FINAL REPORT SUMMARY FOR
"BAKKEN PRODUCTION OPTIMIZATION PROGRAM"
INDUSTRIAL COMMISSION OF NORTH DAKOTA CONTRACT NO. G-030-060

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

BPOP was a premier public–private partnership harnessing the best minds in North Dakota and in industry. BPOP demonstrated how effective a public–private partnership can be. It demonstrated that researchers, state lawmakers, state regulators, and industry can work together for positive results for shareholders and taxpayers alike. 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.

BPOP conducted focused research in the areas of hydrocarbon utilization, water management, waste management, systems failure analysis, site logistics, spills remediation, and land reclamation. The centerpiece of BPOP was a massive project conducted by Continental to determine optimal well spacing within the Bakken. A small sampling of concrete examples of these impacts includes the following:

- Continental's Hawkinson Project, completed within BPOP, determined that the Bakken and Three Forks Formations represent unique and distinct reserves, which has enormous implications for current estimates of recoverable resources.
- BPOP facilitated a science-based process to determine if a change in rules regarding state drill spacing unit (DSU) setbacks was prudent, then supported state regulators in adopting the required changes. More oil will now be extracted from each DSU as a result of program efforts to justify a change in rules regarding the minimum distance between a well bore and the boundaries of each DSU.
- BPOP led an analysis of gas-flaring trends, and helped industry and the state of North Dakota determine appropriate flared gas reduction goals over a period of years. Program efforts to address flaring reduction resulted in new rules on flaring that were defined collaboratively, with industry and state interests working together.
- BPOP researchers provided science-based support to state regulators and industry during a critical discussion on how to best manage radiological waste associated with oil exploration and development.
- BPOP coordinated discussions with state regulators and industry groups on the topic of best practices for remediation of brine spills associated with oil development. BPOP then completed a best practices remediation manual with these groups.

The final report on this program summarizes BPOP achievements at the end of the original 3-year contract. The program continues as BPOP 2.0 during the period of November 2016 – October 2019. Many of the efforts begun under BPOP 1.0 will continue under BPOP 2.0.

Bakken Production Optimization Program

FINAL REPORT

Years 1–3 (2013–2016)

EERC

UND UNIVERSITY OF NORTH DAKOTA

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ACKNOWLEDGMENTS

The EERC would like to thank all state and industry program members for their active participation in this program. Without active engagement from all members, this program would not have been able to accomplish the numerous tangible, high-impact results described in this final report. Although the EERC led this effort, it could not have achieved success alone. The successes of this program were made possible only by enthusiastic participation of member companies and state agencies.

The EERC would specifically like to thank the following companies and North Dakota State agencies:

- ConocoPhillips Company
- Continental Resources, Inc.
- Hess Corporation
- Hitachi Data Systems
- Marathon Oil Corporation
- North Dakota Industrial Commission
- Nuverra Environmental Solutions, Inc.
- Oasis Petroleum Inc.
- Oil & Gas Research Council
- SM Energy Company
- Whiting Petroleum Corporation
- XTO Energy Inc.

Additionally, the program received extensive support, collaboration, and cooperation from the North Dakota Petroleum Council.

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BAKKEN PRODUCTION OPTIMIZATION PROGRAM

Final Report, Years 1–3 (2013–2016)

INTRODUCTION

In June 2013, a consortium comprising the Energy & Environmental Research Center (EERC); Continental Resources, Inc. (Continental); and several of the largest oil producers in the state was awarded North Dakota Oil and Gas Research Program funding to complete the 3-year, $117 million Bakken Production Optimization Program (BPOP), 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

BPOP comprised two major work segments. Continental was responsible for planning and execution of the Hawkinson Project, and the EERC led a number of activities under the umbrella of "optimization of wellsite operations," both of which are detailed in Figure 1.

BPOP was a premier public–private partnership harnessing North Dakota research scientists and industry to maximize productivity of the Bakken oil play while simultaneously reducing its environmental footprint. BPOP has demonstrated how effective a public–private partnership can be and that researchers, state lawmakers, state regulators, and industry can work together for positive results for shareholders and taxpayers alike.

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. The following is a small sampling of concrete examples of these impacts:

- The Hawkinson Project, completed within BPOP, determined that the Bakken and Three Forks Formations represent unique and distinct reserves, which has enormous implications for current estimates of recoverable resources.
- BPOP facilitated a science-based process to determine if a change in rules regarding state drill spacing unit (DSU) setbacks was prudent, then supported state regulators in adopting the required changes. More oil will now be

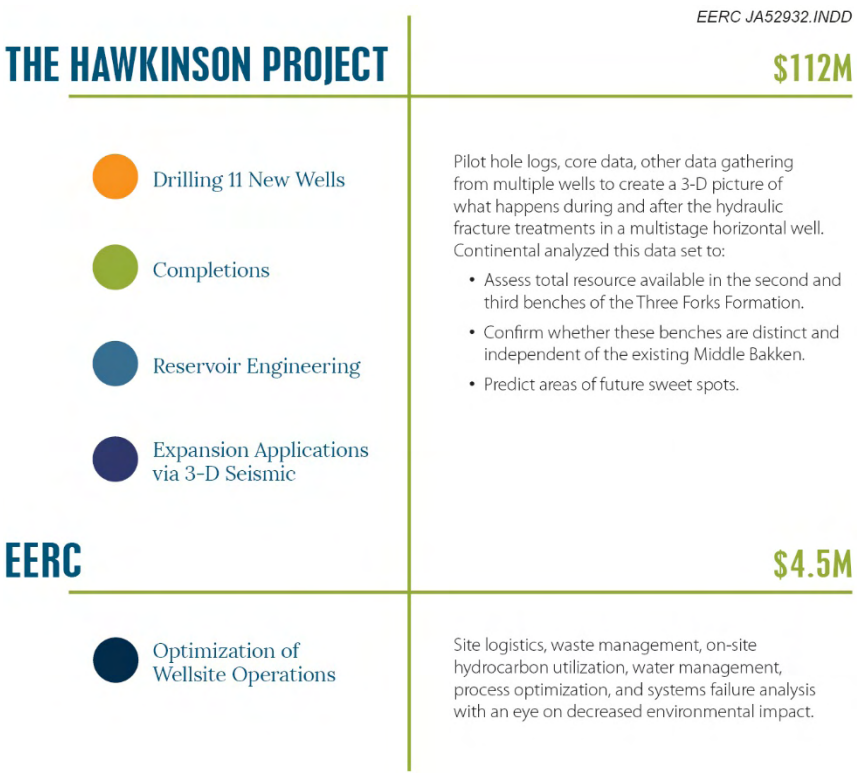

Figure 1. Overview of Bakken Production Optimization Program.

extracted from each DSU as a result of program efforts to justify a change in rules regarding the minimum distance between a well bore and the boundaries of each DSU.

- BPOP led an analysis of gas-flaring trends and helped industry and the state of North Dakota determine appropriate flared gas reduction goals over a period of years. Program efforts to address flaring reduction resulted in new rules on flaring that were defined collaboratively, with industry and state interests working together.
- BPOP researchers provided science-based support to state regulators and industry during a critical discussion on how to best manage naturally occurring radioactive waste associated with oil production.
- BPOP coordinated discussions with state regulators and industry groups on the topic of best practices for remediation of brine spills associated with oil development. BPOP then completed a best practices remediation manual in conjuction with these groups.

This report, summarizing BPOP achievements at the end of the original 3-year contract, was produced as a final report on the first 3 years of the program. The program continues as BPOP 2.0 during the period spanning from November 2016 to October 2019. Many of the efforts begun under BPOP 1.0 will continue under BPOP 2.0. This summary is intended for public distribution and is intended to highlight the important work of this 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.

A comprehensive list of BPOP products is presented in Appendix A.

RESULTS AND DISCUSSION

PROJECT MANAGEMENT

MEMBERSHIP

The North Dakota Industrial Commission (NDIC) committed $8.0 million in matching funds over 3 years to support a consortium of industry partners conducting research focused on improving the efficiency and reducing the environmental footprint of oil production in North Dakota. The EERC, along with original partners Continental, Marathon Oil Corporation (Marathon), and Whiting Petroleum Corporation (Whiting), then sought and obtained additional member commitments from organizations interested in participation in this consortium.

This was a member-driven program with the goal of providing solutions to nonconfidential wellsite productivity issues affecting all Bakken producers. Employing a consortium approach for these issues minimized corporate financial and staffing input, made solutions available to consortium companies without dedicating staff resources, and partnered with the state of North Dakota to ensure transparency and continued cooperative efforts to assist producers in getting the most out of wellsite economics.

Additional membership participation was solicited in the following categories:

- $100,000 per year for producers with 150 wells or more
- $50,000 per year for producers with fewer than 150 wells
- $25,000 per year for service companies

Program member benefits included:

- Ability to guide research efforts to issues highest on individual company priority lists.
- Rapid information sharing among consortium members.
- Engagement with professional researchers focused on high-priority wellsite productivity issues.

Membership in this consortium-facilitated program is shown in Figure 2.

Figure 2. BPOP consortium partners.

AWARDS

In October 2014, the EERC received the Interstate Oil and Gas Compact Commission's 2014 Stewardship Award in the Environmental Partnership category for its BPOP work, as shown in Figure 3. The EERC accepted this award on behalf of its state and industry partners. The unique business environment present in North Dakota, combined with a state government eager to responsibly develop mineral resources, has enabled collaboration among highly competitive companies in a world-class shale play. This collaboration, in turn, has enabled BPOP to achieve the results discussed in this report.

Figure 3. IOGCC Stewardship Award.

OUTREACH

FACT SHEETS

Seven fact sheets were created to educate and inform stakeholders on key Bakken headline issues from 2013 to 2015. The fact sheets , shown in Figure 4, are science-based and written for public consumption.

These fact sheets were distributed widely by the EERC, by state agencies such as the Department of Mineral Resources, and by the North Dakota Petroleum Council (NDPC).

- **FLARING –** 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.

Figure 4. BakkenSmart fact sheet series.

- **WATER –** 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.
- **NORM –** The NORM fact sheet explains what naturally occurring radioactive material is, what radiation is in layperson's terms, what levels of radioactivity are hazardous, how NORM is regulated in North Dakota, and how NORM waste is disposed of safely.
- **SPILLS –** 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 provides an objective perspective on spill statistics.
- **RECLAMATION –** The reclamation fact sheet explains the reclamation process, parties typically involved in a reclamation project, how disturbed areas are reclaimed, and how spill sites are reclaimed.
- **HYDRAULIC FRACTURING –** The hydraulic fracturing fact sheet explains fundamental aspects of hydraulic fracturing,and dispels misinformation frequently and erroneously reported.
- **FUGITIVE EMISSIONS –** The fugitive emissions fact sheet explains the nature of fugitive emissions, factors driving regulatory interest in this topic, the measurement of fugitive emissions, and regulation of fugitive emissions.

- **BAKKEN FLARES AND SATELLITE IMAGES –** The Bakken flares and satellite images fact sheet explains the science behind satellite images, how visible light and other radiant emissions (heat sources) can be represented in these images, and the contribution flaring makes relative to other sources of light and heat.

CONFERENCE PRESENTATIONS

Results of BPOP activities were presented at nearly two dozen conferences and forums in the United States and Canada, highlighting the value of this unique state/industry consortium. The presentations also demonstrated North Dakota's leadership in developing unconventional shale resources.

PRESENTATIONS TO STATE AND FEDERAL GOVERNMENT

EERC staff also regularly briefed state and federal government agencies on program results, ensuring a truly engaged state member of the consortia-based program. The federal briefings demonstrated North Dakota government's leadership in shale development practices and policies to such agencies as the U.S. Department of Energy. During the 3-year program, over three dozen BPOP briefings were given to such state institutions as NDIC, the Oil & Gas Research Program, the Department of Mineral Resources, the Energy Development and Transmission Interim Legislative Committee, the EmPower Commission, the North Dakota Department of Health (NDDH), and others.

MEMBERS-ONLY WEB SITE

To facilitate rapid transfer of information and broad dissemination of program products to all program members, the EERC created a members-only, password-protected Web site (Figure 5). This Web site was used to store and make available each and every major product of the program. Members were encouraged to create a log-in account on the site to gain access to the latest program developments and deep reporting of results from program activities. At project end, over 120 program product documents are available for download to program members on this Web site.

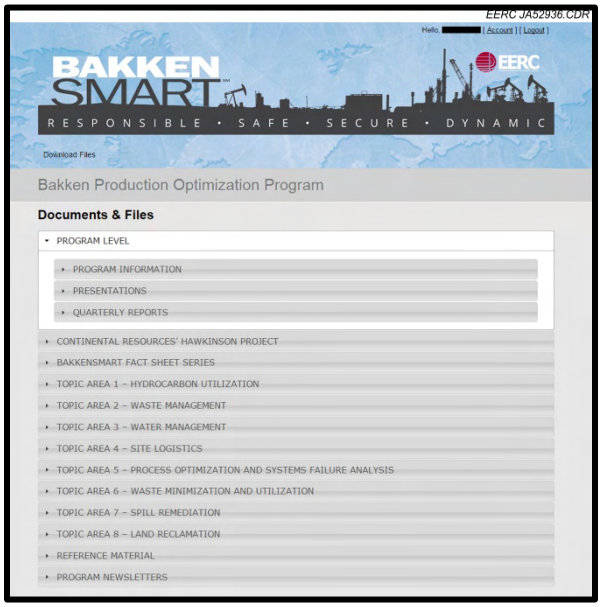

Figure 5. Members-only Web site.

MEMBER NEWSLETTERS

To keep all program members apprised of significant program developments and to encourage deep industry engagement in all facets of program activities, the EERC published electronic newsletters periodically. A partial example is shown in Figure 6. These newsletters served to extend engagement in BPOP activities within the organizational structures of member companies, beyond the senior management engaged largely through the contracting and invoicing processes, and beyond the senior technical leads who typically attended BPOP meetings. Electronic newsletters were delivered to over 200 industry contacts each time a newsletter was completed.

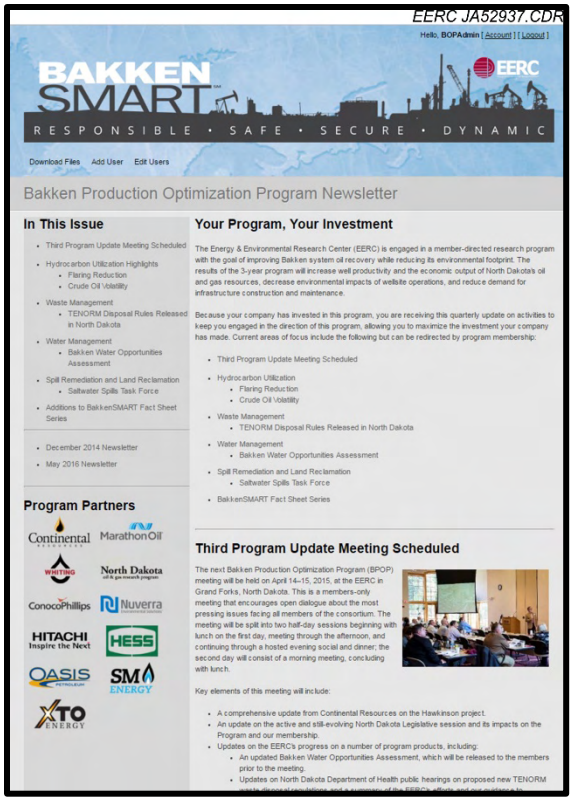

Figure 6. Sample BPOP Newsletter to members.

PLATFORM FOR TECHNICAL INDUSTRY FORUMS

Oil and gas industry research consortia are often faced with challenges with respect to the open exchange of information and ideas. This is partly because of the competitive nature of petroleum exploration and resource development and partly due to regulatory limitations imposed by the U.S. Securities and Exchange Commission. In some instances, dialogue amongst participants can even be hampered by the need to avoid potential violations of federal antitrust laws. One of BPOP's greatest successes was its ability to serve as a platform for open technical exchanges during hosted industry forums. BPOP specifically targeted these open exchanges in its effort to elicit earnest conversation on issues affecting all producers. The EERC then utilized information gleaned from these exchanges to develop new approaches to issues experienced broadly by industry on its quest to optimize Bakken production.

The EERC was told by multiple BPOP member companies that previous industry forums had not met this level of success in facilitating open technical discussion. It was this feature of the program that enabled BPOP to serve as a platform for one of the most significant results of the program – the changes to prior state rules on setbacks from DSU boundaries.

SETBACKS

The state of North Dakota currently imposes setback rules on DSU for Bakken–Three Forks oil production. These rules exist to allow efficient resource development within a DSU while protecting the correlative rights of resource owners in adjacent DSUs. Prior setback rules stipulated that the total depth (TD) of a horizontal wellbore in the Bakken–Three Forks petroleum system should not penetrate within 200 ft of a DSU boundary (200-ft setback), as described in Figure 7.

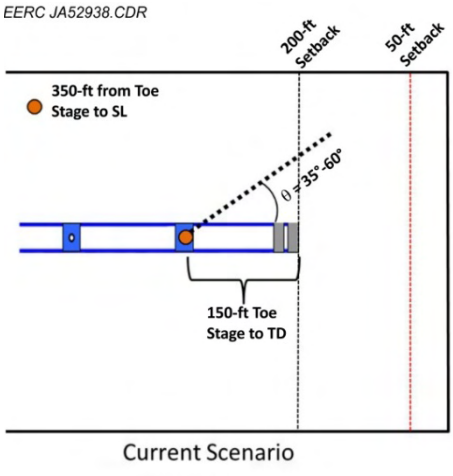

Figure 7**.** Well toe setback diagram.

A variety of opinions existed about the 200-ft setback and its ability to properly balance the needs of efficient development and correlative rights.

To help better describe the impact of the 200-ft setback rule, several operators that are members of BPOP each performed an agreed suite of representative simulation cases and presented their results in a common format for the benefit of interested parties. The EERC functioned to ensure the

simulations were conducted on comparable assumptions – acting as a facilitator.

These simulations resulted in a variety of opinions on recommendations for modifications to existing setback rules enforced by the state of North Dakota. In November 2016, industry and the EERC presented their case to NDIC for consideration. In December, the NDIC modified the rules as follows:

- Noncemented well heels shall be no closer than 150 ft from the DSU boundary.
- In openhole completions, the well toe shall be no closer than 150 ft from the DSU boundary.
- In cemented casing or liner completions, the well toe shall be no closer than 50 ft, unless the well is to be hydraulically fractured through the casing shoe; in that case, the distance limit becomes 150 ft.
- In external casing packer completions, the well toe shall be no closer than 100 ft from the DSU boundary.

It has been openly stated by industry representatives that without the collaboratory guidance provided by BPOP and BPOP's refereeing, this significant change in DSU setbacks would not have happened. These changes, supported by collaborative science, will now allow operators and the state of North Dakota to maximize the extraction of recoverable resources without undue risk to correlative rights.

An estimate of the return on investment of NDIC funds via the Oil & Gas Research Program was calculated. An anticipated increase in tax revenue is based on average per-well production increases resulting from the new rule, as modeled by four large North Dakota oil and gas producers. This anticipated increase in tax revenue is estimated to be approximately $1.27 billion.

ENVIRONMENTAL PEER GROUP

At the direction of BPOP members, the EERC was able to serve as a technical resource to the Environmental Peer Group, an industry working group of company environmental experts who meet on a quarterly basis to discuss issues common to participating entities. These meetings focus on current and future headline issues such as TENORM (technologically enhanced naturally occurring radioactive material) disposal, saltwater spill remediation, drill cuttings disposal, gas-flaring mitigation, surface process design, fugitive emissions, etc. These topics so closely mirrored the topics studied by the EERC within the confines of BPOP, that BPOP member companies leading the Environmental Peer Group asked the EERC to begin attending these meetings regularly.

EERC staff were able to support these meetings, providing relevant scientific insight on various topics. EERC staff were also tasked by BPOP members via these meetings with assisting efforts on various environmental challenges. This proved to be a valuable addition to BPOP tasks and kept the program tightly focused on issues being managed in real time, on the ground by BPOP members.

NDPC TASK FORCES

Also at the direction of BPOP members, the EERC was able to provide robust technical and scientific support to multiple task forces organized by NDPC. EERC staff were asked to provide ongoing, substantial support to the following NDPC task forces:

- Flaring Task Force
- NORM Task Force
- Saltwater Spills Task Force

EERC support for these task forces is described more specifically elsewhere in this report.

CONTINENTAL'S HAWKINSON PROJECT

The Hawkinson Project, executed by Continental in four phases as described in Figure 8, 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 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 that these formations are indeed separate in its evaluation of the Middle Bakken and first bench of the Three Forks with the Mathistad Project.

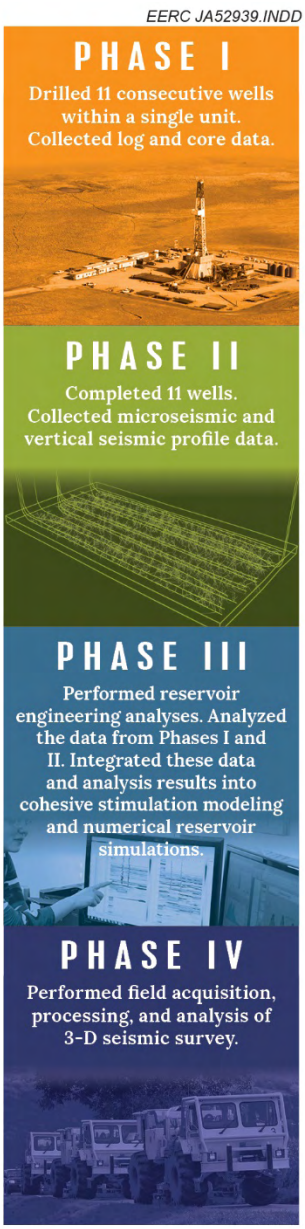

Figure 8. Summary of Hawkinson Project phases.

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 streamlined 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. Industry firsts accomplished by the Hawkinson Project are shown below.

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 ft 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 ft MD)
- Most footage of tractored tools in a single project (microseismic >270,000 ft; USIT >40,000 ft)
- Longest lateral footage pulling ten geophone shuttles (>21,000 ft 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

The subsurface portion of the work resulted in a one-of-a-kind effort to give a 3-D 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. Examples of analysis results are shown in Figure 9.

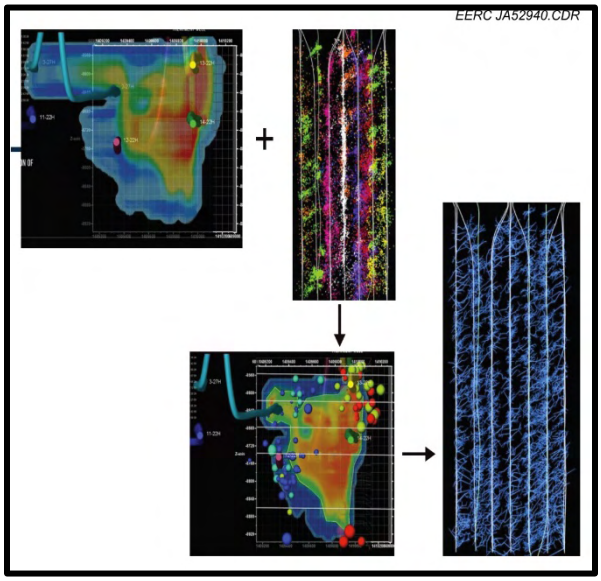

Figure 9. Reservoir insights resulting from Hawkinson data analysis.

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.
- 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.

EERC OPTIMIZATION OF WELLSITE OPERATIONS ACTIVITIES

The EERC conducted multiple parallel activities to advance the goal of optimization of wellsite operations. These activities were driven by the common needs program members. In general, BPOP addressed 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 goal of this phase of BPOP was 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 BPOP was engaged during the 2013–2016 period of performance.

HYDROCARBON UTILIZATION

FLARING REDUCTION

Flaring Task Force

The EERC supported 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 statiscal flaring analyses that served as the foundation for these plans. The BPOP team presented the resulting plan to Governor Dalrymple in January 2014. This plan was eventually endorsed by Governor Dalrymple and is now integral to regulations enforced by the North Dakota Department of Mineral Resources. The plan approved by NDIC included associated gas capture targets as follows:

Gas Capture Deadline	Gas Capture Target, *% flared max.*
October 2014	74% *(less than 26% flared)*
January 2015	77% *(less than 23% flared)*
April 2016	*80% (less than 20% flared)*
November 2016	85% *(less than 15% flared)*
October 2018	*88% (less than 12% flared)*
November 2020	91% *(less than 9% flared)*

Flaring Database

The EERC supported BPOP 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. Figure 10 shows a screen capture of the database. The database can be examined at www.undeerc.org/Flaring_Solutions/.

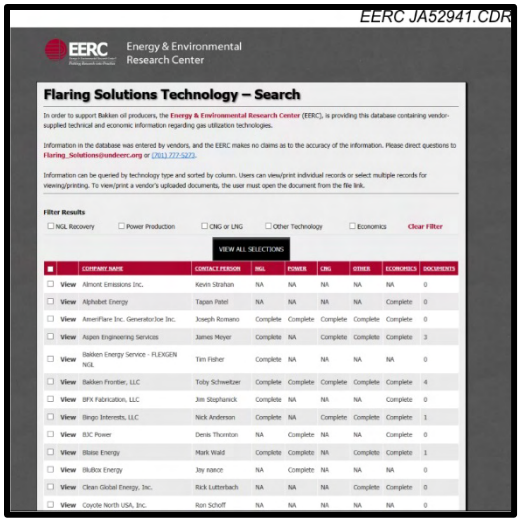

Figure 10. Flaring Solutions Technology Database.

The database entries were solicited and refereed by EERC staff. Industry continues to utilize this database to gather information on possible solutions to flaring at wellsites not yet served by gas gathering pipelines or where gathering capacity is insufficient to capture all of the produced gas.

PRODUCED FLUIDS CHARACTERIZATION

In support of wide-ranging activities associated with BPOP tasks, the EERC assembled all known physical and chemical property data pertaining to Bakken Formation produced fluids – crude oil, associated gas, and produced water. These data were be used in the holistic, "system of systems" approach toward which BPOP turned at the end of the program, as the EERC anticipated a BPOP 2.0. Within this produced fluids characterization activity, the EERC developed and populated a GIS (geographic information systems)-compatible database to compile all existing data available to EERC staff. This included public information housed at the North Dakota Department of Mineral Resources, public information housed at the U.S. Geological Survey (USGS), data developed via other EERC projects and programs, and data provided to EERC staff by industry.

The data set currently contains data from 943 produced water samples, 507 crude oil samples, and 718 associated gas samples. With sufficient data entered into the database, the EERC then began a preliminary evaluation of spatial and temporal data to identify potential data gaps that could be filled during BPOP 2.0 activities. An example of analysis results is shown in Figure 11. Preliminary results of this evaluation indicate that the data gaps of highest priority include:

- Specific temporal data on fluid composition on individual wells.
- Additional compositional information (e.g., aliphatic content, aromatic content, light ends content, water chemistry).

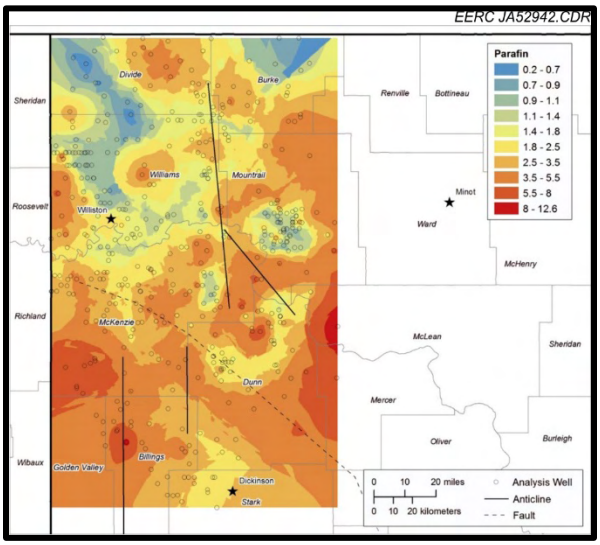

Figure 11. Example of maps created using preliminary results of produced fluids database development.

This work also resulted in recommendations regarding future sampling efforts. Downhole sampling must maintain downhole conditions (pressure, temperature) to obtain accurate compositional and PVT (pressure, volume, temperature) analyses. This means that a more methodical approach to sampling must be promoted within BPOP 2.0 activities. For produced fluid samples taken at the separator at the wellsite, BPOP 2.0 activities must strive to attain accurate separator flow rate measurements and stability in separation conditions to achieve accurate determination of reservoir phase behavior from the recombined fluids.

INVESTIGATION OF OIL COMPOSITIONAL ANALYSIS FOR SOURCE DETERMINATION

The EERC analyzed a limited set of 43 samples of Upper, Lower, and Middle Bakken rock to begin to explore the hypothesis that aromatic/aliphatic tracers can be used to better understand oil transport and oil sources within the reservoir system, thus potentially impacting the estimates of recoverable reserves.

The ratios of aromatic to aliphatic hydrocarbons in rock samples from nine well locations were consistently fourfold to tenfold higher in the 20 upper and lower shale samples than in all of the 23 Three Forks and Middle Bakken rock samples tested, as shown in Figure 12. The aromatic/aliphatic ratios in Three Forks and Middle Bakken samples were all similar to that of a typical produced Bakken crude oil, while the ratios from upper and lower shales averaged seven times as high. Aromatic/aliphatic ratios from upper and lower shales corresponded to shale maturity maps, with the higher ratios affiliated with less mature zones.

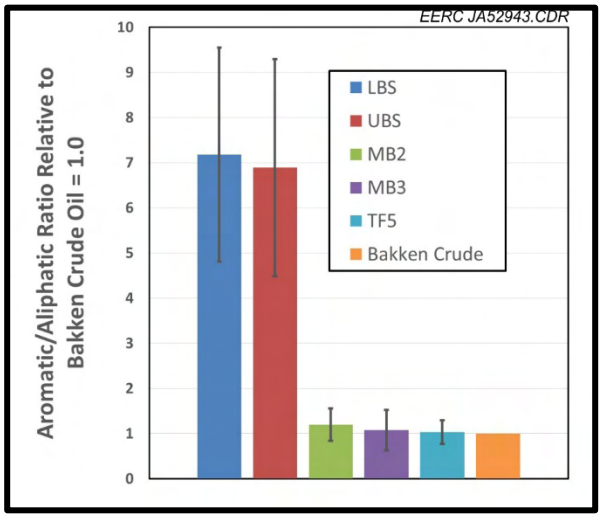

Figure 12. Data showing distinct differences in aromatic/aliphatic ratios from various portions of Bakken/Three Forks System.

These results suggest that aromatic/aliphatic tracers could be useful for better understanding oil transport and sources in the reservoir, allow better well management (e.g., by determining the relative contributions of the shales and Middle Bakken to produced oil), and support the development of more accurate recoverable reserves estimates for the Bakken petroleum system. These results also provide strong indication that further investigations of this hypothesis are justified.

INVESTIGATION OF RICH GAS FOR ENHANCED OIL RECOVERY (EOR)

The advent of horizontal drilling and hydraulic fracturing unlocked unconventional reserves such as those in the Bakken Formation. It is critically important to now investigate the next revolutionary advancement in oil production. This next advancement might be the application of EOR techniques to increase the amount of oil currently recoverable from the tight shale formations. Rich gas may be a prime candidate for an EOR working fluid for many reasons. Capture and production of natural gas in the Bakken play is resulting in increasing concern over what options are available to utilize excess ethane that must be removed from the gas stream to meet downstream and/or interstate pipeline natural gas specifications. In essence, the cost of transporting Bakken ethane to potential users exceeds its commercial value. The purpose of these investigations was to perform initial laboratory experiments to determine the potential for utilizing ethane as an injectant for EOR in the Bakken.

Three laboratory methods for investigating EOR using CO_2 were performed using ethane as the injected fluid. These three experiments were:

1. Measuring the multiple-contact minimum miscibility pressure (MMP) of ethane (as compared to CO_2) at Bakken reservoir temperature of 230°F (110°C), including the effect of associated methane in each fluid.
2. Collecting and analyzing the Bakken crude oil hydrocarbons that are mobilized into an upper “miscible” phase.
3. Exposing rock samples collected from a Bakken well to ethane to determine the rate of crude oil recovery from untreated Bakken rocks.

Each of these experiments had previously been performed using CO_2, which allowed a direct comparison of the relative capabilities of ethane and CO_2 as potential EOR fluids. Figure 13 summarizes this comparison.

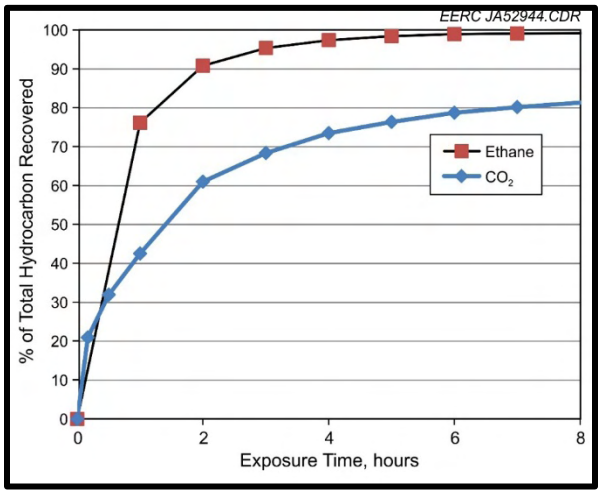

Figure 13. Comparing EOR potential for CO_2 and ethane.

All three laboratory studies support the conclusion that ethane is an excellent candidate EOR fluid for achieving lower crude oil MMPs, for more efficiently mobilizing crude oil hydrocarbons into the mobile "miscible" phase, and (based on initial results) for recovering crude oil hydrocarbons from Bakken rock samples. However, it is important to note that these lab experiments only mimic some of the processes necessary to achieve EOR from the actual reservoir and that substantial laboratory research into EOR mechanisms, model development, and pilot-scale tests will be needed to exploit the use of EOR fluids in tight/fractured plays like the Bakken. It is also important to note that neither ethane nor CO_2 is currently available in sufficient quantities to satisfy demand if these approaches were to be broadly applied. This is the focus of research continuing in BPOP 2.0.

SIMULATION OF ETHANE FLOODING IN CONVENTIONAL RESOURCES

There are many depleted conventional reservoirs and developing unconventional reservoirs in the Williston Basin. Production from many of the conventional reservoirs are stagnant after primary depletion or waterflooding without carrying out EOR operations, despite the fact that numerous field demonstrations have shown that CO_2 flooding can be an effective and economically attractive EOR method. The EERC MMP experiments described in the prior section have shown that ethane can also produce desirable EOR effects.

With this knowledge, BPOP researchers at the EERC conducted reservoir simulations to investigate ethane flooding in a conventional reservoir using an existing history-matched reservoir simulation of a CO_2 EOR project. In this study, typical conventional reservoir conditions were selected to investigate the EOR performance of CO_2 compared to ethane.

Utilizing a tuned, nine-component PVT model, a numerical simulation for a representative conventional reservoir was selected to investigate ethane EOR performance. The simulation model was history-matched to production data including primary depletion, waterflooding, and CO_2 flooding stages to ensure the model was able to reliably represent reservoir performance.

Results showed that miscible flooding is more easily attainable for ethane than for CO_2 in the reservoir conditions (see Figure 14). Results also showed that ethane maintains miscibility, even with limited processing and reinjection of produced gas from the field. The oil recovery performance from ethane injection is better than from CO_2 in all simulation cases studied. Considering the availability of ethane in the Williston Basin area, ethane EOR may be a good candidate for conventional reservoirs in the basin and could potentially aid in commoditizing ethane-rich natural gas resources in the region.

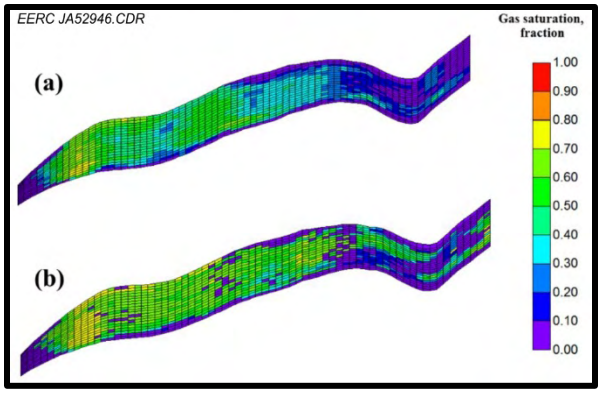

Figure 14. Snapshot of verical sweep performance of CO_2 and ethane after 42 years of flooding.

SURFACE FACILITIES PROCESS MODEL DEVELOPMENT

To facilitate a "system of systems" approach to optimizing production from the Bakken system, the EERC began development of a surface facilities process model (summarized in Figure 15). Having a detailed understanding of this step in the production cycle is important since wellsite operations are a central to many production concerns including crude oil vapor pressure, natural gas and natural gas liquids recovery, and storage tank vapor generation rates.

In development of this model, EERC staff worked with a BPOP member to identify "typical" wellsite process design parameters and performance data for each unit of process equipment. The initial static, or steady-state, model was created using Aspen HYSYS® process simulation software. Trends predicted by the static model were validated by comparing them to field observations from the member company. During discussion of the steady-state model's applicability, it was determined that a dynamic model was needed to accurately capture the non-steady-state behavior of actual wellsite operations. This dynamic model, created using VMGSim Dynamics™ software, is being used to assist in BPOP efforts to determine the impacts to crude oil composition, crude oil volatility, gas flaring, and produced water flow volumes as reservoir changes drive changes in process unit operations.

Ultimately, this model will be employed to predict operational issues arising from changes in well fluid production rates and compositions. This model may prove beneficial in helping BPOP member companies alter wellsite process designs to accommodate evolving knowledge of fluids production from the Bakken–Three Forks petroleum system. The model may also be used to predict changes in flare performance, crude oil quality, and produced water disposal quantities during periods of process upsets.

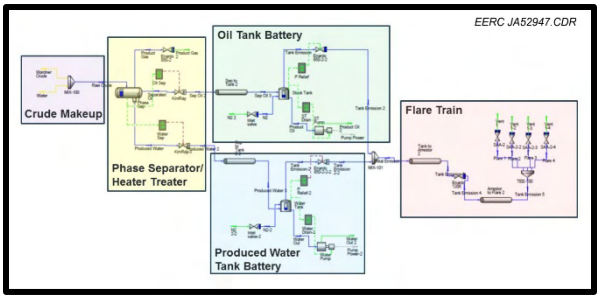

Figure 15. Reconfigurable facility process model.

The EERC also hopes to employ this model to develop an understanding of implications of a variety of alternative production strategies, including new completions techniques and EOR.

DECLINE CURVE ANALYSIS

The EERC analyzed hydraulic fracturing and other trends within the Bakken petroleum system during the period from 2006 into the first half of 2016. This period of the Bakken's development included a transition to a low-oil-price environment, which spurred experimentation with hydraulic fracturing parameters away from conventional values. Explored parameters included number of fracture stages, amount of proppant injected, and volume of fluid used for fracturing. Distinct subcategories of fracture conditions were identified and analyzed for their impact on water use, and oil and water production.

The EERC completed a preliminary investigation using Arps' decline curve analysis to determine if basinwide production trends and performance drivers could be identified for the Bakken Formation. Differences in performance have been identified, and more in

depth analysis using more advanced decline curve analyses may improve understanding of Bakken current and future production performance. The main objectives were to select a representative and diverse sample set from producing Bakken wells, analyze, and then inspect their production performance by different groups (county, vintage, stage spacing, and proppant amount) in order to understand the influence if any of these factors on initial production, overall performance, and estimated ultimate recovery using decline curve analysis.

A data set consisting of 200 Bakken wells producing from McKenzie, Williams, Mountrail, and Dunn Counties within North Dakota was used to evaluate production performance in this study. The results of this analysis showed that:

- A majority of the selected wells are in boundary-dominated flow.
- When the oldest wells are compared to the most recent wells, results of analysis by well vintage indicate that advances in drilling and completion technologies over the years have not only increased estimated ultimate recovery (EUR) but have also speeded up oil recovery from the reservoir. Older wells that were identified as underperforming could be restimulated to improve their production performance. Oil production performance improved with decreasing spacing between fracture stages.
- With respect to proppant loading, there was a general direct trend of increasing peak oil rate with higher amounts of the proppant used per stage to complete the well. However, the same trend was not reflected in estimating the ultimate oil recovery.
- Based on the limited number of wells and their relatively short operating history, the estimated well operating life required to attain an abandonment oil rate of 5 stb/d will range from a minimum of 30 years to as high as 48 years.

Gas production from the same data set of wells was also analyzed in similar ways:

- McKenzie and Williams Counties are likely to have wells with peak gas production rates 75% to 100% higher than rates for Dunn and Mountrail Counties.
- In general, peak gas production and estimated ultimate recovery, gas (EURg) are expected to increase as the distance between stages decreases.
- While increasing proppant loading tended to increase the peak gas production rate, no firm trend was established between proppant loading and EURg.

The gas production rate corresponding to the abandonment oil rate is estimated to be in the range of 4.5 to 7.5 Mscfd.

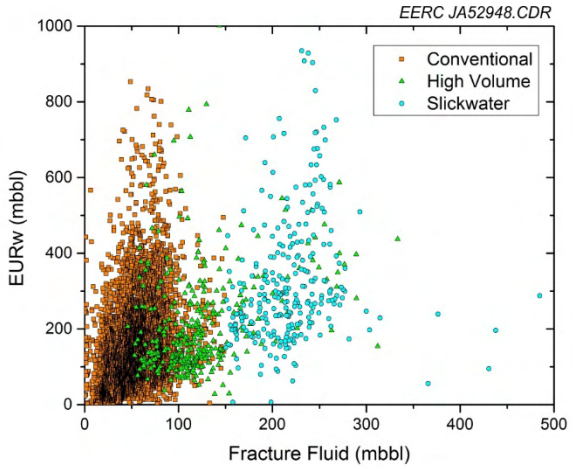

Figure 16. Comparing EURw with injected fracture fluid volume.

With respect to water production, more aggressively fractured wells produced more water; however, Figure 16 reveals little to no correlation between the amount of fluid used for fracturing and the total estimated quantity of produced water on an individual well basis. For the Bakken well population as a whole, new wells in 2015 required approximately 0.7 bbl of fracture fluid per stb of total estimated oil recovery. These wells also produced approximately 1.1 bbl of total estimated water

recovery per stb of total estimated oil recovery. Trends within the well population subcategories suggest that these summary ratios could decrease slightly in the future.

WASTE MANAGEMENT

TENORM WASTE DISPOSAL

NORM Task Force

BPOP representatives served as subject matter experts and advisors to the NDPC 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 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 Primer

The NORM Primer (Figure 17) 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 pertinent questions. It served as a mechanism to ensure that industry and state interests were speaking with commonality on facts.

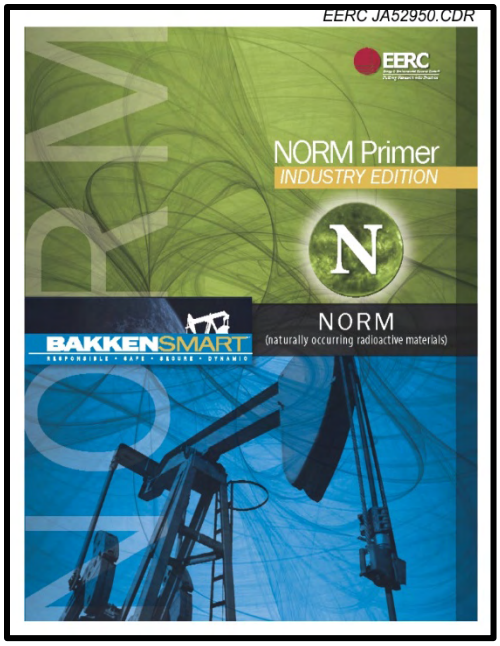

Figure 17. NORM Primer cover page.

TENORM Analysis of 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 (isotopes Ra-226 and Ra-228). The results (Figure 18) of this survey were shared with industry and NDDH. The EERC also supported the NORM Task Force in interpretation of the results. This work was completed in support of comments written by industry in response to NDDH's release of a draft of its new rules for in-state TENORM disposal.

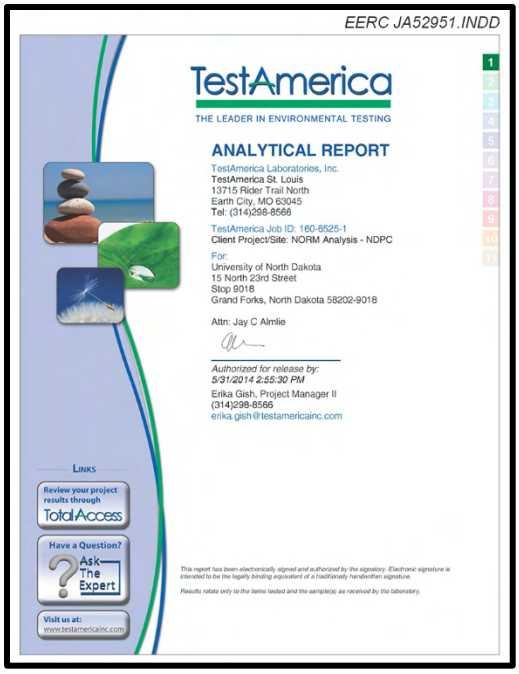

Figure 18. TENORM Sampling Analysis Report cover page.

WATER MANAGEMENT

BAKKEN WATER MANAGEMENT PRACTICES AND POTENTIAL OUTLOOK

As a product of water management activities within BPOP, the EERC completed a comprehensive assessment of water management practices in the state. This report (shown in Figure 19) provided a summary of water use and handling trends in the Bakken, an 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.

The report can be used by industry to identify potential freshwater resources and produced water disposal opportunities. It can be used by regulators to calibrate an understanding of anticipated trends in water demands for the oil and gas industry. It can be used as an outreach tool to legislators and the general public to help all concerned parties gain an understanding of the true needs of industry for water resources and compare those needs against needs from other sectors of North Dakota's economy.

This report can be downloaded at: www.undeerc.org/Bakken/Water-Study.aspx.

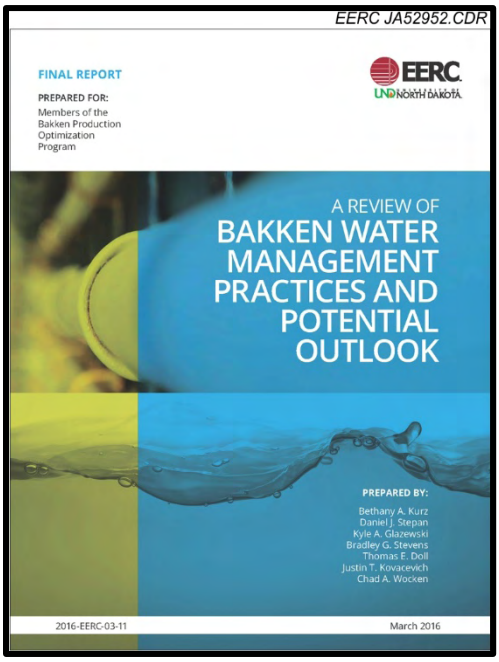

Figure 19. Water Management Practices cover page.

DAKOTA SANDSTONE CAPACITY MODELING

The increase in oil and gas production in North Dakota due to Bakken petroleum system development has resulted in a threefold increase in produced water generation over the past decade. As of 2015, nearly 440 million barrels of water were disposed of in North Dakota's saltwater disposal (SWD) wells. This trend is expected to increase in the coming decades with the continued extraction of oil and gas from the Bakken. As of 2015, 94 vol% of all SWD occurred within the Inyan Kara Formation of the Dakota Group.

Because of industry's current reliance on the Inyan Kara as a SWD target, an effort is under way through BPOP to evaluate the disposal capacity of the Inyan Kara and to identify locations where additional disposal may be optimal or problematic based upon geologic characteristics, injection rates, and

proximity to existing SWD wells. A reservoir simulation model was developed to enable the assessment of current and potential future SWD scenarios in a portion of western North Dakota with a high concentration of SWD wells. The areal extent of the model encompasses most of McKenzie County and a portion of northwestern Dunn County, as shown in Figure 20. A preliminary validation of the model has been completed, and initial simulation results have been produced that will allow for full model calibration.

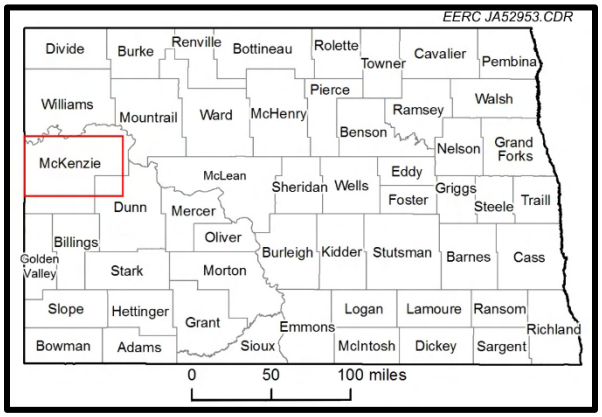

Figure 20. Initial focus area of Dakota Sandstone modeling.

This effort will continue under BPOP 2.0 and will focus on improving the model calibration through refined history matching of the predicted wellhead pressure with the field-reported data for each well. This will entail modification of the reservoir properties and adjustment of the individual SWD well characteristics.

FAILURE ANALYSES

SUCKER ROD GUIDE PREMATURE DETERIORATION

North Dakota wellsite operators have reported a number of premature failures of plastic rod guides. The failures have most often occurred in green-colored guides that were being pilot-tested by a reputable rod guide manufacturer. It was reported to the EERC that the standard rod guide used by multiple operators is black and made of polyphthalamide (PPA). The two types of rod guides are shown in Figure 21. The rod guide manufacturer stated that the green material is also PPA. Operators have reported that the black guides have an expected lifetime of several years in Bakken operations, but many of the green guides have failed by crumbling, sometimes into a green mud, in time frames of less than a year.

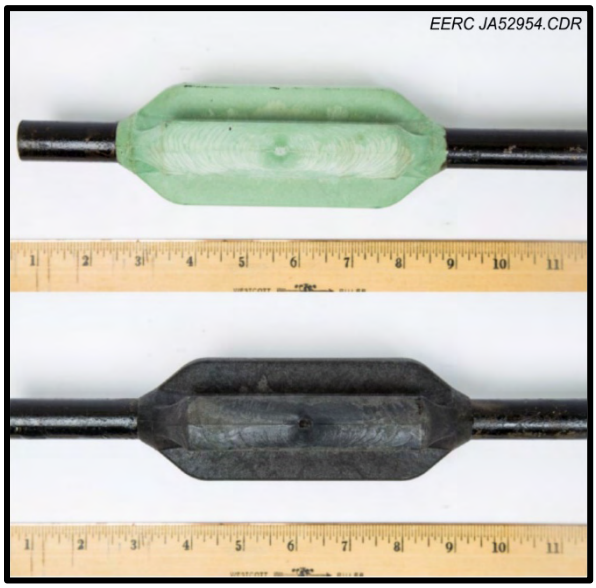

Figure 21. Types of sucker rod guides analyzed.

The EERC was asked by BPOP members to analyze the green and black materials to determine whether they are made of the same material and to provide suggestions on how to specify materials or molding methods to increase guide lifetimes. The EERC was also asked to perform the same analyses on three types of guides made by two alternate rod guide manufacturers. Select analyses were chosen only to determine differences in composition and some physical properties of the materials. These analyses were not designed to determine the likely relative performances or lifetimes of the materials in field use.

Differential scanning calorimetry (DSC) and Fourier transform infrared (FTIR) analyses indicate that the baseline green and black guides provided to the EERC were made out of different types of plastics. Resin manufacturer representatives have informed the

EERC that the DSC data and preliminary data from measurements of the viscosities of the plastics indicate that the black plastic is a known resin, but the green plastic is likely mixed with other resins or additives. FTIR data seem to corroborate this assessment. Thermogravimetric analysis (TGA) indicates that the green guide contains significantly more reinforcing or filler than the black guides. Tensile testing shows that the black guides are significantly stronger than the green guides, but both are much weaker than shown in manufacturer data for reinforced material made of the known resins, likely because of high porosity measured by the EERC. The material in the black guide that had been exposed to downhole conditions was only one-half as strong as unused material.

SPILL REMEDIATION AND LAND RECLAMATION

SALTWATER SPILLS TASK FORCE SUPPORT

BPOP provided subject matter expertise to NDPC's Saltwater Spills Task Force during 2014–2016. 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 valid soil science. It is through this partnership with the EERC, NDSU, the Saltwater Spills Task Force, and industry at large that the Spills Cleanup Primer and the Remediation Resource Manual were created.

SPILLS PRIMER

The Spills Cleanup Primer (Figure 22) 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.

Figure 22. Spills Primer cover page.

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 oilfield-related spills. This field guide is shown in Figure 23. 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.

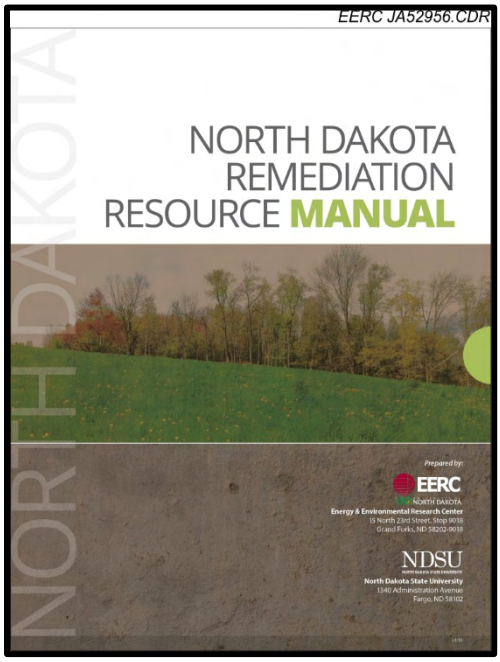

Figure 23. North Dakota Remediation Resource Manual cover page.

MEMBERSHIP AND FINANCIAL INFORMATION

BPOP was sponsored by the NDIC Oil and Gas Research Council, Continental, and a consortium of Bakken producers and service companies. As shown in Table 1, the originally proposed budget for this program was $115,784,500. As the program progressed, the EERC estimated that an additional $1,050,000 would be attained from industry partners beyond what was originally planned (from $1.2M to $2.25M); the EERC was able to secure $2,025,000.

Continental's expected in-kind contribution was $106,030,000. Continental ultimately reported in-kind contributions of $99,166,805 which represents approximately $6.9 million less than what was projected at the beginning of the project. This differential is largely attributed to actual expenditures coming in slightly lower than original estimates. The differential amounts to a 6.4% variance, which may be considered within expectations for a project of this magnitude.

Table 1 enumerates the evolution of the budget over the course of the program's execution.

Cash contributions from industry totaling $2,025,000 were as follows:

- $300,000 each from Marathon, SM Energy Company, ConocoPhillips, XTO Energy, and Hess Corporation for a total of $1,500,000.
- $200,000 each from Whiting and Oasis Petroleum North America for a total of $400,000.
- $75,000 from Nuverra Environmental Solutions.
- $50,000 from Hitachi Data Systems.

Expenses to date by funding source are listed in Table 2.

Table 1. BPOP – Budget Evolution

	Proposed Budget*	Expected Budget	Final Budget	Variance from Original Budget
NDIC** – Cash	$8,554,500	$8,554,500	$8,554,500	0%
Industry – Cash	$1,200,000	$2,250,000	$2,025,000	69%
Continental – In-Kind	$106,030,000	$106,030,000	$99,166,805	−6%
	$115,784,500	**$116,834,500**	**$109,746,305**	−5%
NDIC Share	7%	7%	8%	
Industry Share	93%	93%	92%	

* EERC Proposals 2013-0176 and 2014-0118.

** Includes $6.26M subcontract to Continental.

Table 2. BPOP – Expenses to Date

	Funding Source		
	NDIC	**Industry**	**Total**
EERC*	$2,293,500	$2,022,488	$4,315,988
Continental – Subcontract	$6,260,000		$6,260,000
Continental – In-Kind		$99,166,805	$99,166,805
Total	**$8,553,500**	**$100,189,293**	**$109,742,793**

*As of the date of this report, not all expenses have posted, therefore actual expenses are an estimate.

CONCLUSION

BPOP represents a successful, award-winning collaboration between the state of North Dakota and its petroleum industry. The work performed within BPOP has achieved the stated goals of maximizing Bakken production while simultaneously minimizing the environmental impact of production activities. The collaborative work completed within the program has demonstrated a new mode of mutually beneficial cooperation between state and industry players to responsibly and productively maximize development of unconventional resources.

At the time of this report, the state of North Dakota has opted to extend this successful program for an additional 3 years. Marathon and Liberty Resources LLC have signed on as anchoring industry partners, while the EERC continues to solicit additional, substantial partners interested in leveraging their corporate research power with this collaborative state–industry framework.

EERC
Energy & Environmental Research Center®
Putting Research into Practice

APPENDIX A

LIST OF BAKKEN PRODUCTION OPTIMIZATION PROGRAM (BPOP) PRODUCTS

LIST OF BAKKEN PRODUCTION OPTIMIZATION PROGRAM (BPOP) PRODUCTS

	Product Type	Product	Date
Program Level	Tools	Members-Only Web Site	8/23/13
	Reports	Quarterly Reports	Many
		BPOP Executive Summary Booklet	5/31/16
		Final Program Report	1/30/17
	Presentations	BPOP Kickoff Meeting	8/15/13
		BPOP Summary to Petroleum Environmental Research Forum (PERF)	11/6/13
		BPOP Semiannual Meeting	8/19/14
		BPOP Semiannual Meeting (WebEx)	1/17/14
		BPOP Summary to Oil & Gas Research Program (OGRP)	1/23/14
		BPOP Semiannual Meeting	3/7/14
		BPOP Summary to Energy Development and Transmission Committee (EDTC)	4/8/14
		BPOP Summary to Horizontal Drilling Canada Conference	9/17/14
		BPOP Summary to EDTC	10/16/14
		BPOP Summary to ND Environmental Peer Group	3/26/15
		BPOP Semiannual Meeting	4/15/15
		BPOP Executive Summary of Progress to Date	5/9/16
		Bakken Research Programs Summary of BPOP at 85th Annual ND Water & Pollution Control Conference	10/24/13
		BPOP Summary at 2nd Annual ND Reclamation Conference	2/24/14
	Newsletters	December 2014 Members' Newsletter	12/23/14
		September 2015 Members' Newsletter	9/11/15
		May 2016 Members' Newsletter	6/8/16
Hawkinson Project	Reports	Hawkinson 14-22H2 Core Report	7/8/14
		Hawkinson Unit Development Project Final Report	5/15/15
Hydrocarbon Utilization	Tools	Flaring Solutions Technology Web Site	11/22/13
		Wellsite Facility Processes Model	12/30/16
	Reports	Hydrocarbon Mobilization Mechanisms Using CO_2 in an Unconventional Oil Play (*Energy Procedia*, v. 63, 2014, p. 7717–7723)	10/5/14
		Laboratory Investigations to Determine the Potential Use of Ethane for Enhanced Oil Recovery in the Bakken	1/15/15
		Laboratory Investigations into the Use of Associated Gas Hydrocarbons for Enhanced Oil Recovery in the Bakken Formation	1/27/15

	Product Type	Product	Date
Hydrocarbon Utilization	Reports	Crude Oil Characterization Research Sampling, Analysis, and Experiment (SAE) Plan (for U.S. Department of Energy)	10/15/15
		Rapid and Simple Capillary-Rise/Vanishing Interfacial Tension Method to Determine Crude Oil Minimum Miscibility Pressure: Pure and Mixed CO_2, Methane, and Ethane (*Energy & Fuels*)	5/12/16
		Rapid and Simple Capillary-Rise/Vanishing Interfacial Tension Method to Determine Crude Oil Minimum Miscibility Pressure: Pure and Mixed CO_2, Methane, and Ethane	7/15/16
		A Systematic Investigation of Gas-Based Improved Oil Recovery Technologies for the Bakken Tight Oil Formation (Unconventional Resources Technology Conference, August 2016)	8/1/16
		Measured Crude Oil MMPs with Pure and Mixed CO_2, Methane, and Ethane, and Their Relevance to Enhanced Oil Recovery from Middle Bakken and Bakken Shales (SPE-185072-MS)	2/15/17
	Presentations	Associated Gas for Enhanced Oil Recovery at BPOP Update Meeting	3/17/14
		Assessment of Remote Capture Technologies to Improve Gas Utilization	5/20/14
		Summary of Flaring at Williston Basin Petroleum Conference	5/20/14
		Hydrocarbon Mobilization Mechanisms Using CO_2 in an Unconventional Oil Play at 12th International Conference on Greenhouse Gas Control Technologies	10/5/14
		A Rapid Method for Determining CO_2/Oil MMP and Visual Observations of CO_2/Oil Interactions at Reservoir Conditions at 12th International Conference on Greenhouse Gas Control Technologies	10/5/14
		Summary of Flaring at Bakken Flaring Alternatives Conference	12/10/14
		Assessing Small-Scale Remote Capture Technologies to Improve Gas Utilization at the Wellhead at Bakken Flaring Alternatives & Gas Capture 2014, Denver	12/10/14
		Small-Scale Remote Capture Technologies to Improve Gas Utilization at North Dakota Petroleum Council (NDPC) Flaring Workshop, Bismarck	1/14/15
		Can We Translate High Oil Recoveries from Bakken Rocks in the Lab Using Associated Natural Gas and CO_2 to the Field? at 23rd Williston Basin Petroleum Conference	4/28/15
		Laboratory Studies on CO_2/Crude Oil Interactions, Mobilization, and "Miscibility" at EOR Conditions at Plains CO_2 Reduction (PCOR) Partnership Annual Meeting	9/15/15
		Can We Translate High Oil Recoveries from Bakken Rocks in the Lab Using Associated Natural Gas and CO_2 to the Field? at NDPC Annual Meeting	9/21/15
		Effects of Reservoir Temperature and Percent Levels of Methane and Ethane on CO_2/Oil MMP Values as Determined Using Vanishing	11/8/15

	Product Type	Product	Date
Hydrocarbon Utilization	Presentations	Interfacial Tension/Capillary Rise at 2015 American Institute of Chemical Engineers (AIChE) Annual Meeting	
		Hydrocarbon Mobilization and Potential CO_2 Storage Mechanisms in the Middle Bakken, Bakken Shales, and Three Forks at 2015 AIChE Annual Meeting	11/8/15
		Laboratory Studies of MMP and Hydrocarbon Mobilization in Conventional and Bakken Plays Using CO_2, Methane, and Ethane at 2015 CO_2 Conference	12/8/15
		BPOP Topical Meeting: Setback Rules at the Energy & Environmental Research Center (EERC), Grand Forks	12/18/15
		Bakken Setback Meeting at Hess Corporation headquarters, Houston	3/31/16
		CO_2 and Hydrogen Phase Behavior and Interactions with Bakken Rocks at the EERC Workshop on Sustainable Development of the Bakken Formation	5/9/16
		Characterization of Tight Oils at the Fall 2015 92nd PERF Meeting at the EERC, Grand Forks	10/7/16
		Flaring Statistics and Remote Hydrocarbon Capture and Utilization (presented at the Fall 2015 92nd PERF Meeting at the EERC, Grand Forks)	10/7/16
		Effects of Reservoir Temperature and Percent Levels of Methane and Ethane on CO_2/Oil MMP Values as Determined Using Vanishing Interfacial Tension/Capillary Rise at 13th International Conference on Greenhouse Gas Control Technologies	11/14/16
Waste Management	Tools	NORM Primer: Industry Edition	9/8/14
	Reports	TestAmerica TENORM Analytical Report	5/31/14
		Letter of Testimony to ND Department of Health (NDDH) Regarding Proposed Regulations on In-State TENORM Disposal	1/20/15
	Presentations	NORM Sample Analysis Results Summary for NDDH	6/12/14
		Understanding How the Application of Drill Cuttings Recycling Strategies and the Use of Associated Gas for Power Rigs Can Reduce Cost and Environmental Impact of Horizontal Drilling at the Horizontal Drilling Canada 2014 Congress	9/17/14
Water Management	Reports	A Review of Bakken Water Management Practices and Potential Outlook	3/30/16
		Modeling of the Inyan Kara Formation to Estimate Saltwater Disposal Capacity: Interim Report	12/30/16
	Presentations	Volumetrics, Treatment, Sourcing, and Recycling of Water Associated with Bakken Hydrocarbon Production at the Fall 2015 92nd PERF Meeting	10/7/15
		Summary of the Bakken Water Assessment Report at the North Dakota Legislature's Energy Development & Transmission Interim Committee	8/30/16

	Product Type	Product	Date
Water Management	Presentations	Summary of the Bakken Water Assessment Report at the North Dakota Legislature's Water Topic Overview Interim Committee	9/23/16
Process Optimization and Failure Analysis	Reports	Final Report on Rod Guide Analyses	11/30/16
Spill Remediation	Tools	Spills Cleanup Primer	4/15/15
		North Dakota Remediation Resource Manual	8/23/16
Land Reclamation	Reports	Comparison of Soil-to-Water Suspension Ratios for Determining Electrical Conductivity of Oil-Production-Water Contaminated Soils (North Dakota State University [NDSU])	1/15/16
		Brine Impacted Soils in Semi-Arid Lands: Electrical Conductivity Thresholds and Ex Situ/In Situ Remediation Comparisons (NDSU)	1/15/16
		Oil-Produced Water Thresholds on Rangeland Plant's Survival Under Greenhouse Conditions (NDSU)	1/15/16
		Evaluation of Soil Treatment Techniques on Remediated Brine Water Spill Sites in Semi-Arid Rangelands (NDSU)	1/15/16
Outreach and Education	Fact Sheets	BakkenSMART Fact Sheet – Flaring	9/16/13
		BakkenSMART Fact Sheet – Water	9/16/13
		BakkenSMART Fact Sheet – NORM	9/16/13
		BakkenSMART Fact Sheet – Spills	10/31/14
		BakkenSMART Fact Sheet – Reclamation	10/31/14
		BakkenSMART Fact Sheet – Bakken Flares and Satellite Images	5/12/15
		BakkenSMART Fact Sheet – Fugitive Emissions	11/23/16
		BakkenSMART Fact Sheet – Hydraulic Fracturing	11/23/16