; Kurz, M.C.; Azzolina, N.A.; Chakhmakhchev, A.; Martin, C.L.; Romuld, L.; Stevens, B.G. *Bakken Production Optimization Program 2.0*; Annual Progress Report (Oct 1, 2018 – Sept 30, 2019) for North Dakota Industrial Commission Contract No. G-040-080; Energy & Environmental Research Center: Grand Forks, ND, Oct 2019.

Gorecki, C.D.; Sorensen, J.A.; Kurz, B.A.; Wocken, C.A.; Harju, J.A.; Kalk, B.P.; Dalkhaa, C.; Hawthorne, S.B.; Heebink, L.V.; Kurz, M.C.; Martin, C.L.; Romuld, L.; Stevens, B.G.; Torres, J.A. *Bakken Production Optimization Program 2.0*; Annual Progress Report (Oct 1, 2017 – Sept 30, 2018) for North Dakota Industrial Commission Contract No. G-040-080; Energy & Environmental Research Center: Grand Forks, ND, Oct 2018.

Gorecki, C.D.; Harju, J.A.; Steadman, E.N.; Heebink, L.V.; Romuld, L.; Hamling, J.A.; Sorensen, J.A.; Pekot, L.J.; Daly, D.J.; Jensen, M.D.; Peck, W.D.; Klapperich, R.J.; Bosshart, N.W.; Votava, T.F.; Ayash, S.C.; Ensrud, J.R. *Annual Assessment Report*; Plains CO_2 Reduction (PCOR) Partnership Phase III Task 12 Deliverable D57 (Oct 1, 2016 – Sept 30, 2017) for U.S. Department of Energy National Energy Technology Laboratory Cooperative Agreement No. DE-FC26-05NT42592; EERC Publication 2018-EERC-01-06; Energy & Environmental Research Center: Grand Forks, ND, Dec 2017.

Sorensen, J.A.; Smith, S.A.; Kurz, B.A.; Hawthorne, S.B.; Jin, L.; Bosshart, N.W.; Torres Rivero, J.A.; Nyberg, C.M.; Heebink, L.V.; Butler, S.K. *Improved Characterization and Modeling of Tight Oil Formations for CO_2 Enhanced Oil Recovery Potential and Storage Capacity Estimation*; Final Report for U.S. Department of Energy National Energy Technology Laboratory Cooperative Agreement No. DE-FE0024454; EERC Publication 2018-EERC-03-04; and North Dakota Industrial Commission; EERC Publication 2017-EERC-12-01; Energy & Environmental Research Center: Grand Forks, ND, Dec 2017.

BETHANY A. KURZ
Assistant Director for Integrated Analytical Solutions
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
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Principal Areas of Expertise

Ms. Kurz' principal areas of expertise include geologic and geochemical characterization of subsurface media for produced gas- or CO_2-based enhanced oil recovery and storage; produced water and drilling waste management; assessment of high-value materials in coal and produced brine; and resource management related to energy development.

Qualifications

M.S., Hydrogeology, University of North Dakota, Grand Forks, ND, 1998.
B.S., Geochemistry, Bridgewater State University, Bridgewater, MA, 1995.

Professional Experience

July 2018–Present: Assistant Director for Integrated Analytical Solutions, EERC, UND. Assists the EERC's management team with developing business opportunities and successfully executing research projects related to oil and gas; natural resource management; and carbon capture, utilization, and storage. Oversees a multidisciplinary team of scientists and engineers who work in the EERC's applied research laboratories, ensuring the quality assurance/quality control of data and results generated by the EERC's laboratories and integrating those results into the applied research efforts conducted by the Subsurface R&D team. Specific activities include the following:

- Currently managing a U.S. Department of Energy National Energy Technology Laboratory-funded effort (Cooperative Agreement No. DE-FE0024233) to use field emission scanning electron microscopy (FESEM) and advanced image analysis to quantify the occurrence of organic matter and clays in the Bakken petroleum system, including their relationship to pore and fracture networks.
- Ongoing management and oversight of multiple laboratory-based efforts to characterize and evaluate the Bakken petroleum system for enhanced oil recovery using supercritical CO_2 and produced hydrocarbon gas.
- Ongoing management of laboratory-based testing of organic-rich shales to support CO_2- and rich gas-based enhanced oil recovery field trials in collaboration with oil and gas industry partners.

2011–July 2018: Principal Hydrogeologist, Laboratory Analysis Group Lead, EERC, UND. Oversaw a multidisciplinary team of scientists and engineers and several of the EERC's analytical research laboratories that focus on classical and advanced wet-chemistry analyses; petrochemical, geochemical, and geomechanical evaluation of rocks and soils; and advanced characterization of various materials, including metals, alloys, catalysts, and corrosion and scale products. Primary areas of interest included evaluation of water supply sources for the oil and gas industry, produced water management, characterization of geologic media for EOR and/or carbon storage, and development and testing of proppants for use in hydraulic fracturing.

2002–2011: Senior Research Manager, Water Management and Flood Mitigation Strategies, EERC. Managed projects, wrote technical reports and proposals, and participated in public outreach and the development of new research focus areas. Research activities included the evaluation of nontraditional water supply sources for municipal and industrial use, flood and drought mitigation, watershed-scale water quality assessments using hydrologic models, and public education and outreach on various water and energy issues.

1998–2002: Research Scientist, Subsurface Remediation Research, EERC. Managed and conducted research involving remediation technologies for contaminated groundwater and soils and performed groundwater sampling and analysis, technical report writing, and proposal research and preparation.

Professional Memberships

Member, Society of Petroleum Engineers.

Served on a National Petroleum Council subcommittee to evaluate and summarize technological improvements that reduce the potential environmental impacts of hydraulic fracturing.

Selected Publications

Kurz, B.A., Sorensen, J.A., Hawthorne, S.B., Smith, S.A., Sanei, H., Ardakani, O., Walls, J., Jin, L., Butler, S.K., Beddoe, C.J., and Mibeck, B.A.F., 2018, The influence of organics on supercritical CO_2 migration in organic-rich shales: Presented at the Unconventional Resources Technology Conference, Houston, Texas, July 23–25, 2018, URTeC Paper No. 2902743.

Sorensen, J.A., and Kurz, B.A., 2018, Taking EOR from the lab to the field – case studies in the Bakken: Presented at the SPE Workshop—Shale Development Optimization – The Quest for Efficiency and Profitability Continues, San Antonio, Texas, May 8–10, 2018.

Smith, S.A., Beddoe, C.L., Mibeck, B.A.F., Heebink, L.V., Kurz, B.A., Peck, W.D., and Jin, L., 2017, Relative permeability of Williston Basin CO_2 storage targets: Energy Procedia, v. 114, p. 2957–2971.

Sorensen, J.A., Kurz, B.A., Hawthorne, S.B., Jin, L., Smith, S.A., and Azenkeng, A., 2017, Laboratory characterization and modeling to examine CO_2 storage and enhanced oil recovery in an unconventional tight oil formation: Energy Procedia, v. 114, p. 5460–5478.

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JAMES A. SORENSEN
Director for Subsurface R&D
Energy & Environmental Research Center (EERC), University of North Dakota (UND)
15 North 23rd Street, Stop 9018, Grand Forks, North Dakota 58202-9018 USA
701.777.5287 (phone), 701.777.5181 (fax), jsorensen@undeerc.org

Principal Areas of Expertise
Mr. Sorensen's primary areas of interest and expertise are enhanced oil recovery (EOR) in unconventional tight oil formations, CO_2 utilization and storage in geologic formations, and tight oil resource assessment and development.

Education
B.S., Geology, University of North Dakota, 1991.
Postgraduate course work in Geology and Hydrogeology, 1993–1995.

Professional Experience
October 2019–Present: Director of Subsurface R&D, EERC, UND. Mr. Sorensen is responsible for developing and managing programs and projects focused on conventional, unconventional, and enhanced oil and gas production; the geological storage of CO_2; geothermal; and other energy and environmental research.

July 2018–September 2019: Assistant Director for Subsurface Strategies, EERC, UND. Mr. Sorensen developed business opportunities, provided technical support and guidance regarding emerging areas of research, and served as a principal investigator and task manager for projects related to the sequestration of CO_2 in geologic media and the sustainable development of tight oil resources.

1999–July 2018: Principal Geologist, EERC, UND. Mr. Sorensen served as manager and co-principal investigator for programs to develop strategies for CO_2 utilization and storage. He also led research focused on enhanced oil recovery (EOR) in the Bakken.

1997–1999: Program Manager, EERC, UND. Mr. Sorensen managed projects focused on produced water management and environmental fate of natural gas-processing chemicals.

1993–1997: Geologist, EERC, UND. Mr. Sorensen conducted field-based hydrogeologic investigations focused on natural gas production sites.

1991–1993: Research Specialist, EERC, UND. Mr. Sorensen assembled and maintained comprehensive databases related to oil and gas drilling, production, and waste management.

Professional Memberships
Society of Petroleum Engineers

Selected Publications
Has coauthored nearly 200 publications, including the following:

Jin, L., Sorensen, J.A., Hawthorne, S.B., Smith, S.A., Pekot, L.J., Bosshart, N.W., Burton-Kelly, M.E., Miller, D.J., Grabanski, C.B., Gorecki, C.D., Steadman, E.N., and Harju, J.A., 2018, Improving oil

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Jin, L., Hawthorne, S.B., Sorensen, J.A., Pekot, L.J., Bosshart, N.W., Gorecki, C.D., Steadman, E.N., and Harju, J.A., 2017, Utilization of produced gas for improved oil recovery and reduced emissions from the Bakken Formation: Presented at the 2017 SPE Health, Safety, Security, Environment & Social Responsibility Conference – North America, New Orleans, Louisiana, April 18–20, 2017, SPE-184414-MS.

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CHAD A. WOCKEN
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Energy & Environmental Research Center (EERC), University of North Dakota (UND)
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701.777.5273 (phone), 701.777.5181 (fax), cwocken@undeerc.org

Principal Areas of Expertise

Mr. Wocken's principal areas of research include developing alternative fuel and chemical processes and innovative energy technologies. Currently, he is leading projects focused on developing and advancing alternative chemical and fuel production processes at the bench, lab, and pilot scale; and optimizing processes associated with oil and gas production and midstream operations. Mr. Wocken currently manages a group of researchers and a lab facility containing batch and continuous reactor systems capable of testing a variety of thermochemical processes.

Qualifications

B.S., Chemical Engineering, University of North Dakota, 1994.
Certifications: U.S. Army Corps of Engineers Construction Quality Management, 40-hr OSHA Health and Safety, 8-hr HAZWOPER Supervisor, 10-hr Construction Safety and Health.

Professional Experience

September 2019–Present: Assistant Director for Transformational Energy, EERC, UND. Mr. Wocken leads projects related to oil and gas processing, alternative fuel development, and process optimization. His activities include research and development of technologies at the bench, pilot, and field demonstration scale.

2009–August 2019: Principal Engineer, Transformational Energy Group Lead (2009–September 2015, Senior Research Manager; 2001–2009, Research Engineer), EERC, UND.

Project/Program Management

- Created a process-modeling team within the EERC's Bakken Production Optimization Program, focused on applying computational modeling expertise to oil well production processes. Modeling activities are focused on addressing the competing goals of reduced fugitive emissions and gas flaring while also reducing crude oil volatility.
- Directed the EERC's associated gas-flaring mitigation activities, aiding industry partners in their efforts to identify technologies to reduce flaring. These efforts led to the creation of the Flaring Solutions Database, a clearinghouse of business and technology solutions that have the potential to utilize gas at the wellhead and reduce flaring.
- Comanaged a Defense Advanced Research Projects Agency (DARPA)-funded project that successfully developed technology to produce drop-in compatible jet fuel for the military from renewable feedstock. Activities included planning work activities, developing and executing a risk-based project management plan, coordinating activities of five project partners to meet project goals, and communicating with the DARPA project manager.
- Managed the scale-up and design of a 300-barrel/day renewable fuel pilot plant capable of producing specification-compliant jet and diesel fuels from renewable oil feedstock.

Technology Development and Research

- Designed and executed an oil and gas gathering pipeline leak detection demonstration project, resulting in tangible performance improvements for three pipeline operators.
- Conducted a technical and economic assessment of alternative uses for associated gas in an effort to reduce the amount of gas being flared in the Williston Basin. Technologies evaluated included gas-processing operations to recover natural gas liquids, the use of rich gas in internal combustion engines for transportation and power, and traditional petrochemical unit operations.
- Performed a system-level engineering evaluation of integrated algae production at a coal-fired power plant to assess carbon uptake, emission control requirements, relative scale, and the viability of water and waste heat utilization.
- Designed, fabricated, and operated several fixed-catalyst bed reactor systems to evaluate a variety of thermocatalytic processes to produce renewable fuels and chemicals.
- Conducted testing at coal-fired power plants, and developed control technologies to reduce atmospheric emission of particulate matter, mercury, and other contaminants.

1995–2001: Project Engineer, URS/Radian International, Salt Lake City, Utah (1997–2001), and Milwaukee, Wisconsin (1995–1997).

Process Design, Operation, and Optimization

- Designed groundwater remediation systems to remove BTEX compounds and chlorinated solvents from groundwater. The projects consisted of site evaluation, technology selection and design of several groundwater circulation wells, air sparge/soil vapor extraction treatment systems, and groundwater extraction with air stripper treatment technology. Design aspects included mass balance calculations, equipment design (pumps, pipe sizing, blowers, filters, etc.), equipment selection and specification, bid/construction specifications, and design drawing development.
- Performed start-up and long-term operations for a variety of groundwater remediation systems. Responsibilities included troubleshooting equipment/system malfunctions, process optimization, writing operations and maintenance manuals, establishing performance verification criteria, defining operational cost, and directing technicians' work.
- Conducted detailed reviews of industrial wastewater treatment systems to identify alternative treatment technologies, process optimizations, cost-saving measures, water reuse and zero discharge alternatives, and regulatory considerations.

Construction Oversight

- Provided on-site quality control oversight for several construction projects consisting of mechanical equipment installation, instrumentation and process control, building and road construction, excavation, and underground utility installation. Daily responsibilities included evaluating work for conformance with construction drawings and specifications; conducting progress meetings; coordinating subcontractor work activities; and facilitating communication between the design firm, client, and subcontractors.

Project Management

- Served as project manager for several large projects that were completed successfully. Activities included developing cost proposals, managing budget and schedule, equipment and subcontractor acquisition, and maintaining effective communication with the client.

1994–1995: Process Engineer, Archer Daniels Midland, Clinton, Iowa.

Plant Operation

- Supervised operations and personnel at a wet corn mill oil extraction and refining plant. Tasks consisted of prioritizing work activities, scheduling maintenance and repairing process equipment, reviewing quality control, and extensive system troubleshooting and failure analysis.

Selected Publications

Energy & Environmental Research Center. *Liquids Gathering Pipelines: A Comprehensive Analysis*; Report for the North Dakota Industrial Commission and the North Dakota Legislative Energy Development and Transmission Committee; Energy & Environmental Research Center: Grand Forks, ND, Dec 2015.

Lord, D.; Luketa, A; Wocken, C.A.; Schlasner, S.; Aulich, T.R.; Allen, R.; Rudeen, D. *Literature Survey of Crude Oil Properties Relevant to Handling and Fire Safety in Transport*; Sandia Report No. SAND2015-1823; Sandia National Laboratories: Albuquerque, NM, and Livermore, CA, March 2015.

Zhang, X.; Scheving, B.; Shoghli, B.; Zygarlicke, C.J.; Wocken, C.A. Quantifying Gas Flaring CH_4 Consumption Using VIIRS. *Remote Sens.* **2015,** *7*, 9529–9541; doi:10.3390/rs70809529.

Stevens, B.G.; Wocken, C.A. Associated Gas Flaring in North Dakota and Opportunities for Remote Capture and Utilization. Presented at the Williston Basin Society of Petroleum Engineers Meeting, Minot, ND, April 24, 2014. Wocken, C.A. Assessment of Remote Capture Technologies to Improve Gas Utilization. Presented at the 2014 Williston Basin Petroleum Conference, Bismarck, ND, May 20–22, 2014.

Wocken, C.A.; Dunham, G.E.; Doll, T.E. Utilization of Associated Gas to Power Drilling Rigs – A Demonstration in the Bakken. Presented at the 21st Williston Basin Petroleum Conference, Regina, SK, April 30 – May 2, 2013.

Wocken, C.A. Utilization of Associated Gas to Power Drilling Rigs – A Demonstration in the Bakken. Webinar for the North Dakota Pipeline Authority, Feb 27, 2013.

Harju, J.A.; Wocken, C.A.; Stevens, B.G.; Almlie, J.C.; Schlasner, S.M. End-Use Technology Study – An Assessment of Alternative Uses for Associated Gas. Presentation for the North Dakota Pipeline Authority Natural Gas End-Use Technology Study Webinar, Nov 5, 2012.

Erickson, T.A.; Holmes, M.J.; Wocken, C.A. Future Issues and Opportunities for the Hydrogen Economy Workshop. Presented at North Dakota State College of Science, Wahpeton, ND, March 28, 2006.

APPENDIX D

LETTERS OF COMMITMENT

LIBERTY RESOURCES

October 21, 2019

Mr. John Harju
Vice President for Strategic Partnerships
Energy & Environmental Research Center
University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

Dear Mr. Harju:

Subject: Liberty Resources LLC – Cost-Share Contribution for the Project Entitled "Bakken Production and Optimization Program – 3.0"

Liberty Resources LLC (Liberty) is pleased to partner with the University of North Dakota Energy & Environmental Research Center (EERC) in the Bakken Production and Optimization Program (BPOP)– Phase III to develop knowledge that will support the optimization of oil production from the Bakken and Three Forks Formations in North Dakota.

Liberty will provide in-kind contributions that will enable this program to proceed. Specifically, Liberty will incur the costs to conduct an enhanced oil recovery (EOR) pilot test at a Bakken/Three Forks production location in North Dakota. As part of this project, Liberty anticipates it will incur the costs associated with acquisition of working fluids, compression, pilot design, well preparation, reservoir surveillance and monitoring, and pilot operations. Liberty has estimated the value of this in-kind contribution to be a minimum of $4,000,000. The EERC and Liberty technical teams will work closely and coordinate the efforts to maximize the value of Liberty's in-kind contribution. Liberty will report actual expenses to EERC on a quarterly basis.

Liberty understands that the key findings generated by these activities will be shared with other BPOP members during the performance period of the Phase III program. Liberty also recognizes that the key findings will be included in a report to BPOP sponsors that will be made publicly available through the North Dakota Industrial Commission (NDIC) upon completion of BPOP-3.0.

Liberty also understands that EERC will utilize the reported actual incurred costs for the purposes of documenting cost share required by the NDIC. The project period of performance is expected to be May 1, 2020 through April 30, 2023. This commitment assumes EERC is awarded the entire proposed amount from NDIC, and negotiation of appropriate terms and conditions for all parties, consistent with those established and carried out in the BPOP 2.0 effort.

Should you have any questions, please do not hesitate to contact me by phone at (303) 749-5732 or by e-mail at gordon.pospisil@libertyresourcesllc.com.

Sincerely,

Gordon Pospisil
Vice President of Business Development
Liberty Resources LLC

EERC
Energy & Environmental Research Center
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November 1, 2019

Ms. Karlene Fine
Executive Director and Secretary
North Dakota Industrial Commission
ATTN: Oil and Gas Research Program
State Capitol – 14th Floor
600 East Boulevard Avenue, Department 405
Bismarck, ND 58505-0840

Dear Ms. Fine:

Subject: Cost Share for EERC Proposal No. 2020-0073, Entitled "Bakken Production Optimization Program 3.0"

The Energy & Environmental Research Center (EERC) is conducting complementary research and development efforts under a multimillion-dollar 10-year Cooperative Agreement with the U.S. Department of Energy (DOE) National Energy Technology Laboratory (NETL), entitled "Joint Program on Research and Development for Fossil Energy-Related Resources." Through this joint program, nonfederal entities can team with the EERC and DOE on projects that address the goals and objectives of DOE's Office of Fossil Energy.

The proposed project to the North Dakota Industrial Commission Oil and Gas Research Program entitled "Bakken Production Optimization Program 3.0," is a viable candidate for funding under this program. Therefore, the EERC will secure $1,500,000 of cash cost share for the proposed project through its Cooperative Agreement with DOE, providing that NDIC commits $6,0000,000 of cash cost share and other industry partners provide at least $4,500,000 of cash and in-kind contributions.

As a cosponsor of the project, DOE would require access to all data generated and a royalty-free right to practice. However, certain project details can often be held confidential for some period of time.

Initiation of the proposed work is contingent upon the execution of a mutually negotiated agreement between the EERC and each of the project sponsors.

If you have any questions, please contact me by phone at (701) 777-5157 or by e-mail at jharju@undeerc.org.

Sincerely,

John A. Harju
Vice President for Strategic Partnerships

JAH/kal

APPENDIX E

BUDGET NOTES

BUDGET NOTES

BACKGROUND

The Energy & Environmental Research Center (EERC) is an independently organized multidisciplinary research center within the University of North Dakota (UND). The EERC is funded through federal and nonfederal grants, contracts, and other agreements. Although the EERC is not affiliated with any one academic department, university faculty may participate in a project, depending on the scope of work and expertise required to perform the project.

INTELLECTUAL PROPERTY

The applicable federal intellectual property (IP) regulations will govern any resulting research agreement(s). In the event that IP with the potential to generate revenue to which the EERC is entitled is developed under this project, such IP, including rights, title, interest, and obligations, may be transferred to the EERC Foundation, a separate legal entity.

BUDGET INFORMATION

The proposed work will be done on a cost-reimbursable basis. The distribution of costs between budget categories (labor, travel, supplies, equipment, etc.) and among funding sources of the same scope of work is for planning purposes only. The project manager may incur and allocate allowable project costs among the funding sources for this scope of work in accordance with Office of Management and Budget (OMB) Uniform Guidance 2 CFR 200.

Escalation of labor and EERC recharge center rates is incorporated into the budget when a project's duration extends beyond the university's current fiscal year (July 1 – June 30). Escalation is calculated by prorating an average annual increase over the anticipated life of the project.

The cost of this project is based on a specific start date indicated at the top of the EERC budget. Any delay in the start of this project may result in a budget increase. Budget category descriptions presented below are for informational purposes; some categories may not appear in the budget.

Salaries: Salary estimates are based on the scope of work and prior experience on projects of similar scope. The labor rate used for specifically identified personnel is the current hourly rate for that individual. The labor category rate is the average rate of a personnel group with similar job descriptions. Salary costs incurred are based on direct hourly effort on the project. Faculty who work on this project may be paid an amount over the normal base salary, creating an overload which is subject to limitation in accordance with university policy. As noted in the UND EERC Cost Accounting Standards Board Disclosure Statement, administrative salary and support costs which can be specifically identified to the project are direct-charged and not charged as facilities and administrative (F&A) costs. Costs for general support services such as contracts and IP, accounting, human resources, procurement, and clerical support of these functions are charged as F&A costs.

Fringe Benefits: Fringe benefits consist of two components which are budgeted as a percentage of direct labor. The first component is a fixed percentage approved annually by the UND cognizant audit agency, the Department of Health and Human Services. This portion of the rate covers vacation, holiday, and sick leave (VSL) and is applied to direct labor for permanent staff eligible for VSL benefits. Only the actual approved rate will be charged to the project. The second component is estimated on the basis of historical

data and is charged as actual expenses for items such as health, life, and unemployment insurance; social security; worker's compensation; and UND retirement contributions.

Travel: Travel may include site visits, fieldwork, meetings, and conferences. Travel costs are estimated and paid in accordance with OMB Uniform Guidance 2 CFR 200, Section 474, and UND travel policies, which can be found at http://und.edu/finance-operations (Policies & Procedures, A–Z Policy Index, Travel). Daily meal rates are based on U.S. General Services Administration (GSA) rates unless further limited by UND travel policies; other estimates such as airfare, lodging, ground transportation, and miscellaneous costs are based on a combination of historical costs and current market prices. Miscellaneous travel costs may include parking fees, Internet charges, long-distance phone, copies, faxes, shipping, and postage.

Equipment: The purchase of a crude oil analyzer is proposed, quoted at $65,797, capable of providing compositional information about the complex mixture that constitutes crude oil. This analyzer will provide data to support fluids characterization and computational modeling of wellsite process equipment. In addition, the purchase of a server, valued at $7000, is proposed to host software license files and GIS (geographic information system) data files and to support the operation of the data management system. The purchase of a high-end workstation quoted at $11,800 is proposed under the U.S. Department of Energy (DOE) match, which will ensure researchers have sufficient computer capacity to perform machine learning activities.

Supplies: Supplies include items and materials that are necessary for the research project and can be directly identified to the project. Supply and material estimates are based on prior experience with similar projects. Examples of supply items are chemicals, gases, glassware, nuts, bolts, piping, data storage, paper, memory, software, toner cartridges, maps, sample containers, minor equipment (value less than $5000), signage, safety items, subscriptions, books, and reference materials. General purpose office supplies (pencils, pens, paper clips, staples, Post-it notes, etc.) are included in the F&A cost.

Subcontracts: Not applicable.

Professional Fees: Not applicable.

Communications: Telephone, cell phone, and fax line charges are included in the F&A cost; however, direct project costs may include line charges at remote locations, long-distance telephone charges, postage, and other data or document transportation costs that can be directly identified to a project. Estimated costs are based on prior experience with similar projects.

Printing and Duplicating: Page rates are established annually by the university's duplicating center. Printing and duplicating costs are allocated to the appropriate funding source. Estimated costs are based on prior experience with similar projects.

Food: Expenditures for project partner meetings where the primary purpose is dissemination of technical information may include the cost of food. The project will not be charged for any costs exceeding the applicable GSA meal rate. EERC employees in attendance will not receive per diem reimbursement for meals that are paid by project funds. The estimated cost is based on the number and location of project partner meetings.

Professional Development: Fees are for memberships in technical areas directly related to work on this project. Technical journals and newsletters received as a result of a membership are used throughout the development and execution of the project by the research team.

Operating Fees: Operating fees generally include EERC recharge centers, outside laboratories, and freight.

EERC recharge center rates are established annually and approved by the university.

Laboratory and analytical recharge fees are charged on a per-sample, hourly, or daily rate. Additionally, laboratory analyses may be performed outside the university when necessary. The estimated cost is based on the test protocol required for the scope of work.

Graphics recharge fees are based on an hourly rate for production of such items as report figures, posters, and/or images for presentations, maps, schematics, Web site design, brochures, and photographs. The estimated cost is based on prior experience with similar projects.

Shop and operations recharge fees cover specific expenses related to the pilot plant and the required expertise of individuals who perform related activities. Fees may be incurred in the pilot plant, at remote locations, or in EERC laboratories whenever these particular skills are required. The rate includes such items as specialized safety training, personal safety items, fall protection harnesses and respirators, CPR certification, annual physicals, protective clothing/eyewear, research by-product disposal, equipment repairs, equipment safety inspections, and labor to direct these activities. The estimated cost is based on the number of hours budgeted for this group of individuals.

Engineering services recharge fees cover specific expenses related to retaining qualified and certified design and engineering personnel. The rate includes training to enhance skill sets and maintain certifications using Webinars and workshops. The rate also includes specialized safety training and related physicals. The estimated cost is based on the number of hours budgeted for this group of individuals.

Software solutions services recharge fees are for development of customized Web sites and interfaces, software applications development, data and financial management systems for comprehensive reporting and predictive analysis tools, and custom integration with existing systems. The estimated cost is based on prior experience with similar projects.

Freight expenditures generally occur for outgoing items and field sample shipments.

Facilities and Administrative Cost: The F&A rate proposed herein is approved by the U.S. Department of Health and Human Services and is applied to modified total direct costs (MTDC). MTDC is defined as total direct costs less individual capital expenditures, such as equipment or software costing $5000 or more with a useful life of greater than 1 year, as well as subawards in excess of the first $25,000 for each award.

Cost Share: The total estimated cost for the proposed effort is $12,000,000. $6,000,000 is requested from the Oil and Gas Research Program ($2,000,000/year). Cash cost share includes $1,500,000 from DOE along with $500,000 from industry partners. Liberty Resources, LLC, will provide in-kind cost share at a value of $4,000,000,