



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.

4 PROGRAM INTRODUCTION

- 6 Anticipated Outcomes
- 8 Partnership and Members

10 OPTIMIZATION OF WELLSITE OPERATIONS

- 12 Flaring Reduction
- 14 Water Opportunities Assessment
- 16 TENORM Waste Disposal
- 18 Spills Remediation

20 THE HAWKINSON PROJECT

- 23 Need for the Project
- 24 Industry Firsts
- 26 Results
- 27 Conclusions

28 PROGRAM WORK CONTINUES

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 occurring 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.

MEMBERS 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



EERC Energy & Environmental Research Center

Flaring Solutions Technology

The Energy & Environmental Research Center is supporting flaring of production in their ongoing efforts to implement techniques and practices to offset chemical wellhead gas and reduce volumes of gas flaring. To facilitate this effort, a web-based data collection tool was created to facilitate collection of technical and economic data-including your company's technology and service-based approaches to either gas utilization and/or removal and provided to oil and gas production companies to evaluate relative to their specific needs.

Please direct contacts to flaring@eerc.utah.edu or (763) 577-5275. Additional technical information, including specifications, design drawings, and capabilities, may be obtained through the link form.

NO TECHNOLOGY

Energy & Environmental Research Center • 21 North 1760 Street, Stop 9018 • Grand Forks, ND 58037-9018 • USA • Phone: (763) 577-5800 • Fax: (763) 577-5141
 © 2007-2011 University of North Dakota Energy & Environmental Research Center (EERC) EERC

EERC Energy & Environmental Research Center

BAKKENSMART

WISDOMFUL • SAFE • SUSTAINABLE • PROFITABLE

FLARING

Natural Gas Processing

What is Associated Gas?

Why Does Flaring Occur?

Value of Products from One Produced Barrel

EERC Energy & Environmental Research Center

NDIC RESOURCE CHARACTERIZATION

Phase I Final Project Report
 (in accordance with NDIC 2011 through June 30, 2012)

Prepared for:
 Bakken Plan
 North Dakota Industrial Commission
 State Capitol, 600 South
 600 East Broadway Avenue
 Bismarck, ND 58505-0100

Contact: Jim Lindquist, PI

Prepared by:
 Chad S. Walker
 Todd R. Aulick
 Mike S. Patten

Energy & Environmental Research Center
 University of North Dakota
 17 North 1760 Street, Stop 9018
 Grand Forks, ND 58037-9018

600-0000-4633 June 2012

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:

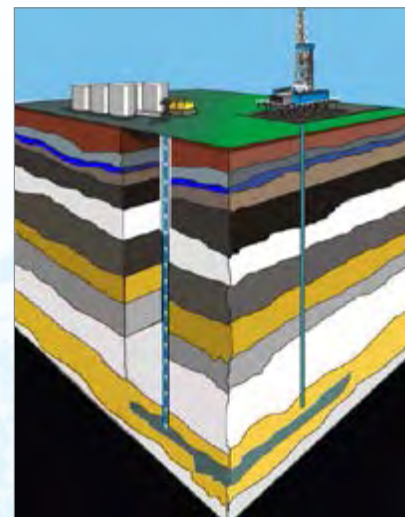
1. A literature survey of public sources of information on crude oil properties.
2. A conceptual crude oil characterization plan that describes the necessary sampling and the analytical and experimental activities needed to provide a comprehensive characterization of crude oil properties.

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.

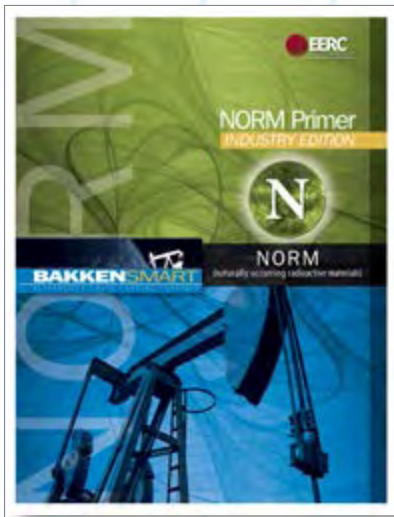
Water Fact Sheet

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

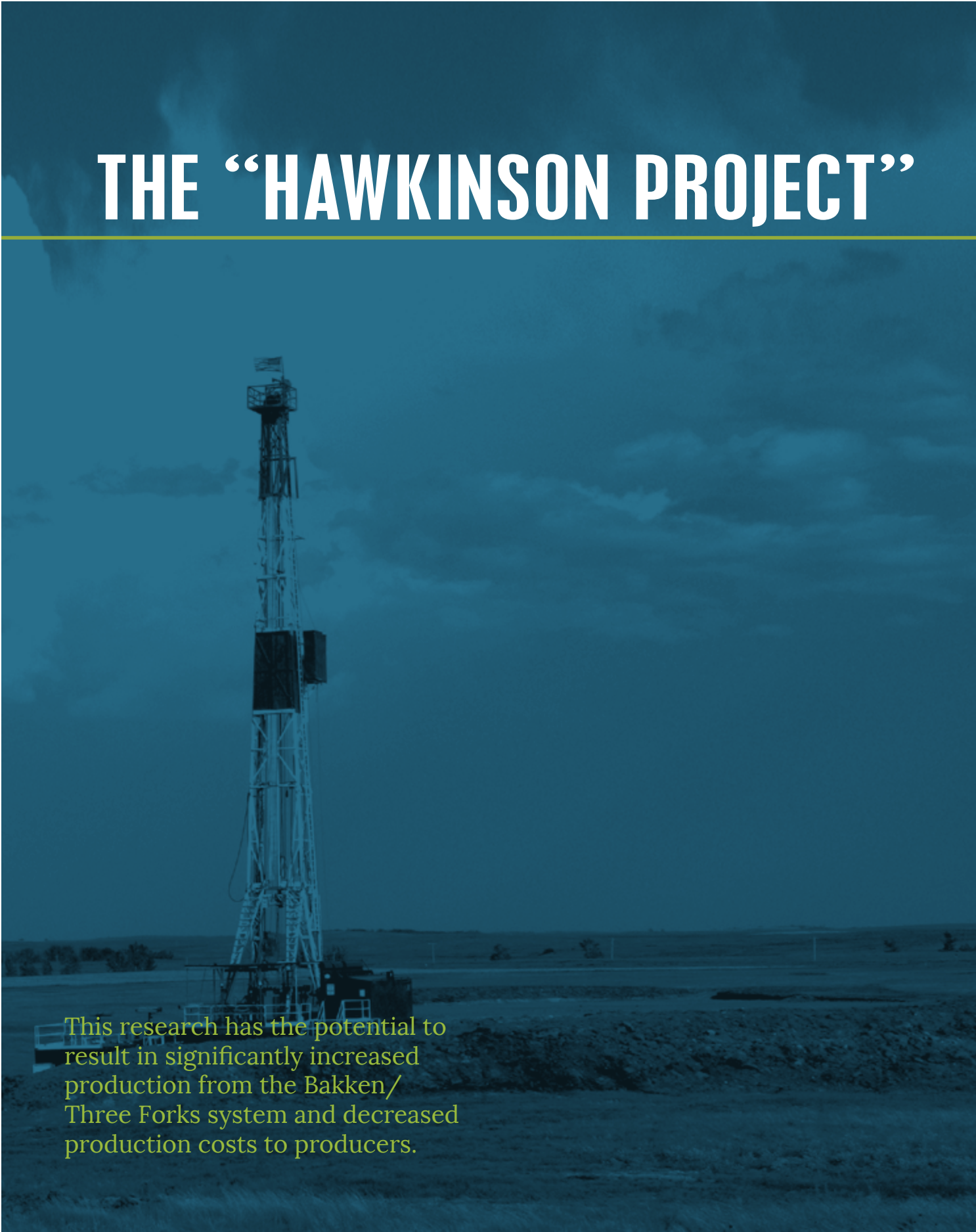
The Spills Cleanup Primer is intended to provide the reader with a fundamental understanding of hydrocarbon and brine spills from oil and gas production and the related remediation and reclamation of these spills. As oil and gas production in the Williston Basin has increased, the number and volume of 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.

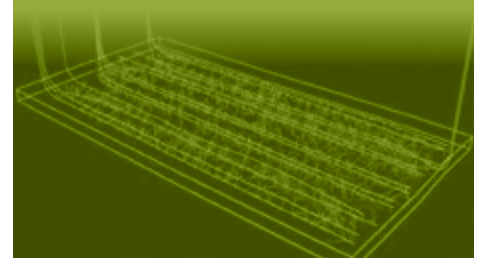
PHASE I

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.

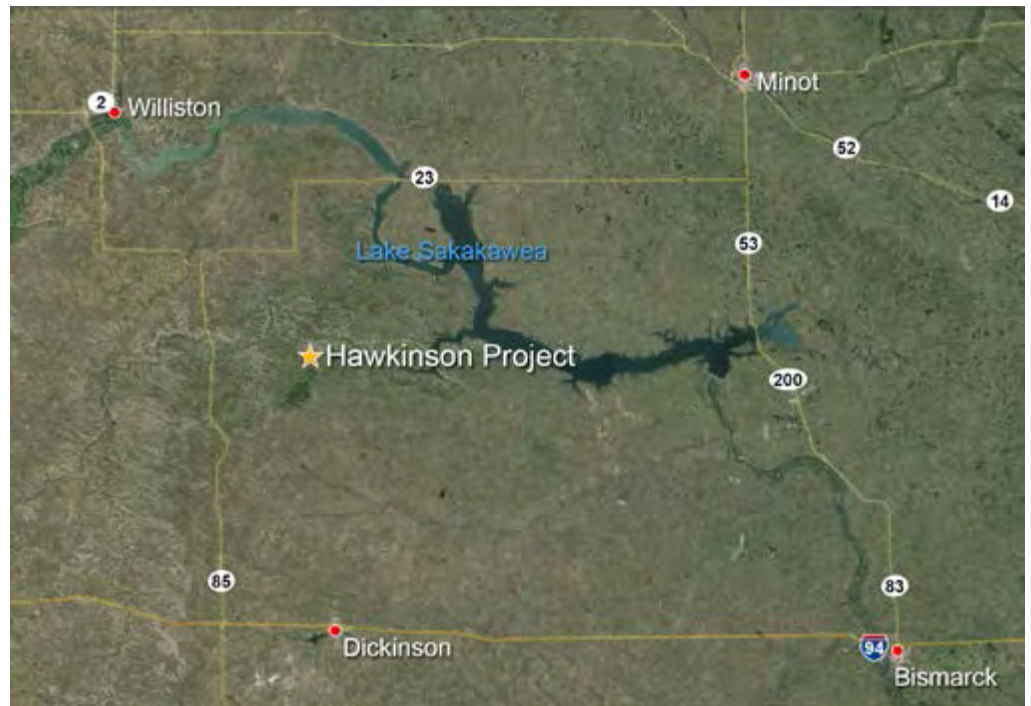


PHASE IV

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

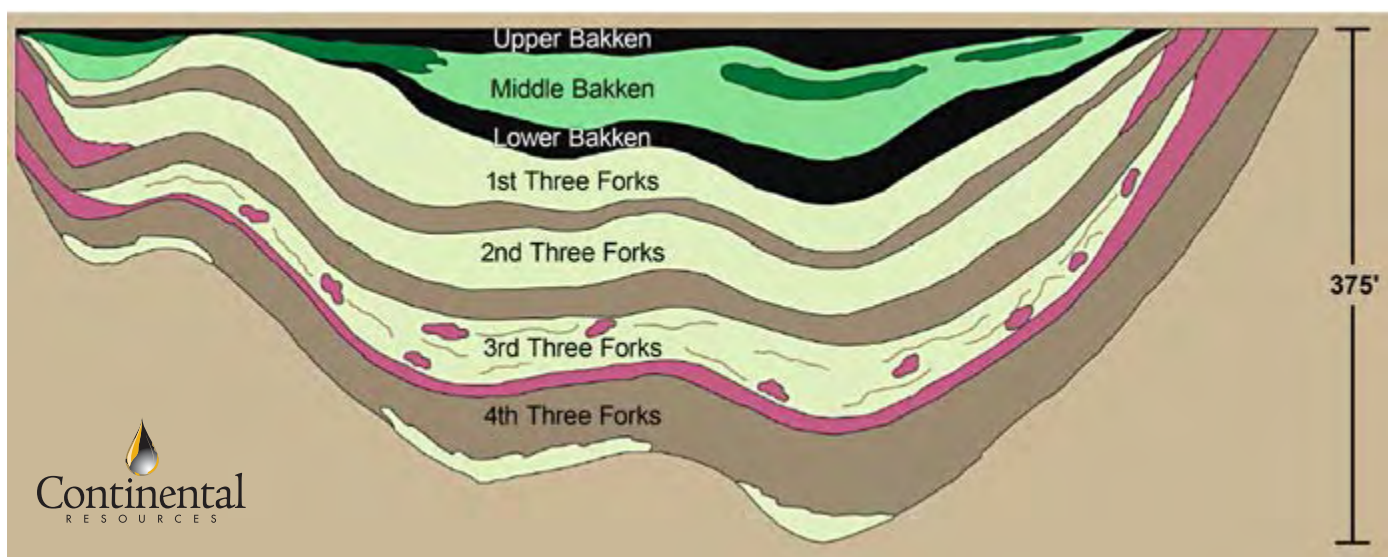
The Hawkinson Project area has already proved productive for the Middle Bakken and first, second, and third benches of the Three Forks zones. The Bakken Formation immediately overlies the Three Forks Formation. This stratigraphic relationship combined with geochemical similarities of the respective formation 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:

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

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.



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

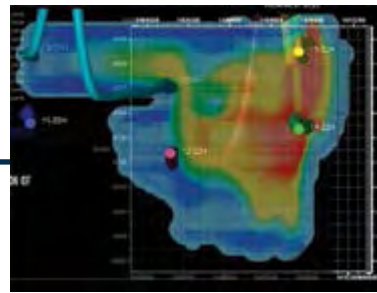
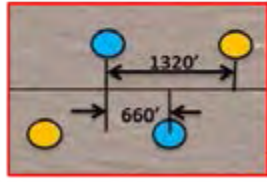
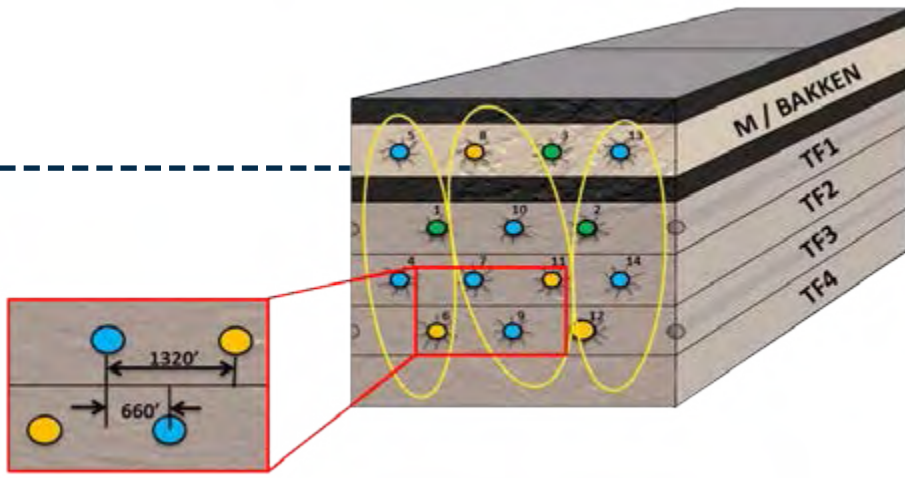
COMPLETIONS

- Completed 11 wells sequentially
- Tracted 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

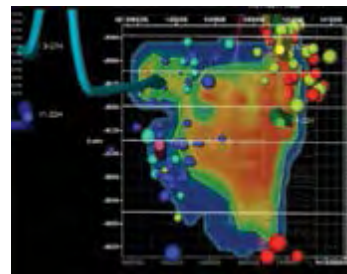
- Ten treatment wells sequentially monitored
- 283 stimulated stages recorded
- 171 tool monitoring days
- Longest laterals with three monitoring wells (>21,000' MD)
- Most footage of tracted tools in a single project (microseismic >270,000'; USIT >40,000')
- Longest lateral footage pulling ten geophone 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



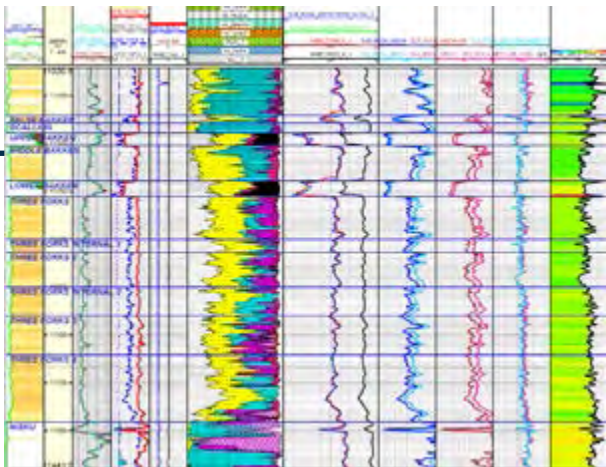
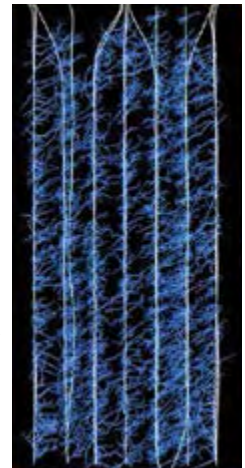
+



↓



→



RESULTS

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 multidisciplinary 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

