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October 15, 2018

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

Dear Ms. Fine:

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

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

Sincerely,

Charles D. Gorecki
Director of Subsurface R&D

CDG/kal

Attachment

BAKKEN PRODUCTION OPTIMIZATION PROGRAM

Quarterly Progress Report

(for the period July 1 – September 30, 2018)

Prepared for:

North Dakota Industrial Commission

Members of the Bakken Production Optimization Program Consortium (BPOP)

ConocoPhillips
Equinor
Hess Corporation
Liberty Resources LLC
Marathon Oil Company
Oasis Petroleum
Petro-Hunt, LLC
WPX Energy
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October 2018

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EXECUTIVE SUMMARY

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

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

- Ongoing collaboration with Liberty Resources (Liberty) to evaluate rich gas enhanced oil recovery (EOR) in the Stomping Horse Oil Factory complex in Williams County.

- Various research efforts to address surface-related issues, including Bakken surface facilities modeling to identify areas to optimize performance, environmental support and produced fluids characterization to support ongoing BPOP activities and to gain a better understanding of geographic and temporal variations in produced oil, water and gas.

- Evaluation of produced brine treatment and storage options, including assessment of the long-term salt water disposal (SWD) potential of the Inyan Kara Formation.

- Evaluation of components that can affect oil production, including assessment of recompletion/refracturing performance, evaluation of geologic and engineering factors that could affect oil production, and analysis of trends in fluid and gas production as a function of completion technique.

This progress report presents an overview of BPOP activities from July 1 through September 30, 2018. During this quarter, a members meeting was held on August 7–8, 2018. The presentations given at the members meeting, which can be found on the members-only Web site, provide details regarding the goals, approach, progress, and current findings for each task.

BPOP activities in support of the rich gas EOR pilot were largely focused on field-based activities at the Leon–Gohrick drill spacing unit (DSU) in the Stomping Horse complex in Williams County, North Dakota. A final round of baseline fluid (oil, gas, water) samples from wells in the Stomping Horse complex was collected and analyzed in early July 2018. Reservoir surveillance and monitoring equipment, including downhole memory gauges to record bottomhole pressure and temperature data, were also deployed in July 2018. In mid-July 2018,

Liberty began initial injection using gas lift compressors into a Three Forks well on the Leon–Gohrick DSU. Subsequent injection into a neighboring Middle Bakken well was conducted in August 2018. Surface and subsurface monitoring data from those injection tests were collected and are in the process of being evaluated and interpreted. Surface facility modeling of the Stomping Horse complex was also completed, the results of which indicate rich gas EOR will not adversely affect the existing configuration of surface facility operations.

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

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

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

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

The remainder of the activities for the next quarter will be determined by NDIC and member input. A survey was provided to each BPOP member following the August 2018 meeting to better define our priority research areas for the next year. The results from the four members that responded to the survey were compiled, and, using this input, individuals from all member companies will be contacted to better define the details of each priority research area.

INTRODUCTION

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

The goals of BPOP are to:

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

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

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

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

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

ACCOMPLISHMENTS DURING REPORTING PERIOD

Enhanced Oil Recovery Task

The goal of the BPOP Enhanced Oil Recovery (EOR) Task is to develop knowledge that will support broad commercial implementation of EOR in the Bakken play. To achieve that goal, the EERC is conducting laboratory-, modeling-, and field-based investigative activities to

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

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

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

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

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

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

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

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

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

- Laboratory-based examinations of rich gas interactions with crude oils and core/cuttings obtained from the Stomping Horse area were conducted to determine the ability of various rich gas mixtures to mobilize oil in the Bakken petroleum system. Results showed that gas mixtures with higher proportions of ethane and/or propane were most effective at mobilizing oil from the rocks, although in some cases pressure also played a substantial role. Laboratory studies previously conducted to determine minimum miscibility pressure (MMP) values for different rich gas components (methane, ethane, and propane individually) using a Middle Bakken crude oil were expanded to include several different ratios of produced gas methane/ethane/propane mixtures. Results showed higher percentages of ethane and/or propane in a rich gas mixture can have a significant impact on lowering MMP values.

- An overview of the laboratory-based experiments, modeling and simulation results, and field-based activities to date was presented at three meetings/conferences this quarter. "Bakken Rich Gas EOR Project" was presented at the Annual Members Meeting held at the EERC August 7–8, 2018, and is available on the members-only Web site. "Bakken Rich Gas EOR Project" was presented at the DOE Mastering the Subsurface Meeting in Pittsburgh, Pennsylvania, on August 15, 2018 (Appendix A). "Stomping Horse Bakken EOR Project – Science & Technology in Action" was presented at the North Dakota Petroleum Council Annual Meeting in Fargo, North Dakota, on September 25, 2018 (Appendix B).

- Modeling and dynamic simulation activities provide technical support and guidance to the design of the pilot injection/production scheme. Static geocellular modeling of the Bakken petroleum system at the Stomping Horse location and dynamic simulations of potential EOR schemes have been used to predict EOR performance using a cyclic multiwell huff 'n' puff scheme. A geocellular model of the Stomping Horse DSU has been created using data provided by Liberty. History-matching exercises, using detailed operational data provided by the project partner have been conducted to validate the geocellular model. Several potential pilot test operational scenarios have been tested with dynamic simulations.

  – During the past quarter, the team has continued work on the calibration of the DSU-scale geologic model, which was previously constructed. The geologic model captures site-specific features such as geologic structure, lithofacies distribution, and initial reservoir pressure and saturation spatial distribution. The DSU model was built to incorporate operational data collected during the field test. The model uses a tailored equation-of-state model, calibrated with pressure–volume–temperature laboratory measurements (provided by Liberty), which allows simulating both lean and rich gas injection operations. The DSU model domain incorporates two well pads, with 11 horizontal wells, perforated in the Middle Bakken or the Three Forks Formations, totaling more than 500 hydraulic fractures. In this quarter, the DSU model was successfully calibrated to reproduce field-observed fluid rates (gas, oil, and water phases) during the first year of historical production. In addition, the model honors the oil production rates during the collected historical period (from August 2013 to December 2017). Furthermore, preliminary results on the evaluation

of the EOR performance using a mechanistic model have shown that 1) injectivity does not seem to be an issue, and 2) higher injection pressures (and therefore higher injected fluid densities) seem to sustain hydrocarbon recovery.

- Laboratory-based flow-through tests using Bakken shale core plugs and rich gas components were initiated to determine the permeability and sorption behavior of rich gas components in Bakken shale. Orders will be placed for the purchase of a high-pressure magnetic balance and specialized centrifuge for use in these investigations.

- Laboratory-based investigations of the miscibility behavior of rich gas components and Middle Bakken crude oil from the Stomping Horse complex under different temperature and pressure conditions were initiated. The purpose of these experiments, which use the same test cell as the MMP studies, is to quantitatively determine hydrocarbon partitioning between different phases to determine which hydrocarbon species are most mobilized as pressure increases and which are lost as pressure decreases.

- Surface facility modeling of the Stomping Horse complex using a dynamic computational modeling package, VMGSim, was completed. The purpose of this modeling was to evaluate the potential effects of rich gas EOR activities on the operations of the infrastructure of the Stomping Horse complex, including compressors, separators, pipes, and the County Line gas-processing plant. Results of the modeling indicate rich gas EOR will not adversely affect surface facility operations at the Stomping Horse complex. A white paper on the results of these surface facility modeling activities will be prepared during the next quarter.

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

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

Refracturing Optimization Task

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

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

Produced Fluid Characterization Task

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

Key accomplishments for this quarter include continued collaboration with key industry partners to obtain access to fluids sample collection and acquisition of existing compositional data to support the ongoing research efforts of individual BPOP program tasks. Sampling and analysis activities have also continued, supporting an increased geographical distribution of data and providing a temporal evaluation of compositional changes throughout a well's production life. Specific activities conducted this quarter include the following:

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

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

- Began sampling and analysis activities on fluid samples from two adjacent producing Bakken wells (one stimulated and one nonstimulated) for the purpose of evaluating compositional differences that may indicate possible fluid migration pathways.

- Conducted additional sample collection and analysis on four separate wells for the purpose of a temporal evaluation of compositional changes throughout the production life of newly established wells.

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

Reservoir Performance Modeling Task

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

However, some older wells outperform younger wells despite the technology improvements, which suggests that geology or other factors have a greater impact on long-term oil production than the engineering practices of drilling and hydraulic fracturing. This study employed multivariate statistical analysis to evaluate the factors that influence well production performance in the Bakken. The database compiled for this work includes 400 wells completed in the Bakken and Three Forks Formations with a broad geographic distribution. Approximately 30 different factors (completion-related and geology-related) were analyzed to assess their effects on short-term (6-month) and long-term (60-month) production using a multivariate statistical approach.

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

Water Injection Reservoir Assessment Task

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

The modeling and simulation portion of this task is complete and a report summarizing the approach, results, and conclusions is available on the BPOP members-only Web site. The results and conclusions of this task were also presented to members during the August 2018 BPOP Annual Members Meeting. A copy of the presentation is also available on the Web site. This report and accompanying presentation will be available to the public in October 2019.

As a complementary activity for this task, the EERC has been working on the development of simplistic spreadsheet-based models that allow the user to estimate the radius of influence of individual SWD wells based on basic geologic characteristics (cumulative sand thickness, average porosity, and average permeability), injection rate, and period of performance. This past quarter, two additional spreadsheet models were developed and included in the overall spreadsheet package.

Brine Treatment and Storage Assessment

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

Bakken Trend Analysis

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

Facility Process Optimization Task

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

Within the past quarter, this task focused on the issue of weather-induced changes to crude oil vapor pressure. Typically, vapor pressure specifications are most difficult to meet during winter months when there is excessive heat loss from exposed process equipment. To evaluate solutions for this problem the EERC created cold-weather models that were validated using site-specific data collected from two BPOP member sites. Specific accomplishments during the quarter included the following:

- Modeling was completed for two member surface facilities regarding the effects of cold-weather operation on oil vapor pressure. The analysis included predicting performance of the as-sampled facilities and evaluating design changes that could ensure vapor pressure compliance during cold weather.

- Results from this study were summarized into a short technical brief and an accompanying set of presentation slides for dissemination to the BPOP membership.

- Individual teleconferences were held with both BPOP members that provided data to the study. During each call, preliminary modeling results were discussed and helpful improvements were noted.

- A summary presentation of the cold-weather vapor pressure modeling work was provided to BPOP members during the Annual Members Meeting on August 8, 2018.

Aromatic/Aliphatic Study Task

Analyses at the EERC of the aromatic and aliphatic hydrocarbons in rock core samples from across the Williston Basin have shown that the aromatic/aliphatic ratios (A/A ratios) are ca.

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

- Data reduction is continuing on the 40 Lower and Upper Bakken shale samples that were extracted and analyzed as reported in previous quarters, as well as the additional 33 rock core samples including several Middle Bakken, Three Forks, Pronghorn, and additional Upper and Lower Bakken shales that were extracted and analyzed for their aromatic/aliphatic ratios reported in the last quarter. These samples were selected to give complete profiles (including multiple depths of single lithofacies for some wells) of multiple wells including all relevant source and reservoir rocks.

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

- An update of these experiments and the results to date was presented at the BPOP Annual Members Meeting.

Environmental Support Task

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

Activities during this quarter included the following:

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

Program Management and Development

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

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

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

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

TRAVEL ACTIVITIES

Representatives from BPOP incurred travel costs for their participation in the following meetings/conferences and sampling trips:

- July 9–12 and August 29, 2018: traveled to the Liberty well sites near Tioga, North Dakota, to conduct sample collection.
- July 17–22, 2018: traveled to New Town, North Dakota, to attend networking events, including a Liberty open house.
- July 18–21, 2018: traveled to the Liberty wellsites near Tioga, North Dakota, to conduct field work related to gas compression and injection.
- July 20–21, 2018: traveled to Tioga, North Dakota, to attend Liberty Resources Community Appreciation Day.
- July 22–26, 2018: traveled to Houston, Texas, to attend the Unconventional Resources Technology Conference.
- August 12–17, 2018: traveled to Pittsburgh, Pennsylvania, to attend the Mastering the Subsurface Through Technology Innovation Partnerships and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting.
- August 30, 2018: traveled to a wellsite owned by Marathon Oil Company to collect samples from a stimulated and nonstimulated Bakken Formation well.

- August 30–31, 2018: traveled to Bismarck, North Dakota, to attend a meeting with XTO.

MEMBERSHIP AND FINANCIAL INFORMATION

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

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

Table 1. BPOP – Original Budget

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

Table 2. BPOP Members

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

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

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

Table 3. BPOP – Expected Budget and Expenses to Date

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

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

FUTURE ACTIVITIES

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

Enhanced Oil Recovery Task

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

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

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

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

Refracturing Optimization Task

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

Produced Fluid Characterization Task

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

the size and usefulness of the database to the various BPOP research efforts. Specific activities to be conducted include the following:

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

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

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

Reservoir Performance Modeling Task

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

Water Injection Reservoir Assessment Task

Activities will focus on expanding and reviewing simplistic spreadsheet models to evaluate the area of influence of SWD wells. The spreadsheet models will also be presented to the BPOP members for input.

Brine Treatment and Storage Assessment

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

Bakken Trend Analysis

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

Facility Process Optimization Task

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

Aromatic/Aliphatic Study Task

Work will continue on the evaluation of the aromatic/aliphatic ratios within crude oil samples. Upcoming activities over the next quarter include ongoing collaboration with the

Canadian Geological Survey and compilation of the aromatic/aliphatic results for the rock samples that have been analyzed to date. The temporal analysis of aromatic/aliphatic ratios from select producing wells will also continue as additional samples are collected.

Environmental Support Task

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

Program Management and Development

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

APPENDIX A

BAKKEN RICH GAS EOR PROJECT

Energy & Environmental Research Center (EERC)

BAKKEN RICH GAS EOR PROJECT

Jim Sorensen

Assistant Director of Subsurface Strategies

U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 13–16, 2018

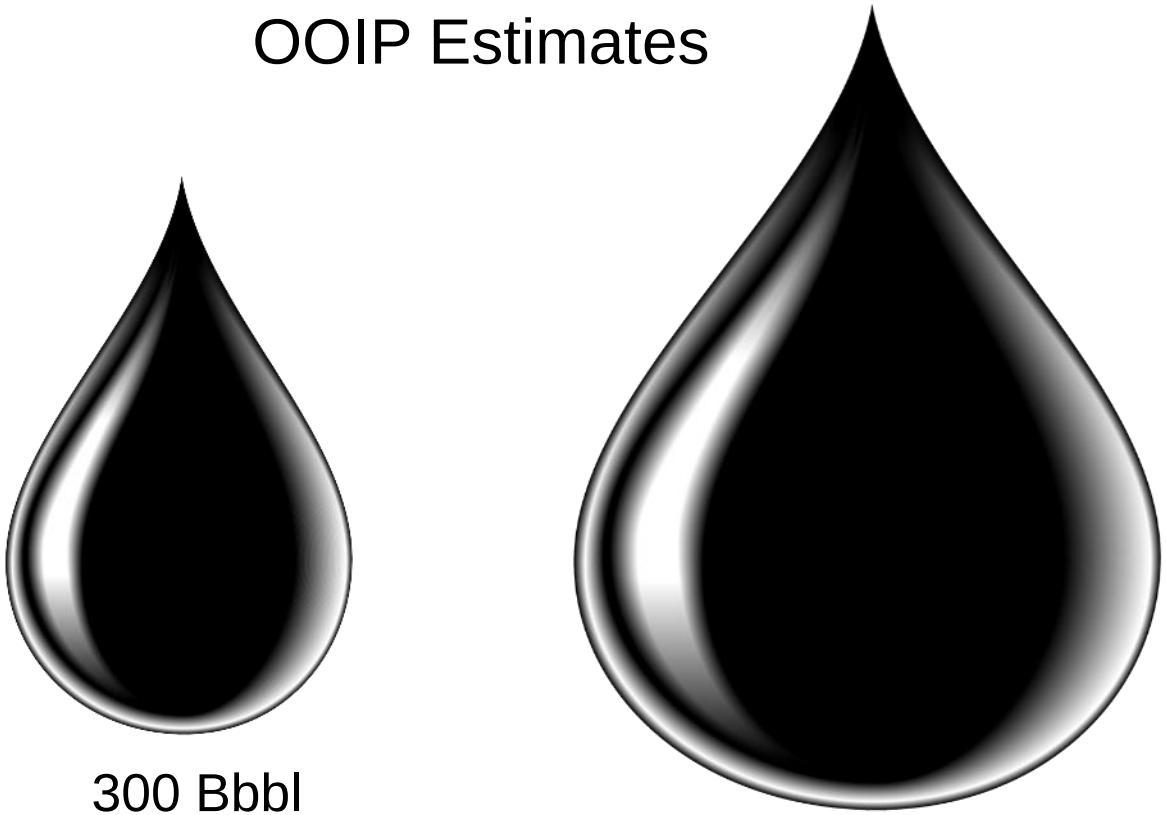
Critical Challenges. Practical Solutions.

PRESENTATION OUTLINE

- Background
- Project Overview
- Key Lessons Learned
- Future Directions

BACKGROUND – BAKKEN EOR SIZE OF THE PRIZE

OOIP Estimates



300 Bbbl
(Flannery and Kraus, 2006)

900 Bbbl
(Continental Resources, 2011)

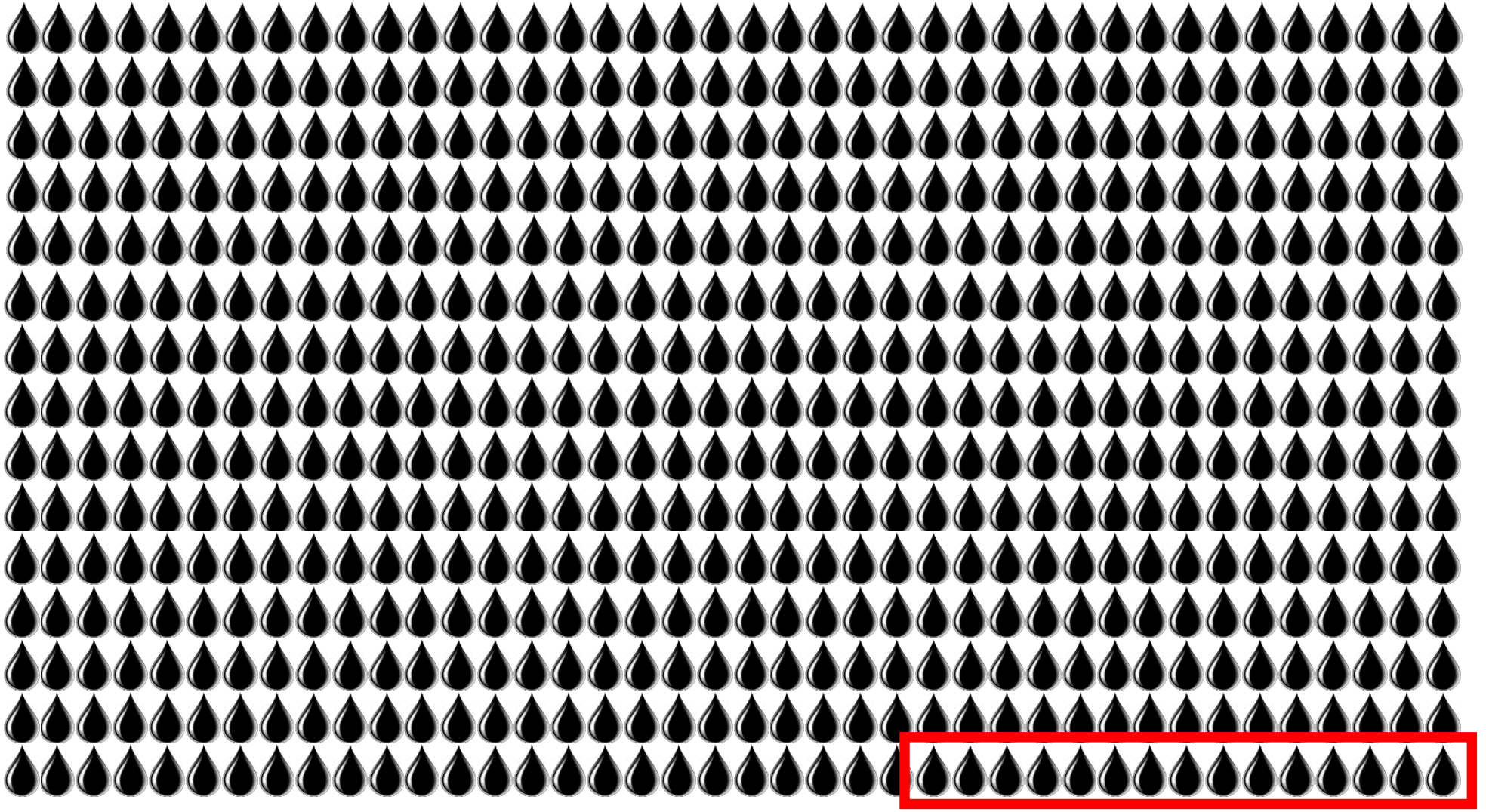
Technically Recoverable Reserve Estimates

7.4 Bbbl
(USGS, 2013)

24 Bbbl
(Continental Resource, 2011)

Business as usual gets about 15 billion barrels

LEAVES A LOT OF BAKKEN OIL TO CHASE!



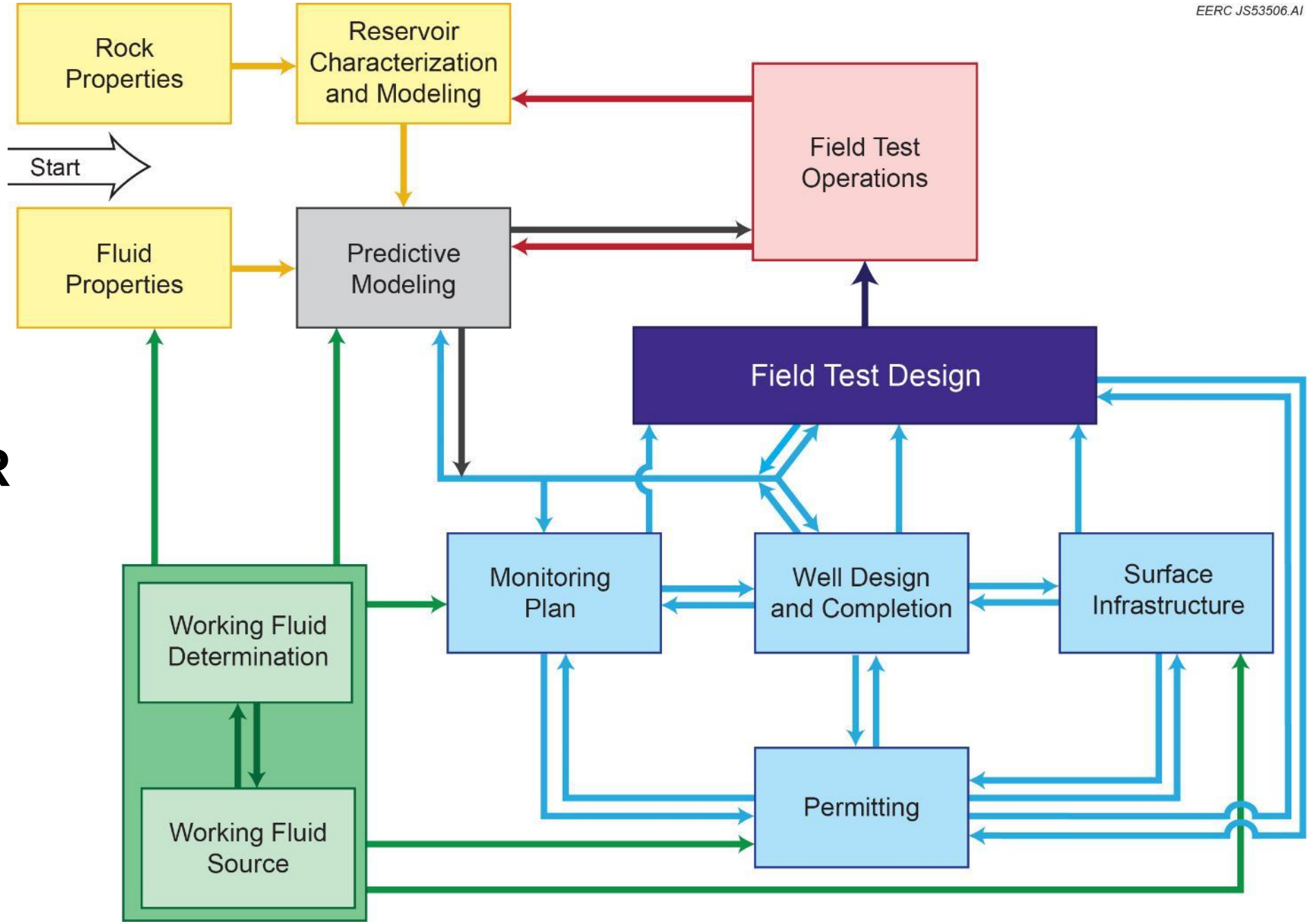
TECHNICAL STATUS

Lab experiments!

Modeling and simulations!

Injection tests!

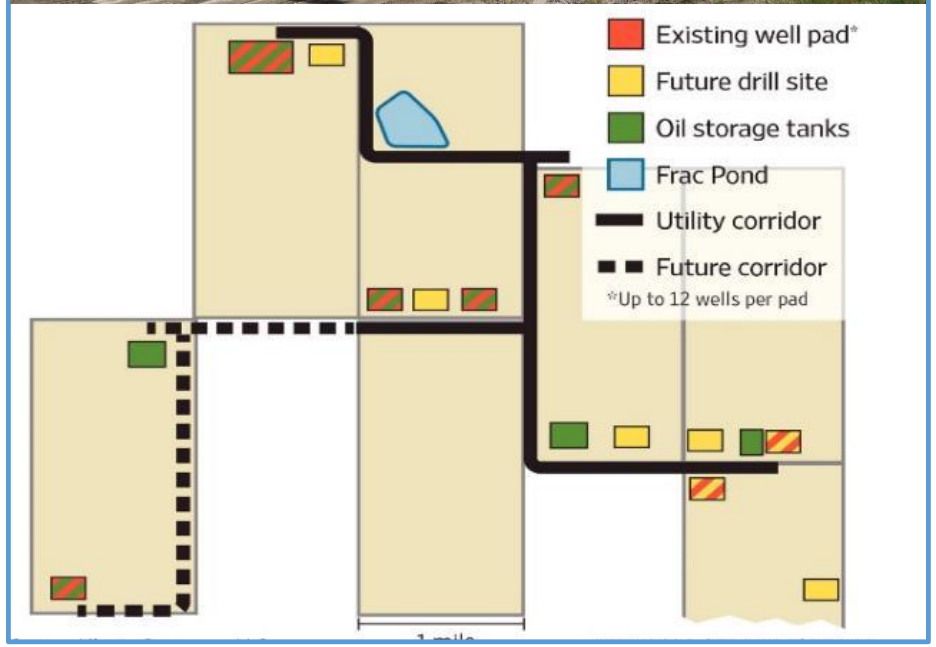
WHAT DOES IT TAKE TO DO AN EFFECTIVE EOR PILOT?



STOMPING HORSE OIL FACTORY

- A methodical, structured approach to oilfield development
- Maximizing field and DSU productivity, ***including the use of rich gas for EOR***

- Liberty approached the EERC in December 2016 to explore partnering on an EOR test at Stomping Horse.
- In 2017 DOE NETL and the North Dakota Oil & Gas Research Program provided funding.



LIBERTY RESOURCES

NETL

North Dakota oil & gas research program

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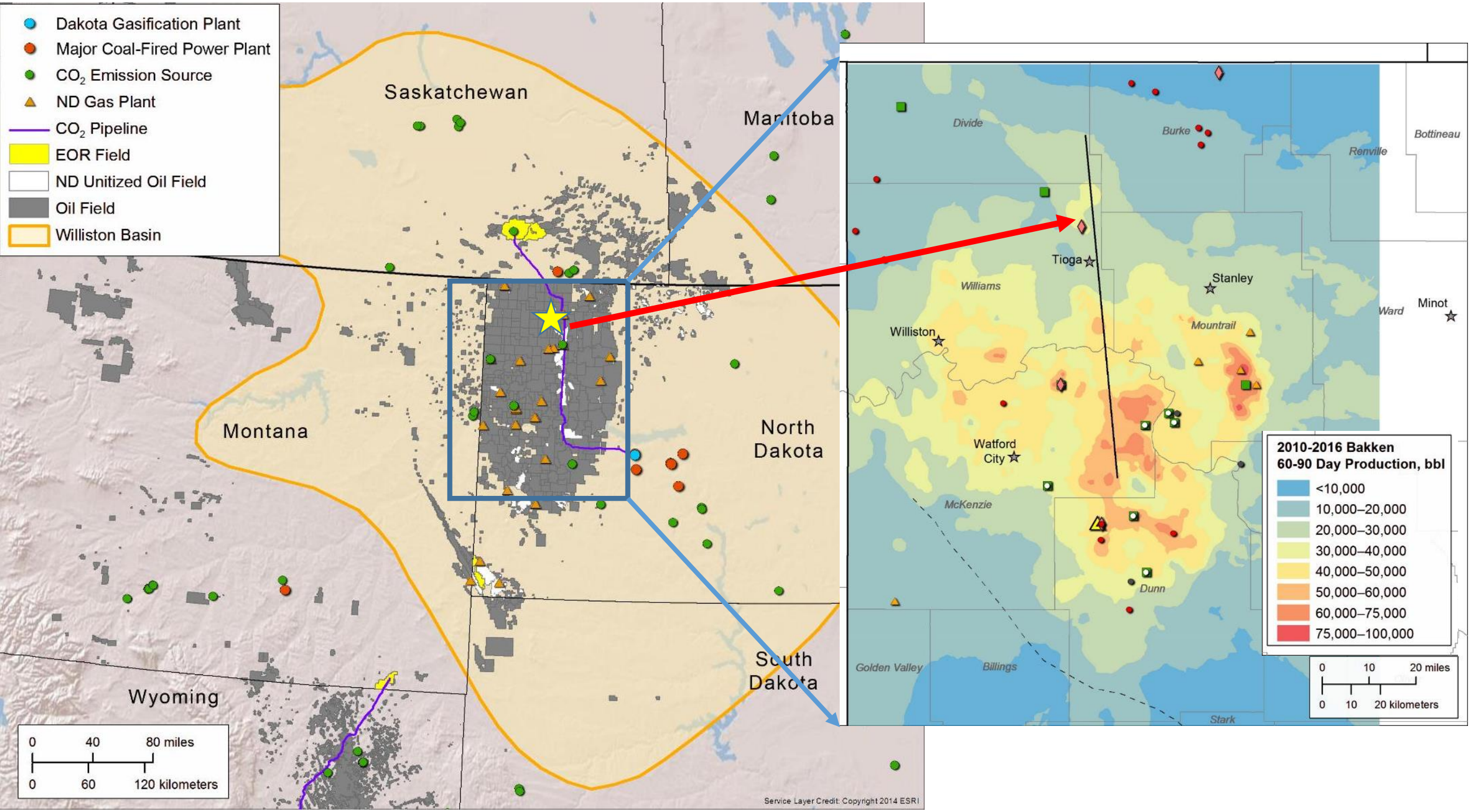
Critical Challenges. Practical Solutions.


Dakota Gasification Plant
Major Coal-Fired Power Plant
CO_2 Emission Source
ND Gas Plant
CO_2 Pipeline
EOR Field
ND Unitized Oil Field
Oil Field
Williston Basin
Saskatchewan
Manitoba
Montana
North Dakota
South Dakota
Wyoming
0 40 80 miles
0 60 120 kilometers
Service Layer Credit: Copyright 2014 ESRI
Divide
Burke
Renville
Bottineau
Williams
Tioga
Stanley
Minot
Ward
Mountrail
Williston
Watford City
McKenzie
Dunn
Golden Valley
Billings
Stark
2010-2016 Bakken
60-90 Day Production, bbl
<10,000
10,000–20,000
20,000–30,000
30,000–40,000
40,000–50,000
50,000–60,000
60,000–75,000
75,000–100,000
0 10 20 miles
0 10 20 kilometers

STOMPING HORSE RICH GAS COMPOSITIONS

Alternative injection compositions available with proximity to LMS's County Line Gas Plant.

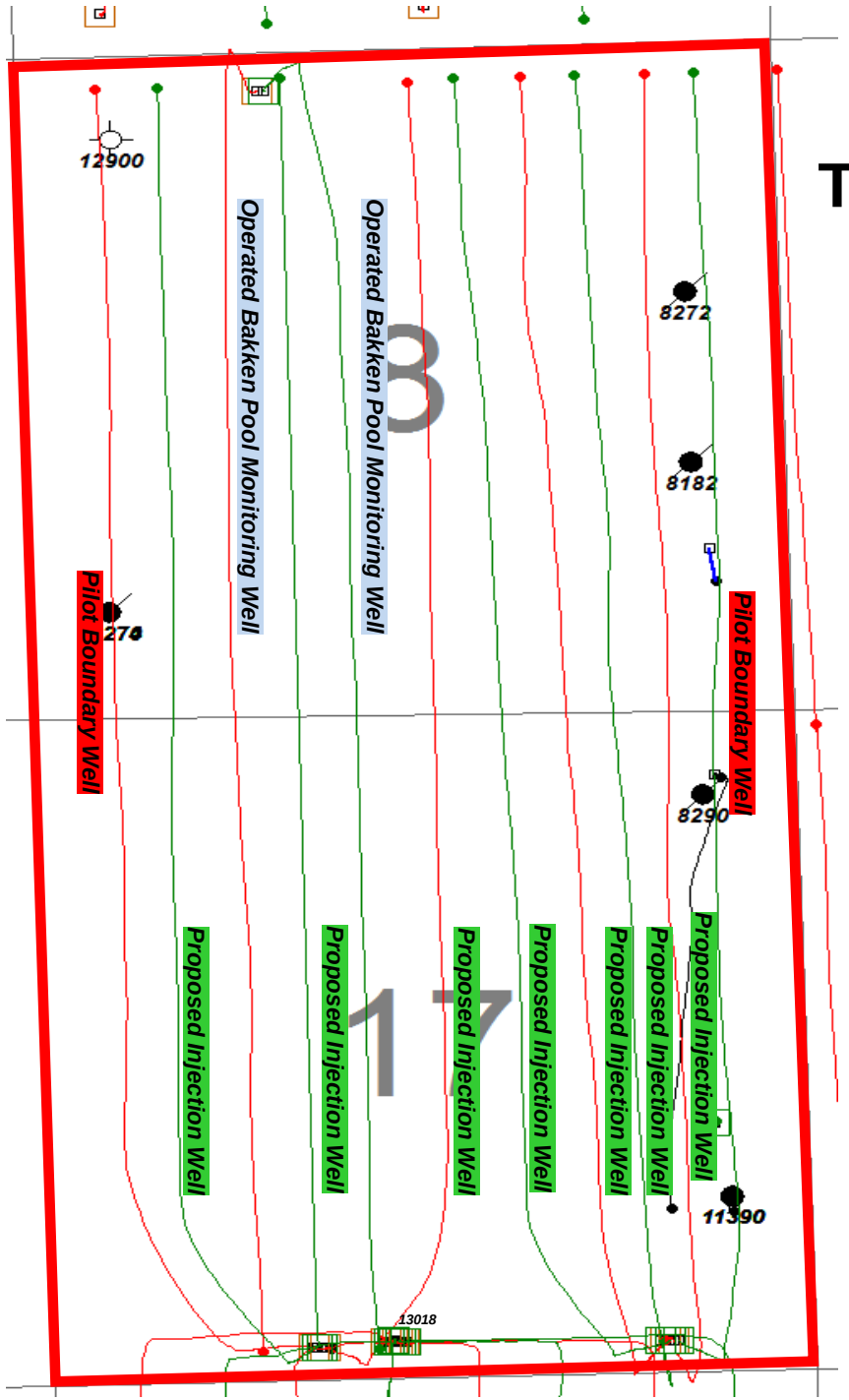
	WELLHEAD	PLANT INLET	DEETHANIZER	PLANT EXIT
METHANE	60%	62.7%	51%	71%
ETHANE	20%	21.4%	46%	22%
PROPANE	10%	11.4%	0.5%	2.0%
C4+	1.4%	1.2%	0.0%	1.6%
CO2	0.8%	0.9%	1.3%	1.0%
BTU	~1500	~1450	~1300	~1175

MULTIWELL PILOT LAYOUT

Planned Injection Wells – Operated Bakken pool well proposed for rich gas injection during EOR pilot.

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

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



The Leon & Gohrick Pads

LIBERTY RESOURCES

Exhibit E-5
Case No. 26035

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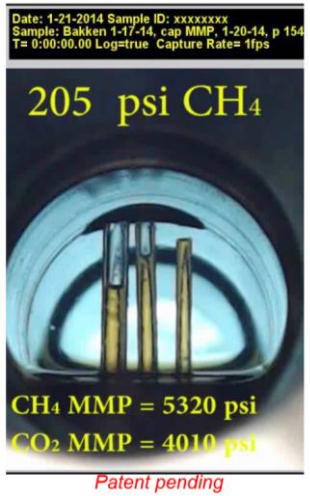
Critical Challenges. **Practical Solutions.**

GOALS AND OBJECTIVES OF THE RESEARCH PROJECT

- Determine the ability of various rich gas mixtures (methane, ethane, propane) to mobilize oil in a Bakken reservoir.
- Determine the changes in gas and fluid compositions over time in both the reservoir and the surface infrastructure environments, assessing how those changes affect reservoir and process facility performance.
- Optimize future commercial-scale tight oil EOR design and operations using data generated in the lab and the field.
- Establish the effectiveness of selected monitoring techniques for reservoir surveillance and injection conformance monitoring.

RICH GAS–OIL FLUID BEHAVIOR AND ROCK EXTRACTION STUDIES

MMP Studies

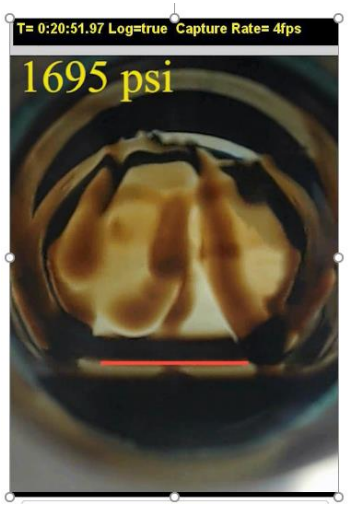


MMP of rich gas components and different rich gas mixtures in oil.

- Methane, ethane, and propane.

Approximately 80 MMP determinations are anticipated.

Miscible Behavior Studies



Which hydrocarbons partition into this "miscible" upper phase?

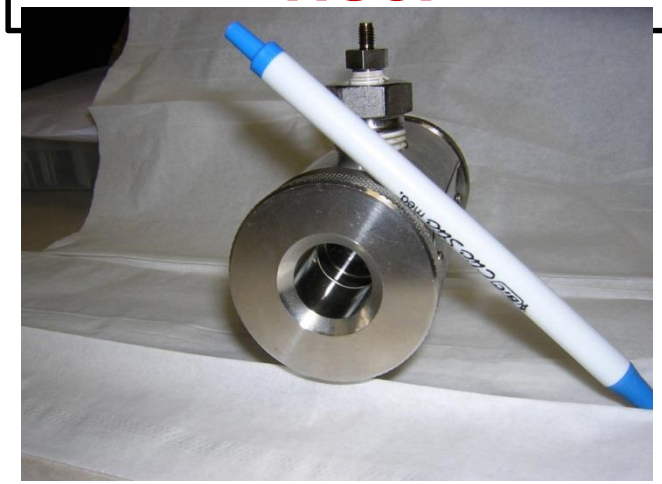
Which hydrocarbons are lost as pressure drops?

Rock Extraction Studies

Determine ability of rich gas components to mobilize oil from the Bakken matrix.

- Methane, ethane, and propane at reservoir conditions.

MMP by vanishing interfacial tension/capillary rise.



1.12, 0.84, 0.68 mm i.d.

Rapid and Simple Capillary-Rise/Vanishing Interfacial Tension Method To Determine Crude Oil Minimum Miscibility Pressure: Pure and Mixed CO_2, Methane, and Ethane

Steven B. Hawthorne, David J. Miller, Lu Jin, and Charles D. Gorecki

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

energy&fuels

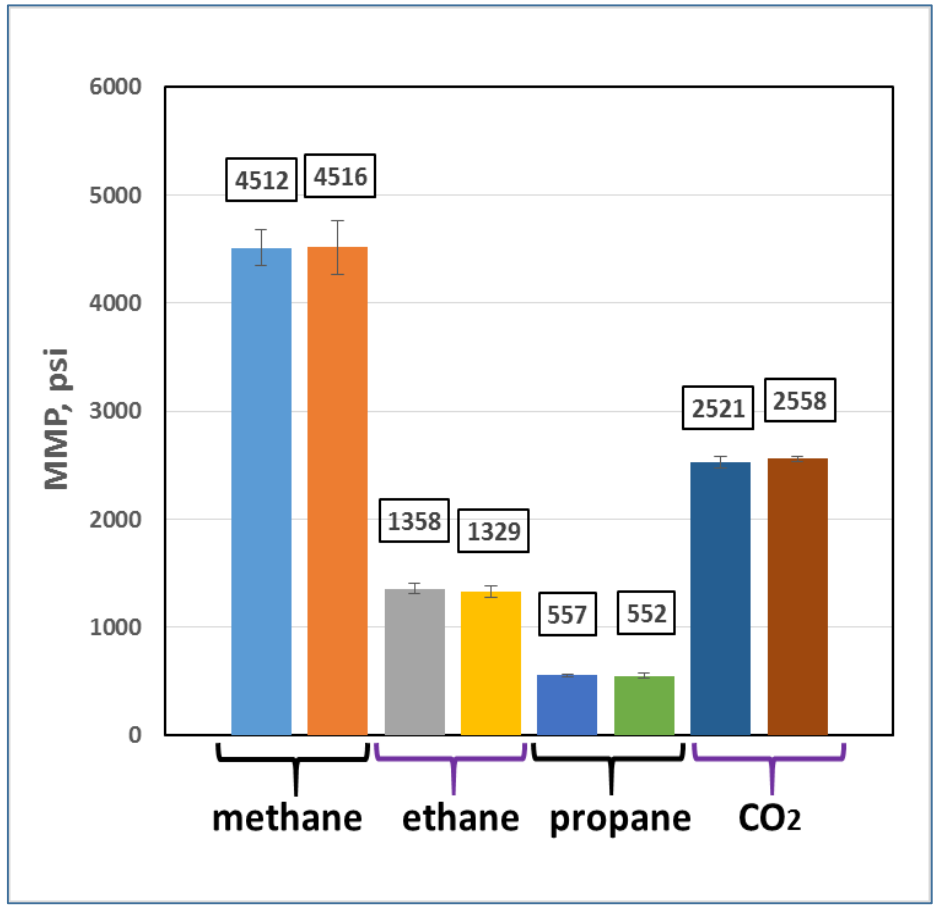
Reprinted from
Volume 30, Number 8, Pages 6365-6372

U.S. Patent 9,851,339

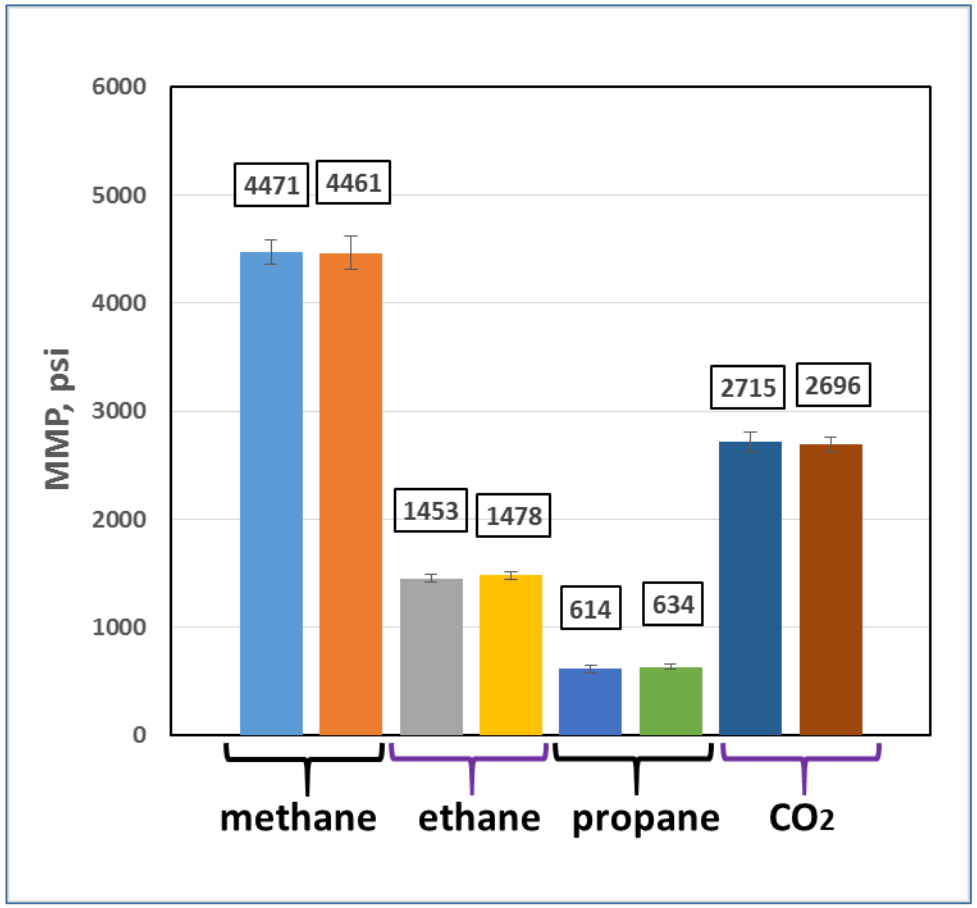
MMP with Methane, Ethane, Propane, and CO_2*

The richer the gas, the lower the MMP!!

Bakken Crude Oil (230 F, 110



Three Forks Crude (264 F,



* CO_2 MMPs were determined under separate funding from the DOE and are presented only for comparison purposes.

ROCK EXTRACTION STUDIES

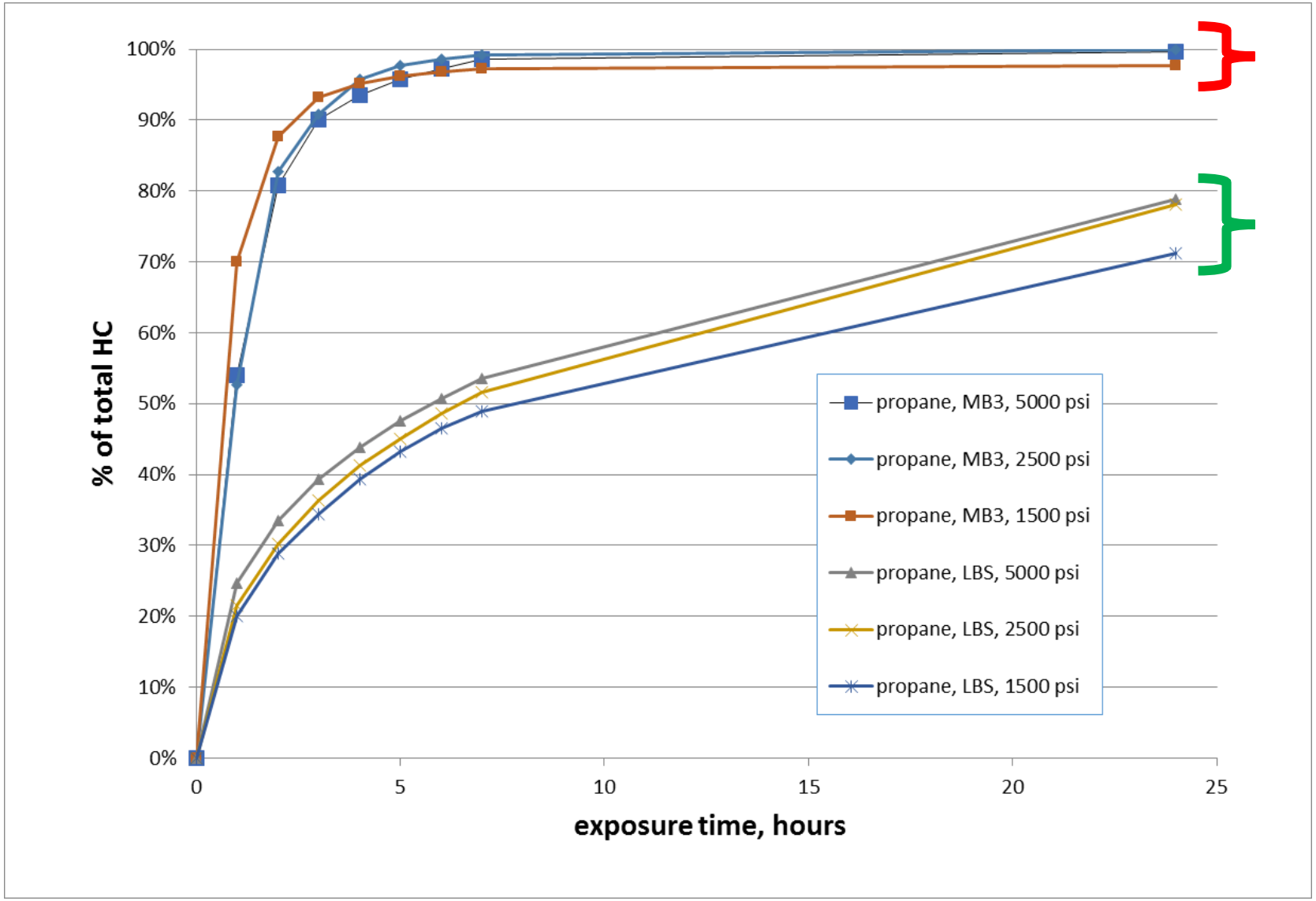
Determine ability of methane, ethane, and propane at different pressures to recover hydrocarbons from Middle Bakken and Bakken Shale rock samples

Laboratory Exposures Include:

>***VERY*** small core samples (11-mm rod for Middle Bakken, 1–3.4 mm crushed rock for Upper and Lower shales).

- Rock is “bathed” in the fluid to mimic fracture flow, not swept with the fluid.
- Recovered oil hydrocarbons are collected periodically and analyzed by gas chromatography/flame ionization detection (GC/FID) (kerogen not determined); 100% recovery based on rock crushed and solvent extracted after gas exposure.
- Exposures at 1500 to 5000 psi, 230 ^{o}F (110 C).

Total HC recovery from Middle Bakken (11-mm rod) and Lower Bakken Shale (1–3.4 mm) using propane is not affected much pressure.



Middle Bakken nonshale results

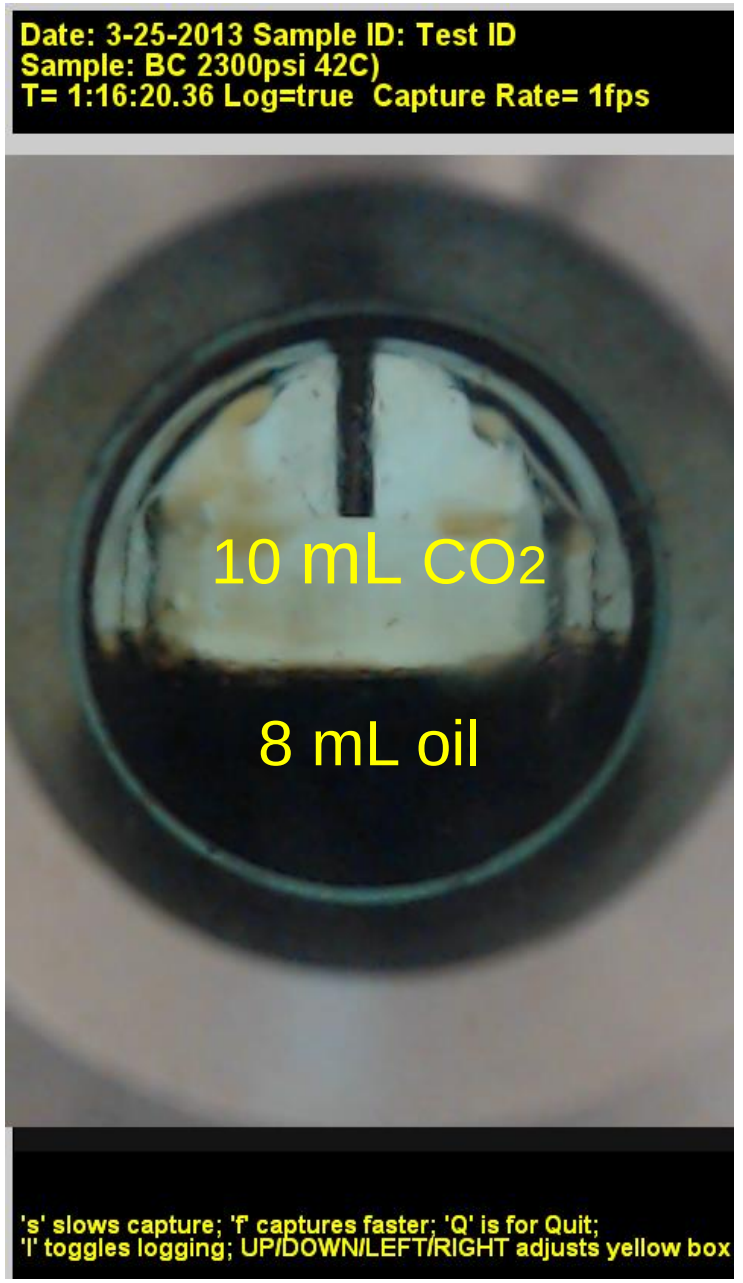
Lower Bakken shale results

MISCIBLE BEHAVIOR STUDIES

We have never observed true chemical miscibility (single phase) between injected fluids (CO_2, methane, ethane, and propane) and crude oil under any T and P conditions.

So if the oil and the injected fluids are not truly miscible, what oil components are in the “miscible” phase?

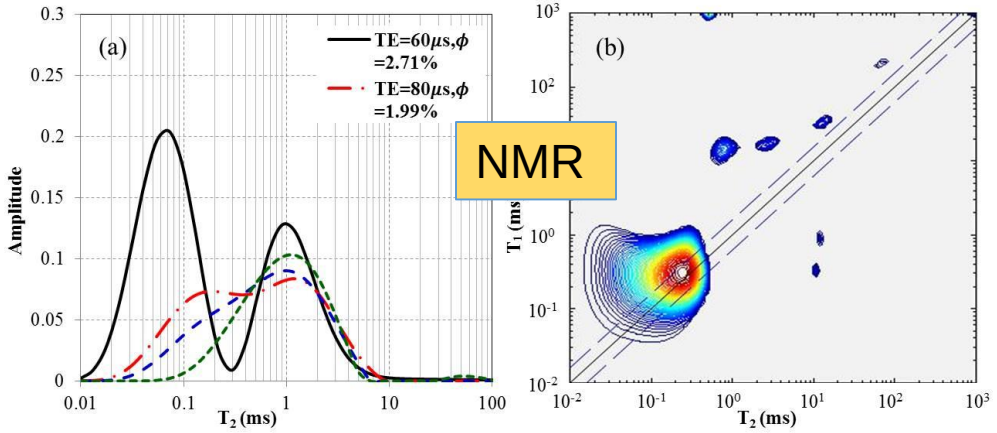
Initial experiments have been conducted, and results are being interpreted and assessed.

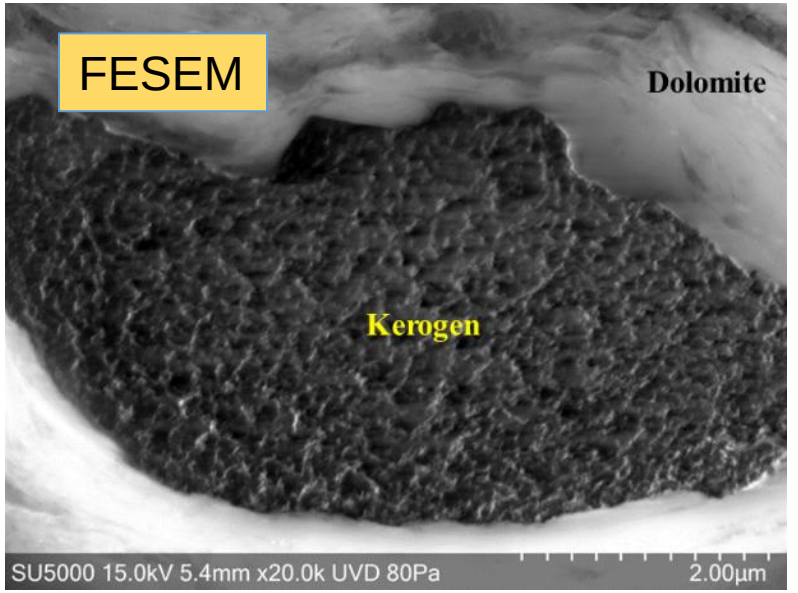


RICH GAS IN SHALE PERMEABILITY AND SORPTION STUDIES

Determine the permeability and sorption behavior of rich gas components in Bakken shale.

- **Flow-through tests using rich gas mixtures (ethane and methane)**
- **Advanced characterization to determine effects of gas exposure on rock properties**
  - **Nuclear magnetic resonance (NMR) to measure gas mobility**
  - **Field emission scanning electron microscopy (FESEM) to evaluate changes in mineralogy, organic matter, and porosity**





RICH GAS CHARACTERIZATION FOR EOR OPERATIONS

Rich Gas Recovery, Processing, and Reinjection and Examinations of Temporal Changes in Fluid Composition

- Determine quality and quantity of rich gas available from Stomping Horse complex
- Process modeling to assess gas treatment requirements and potential effects of changing fluid composition on equipment
- Modeling to help determine compression requirements

FLUIDS MONITORING

- Baseline gas composition has been established by the EERC for all 24 wells within the study area.
- Background crude and water samples have been collected and analyzed.
  - Evaluating API gravity, molecular weight distribution, and general water chemistry.

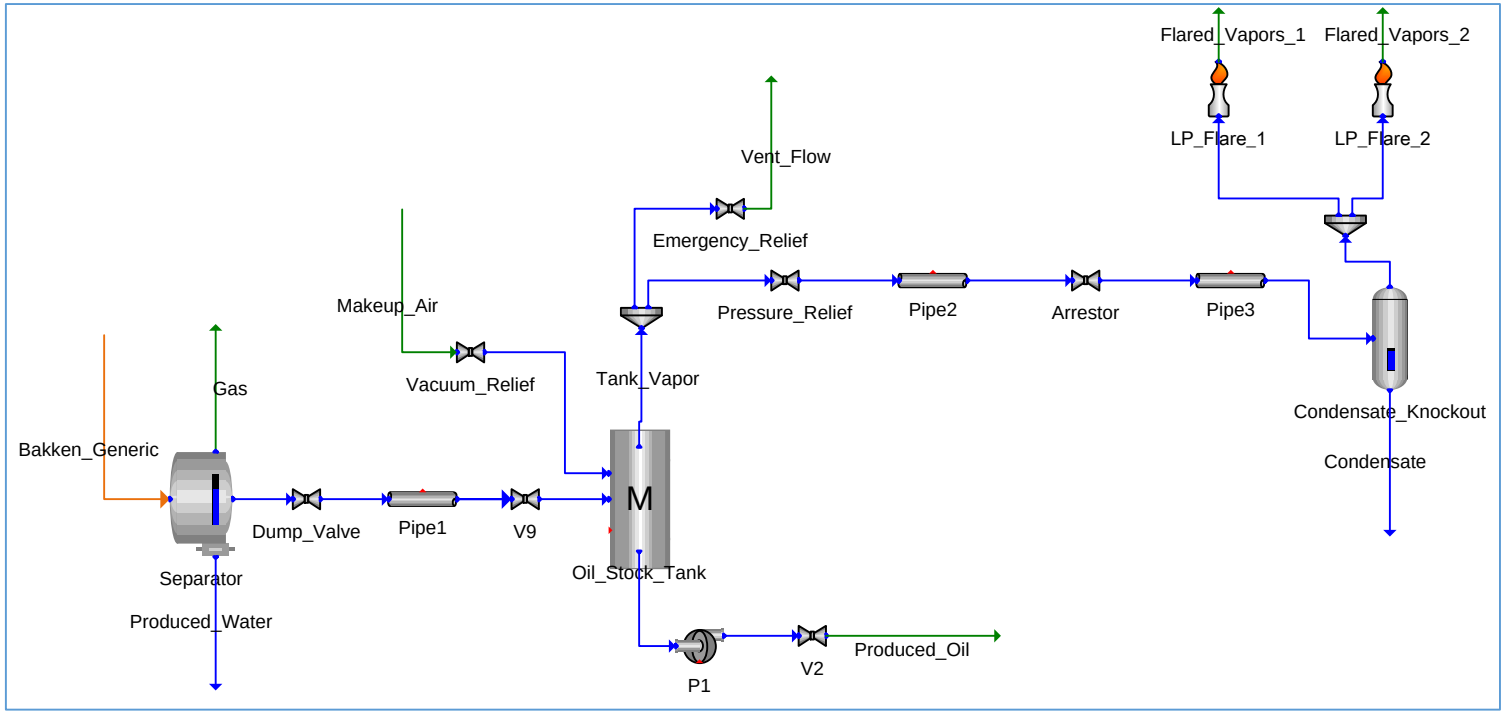
SURFACE FACILITY MODELING

- The purpose of this task is to evaluate how rich gas injection may impact surface equipment.

- Rich gas injection can impact:
  - Production rates.
  - Gas to oil ratio.
  - Produced fluid properties.
  - Separation efficiency.
  - Fluid velocity and pipe sizing.

SURFACE FACILITY MODELING – STATUS

- A dynamic computational modeling package, VMGSim was used to build a representation of the Stomping Horse facility.
- A representative produced fluid composition was developed based on historical analytical data (oil, water and gas).
- Simulations are ongoing to evaluate the effects of EOR gas injection on operations including:
  - Separator sizing.
  - Fluid velocity in pipes.



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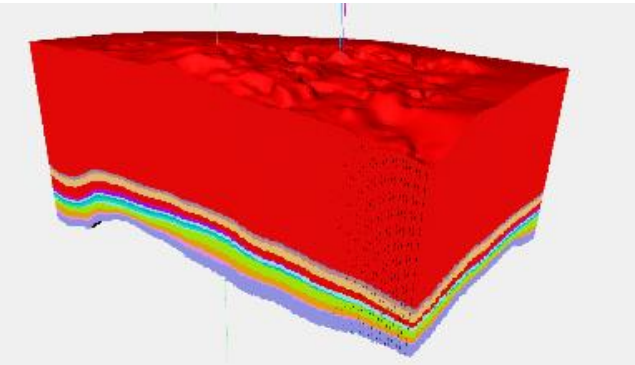
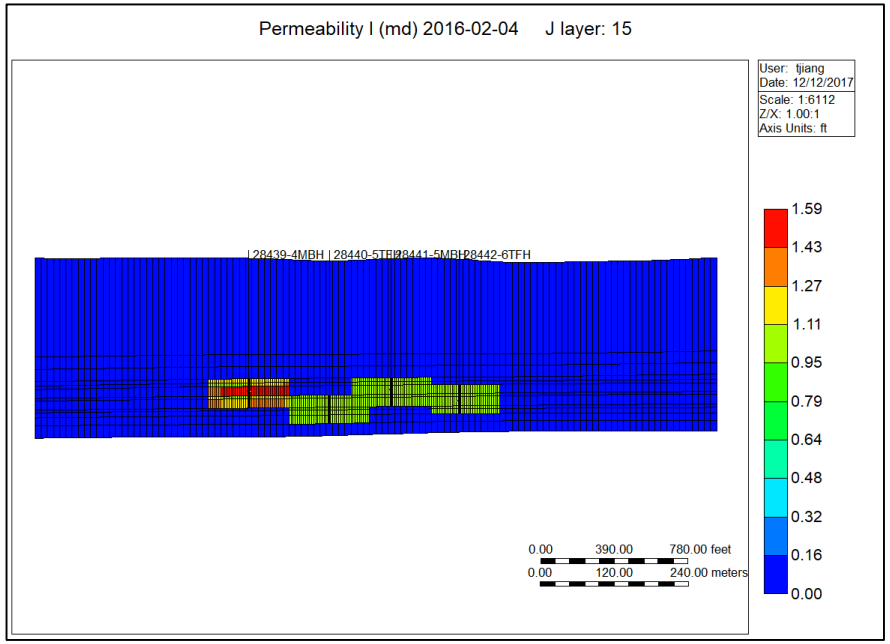
ITERATIVE MODELING OF SUBSURFACE EOR COMPONENTS

Bakken Reservoir Modeling and Simulations

- **Static geocellular modeling of the Bakken petroleum system at Stomping Horse**
- **Dynamic simulations of potential EOR schemes**
  - Different injection–production scenarios with an emphasis on cyclic multiwell huff ‘n’ puff (CMWHP).
  - Concept is CMWHP can improve fluid conformance in the reservoir and result in more fluid-matrix contact time.
  - Evaluation of sensitivity to compositional changes.

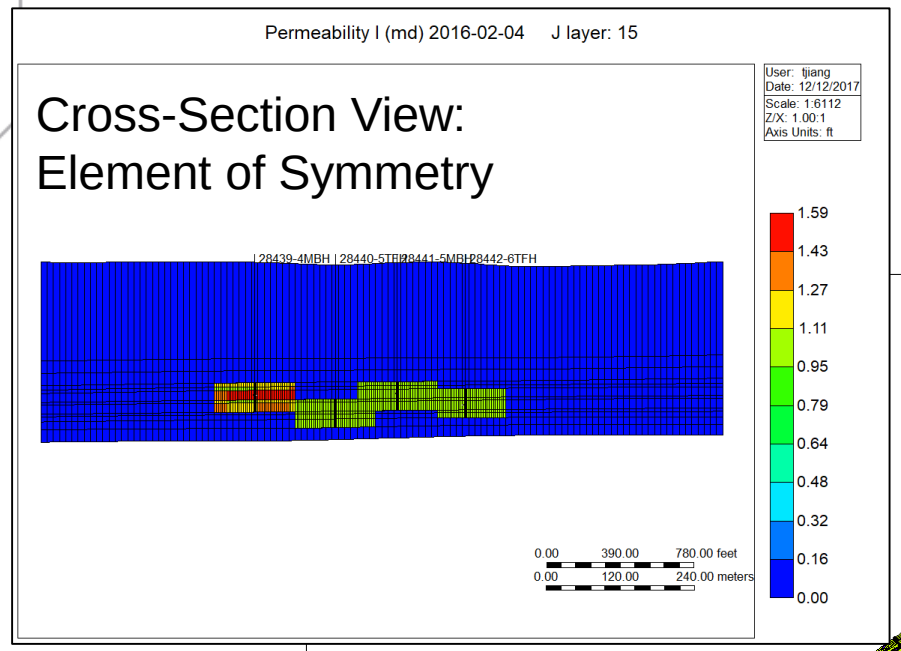


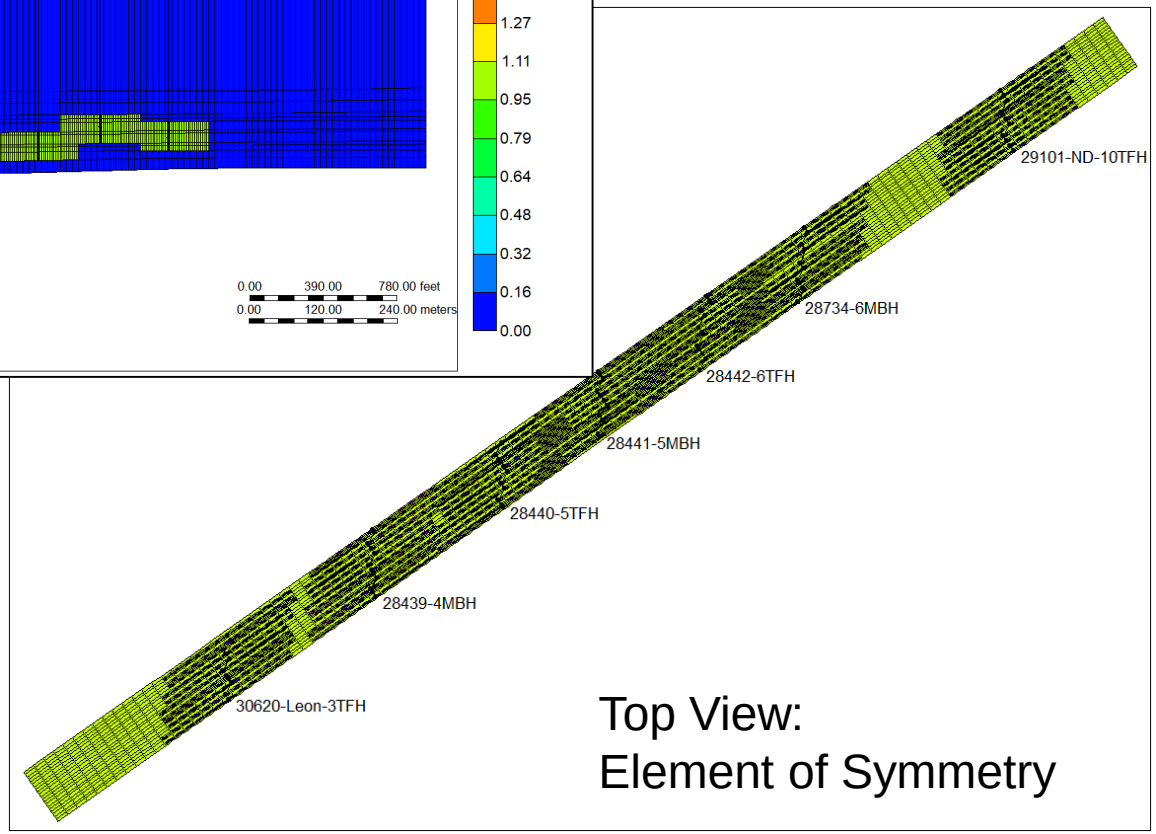


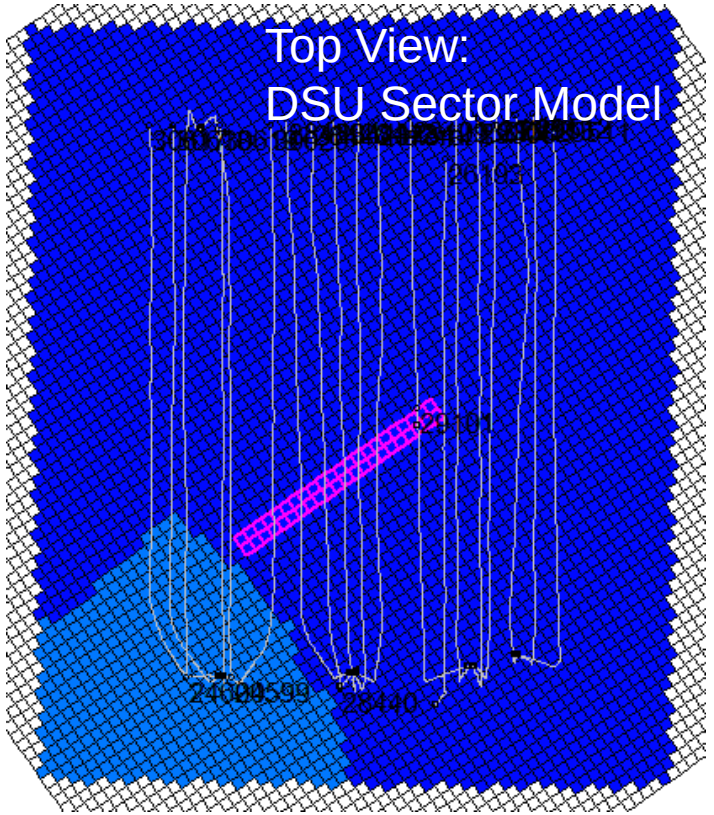
SINGLE-STAGE MODEL

Model Assumptions:

- Single porosity mode.
- Each stage of individual well performs the same.
- Neglected wellbore undulation.
- Perforations placed into the target formations.
- Hydraulic fracture geometry and parameters are the same along the well.

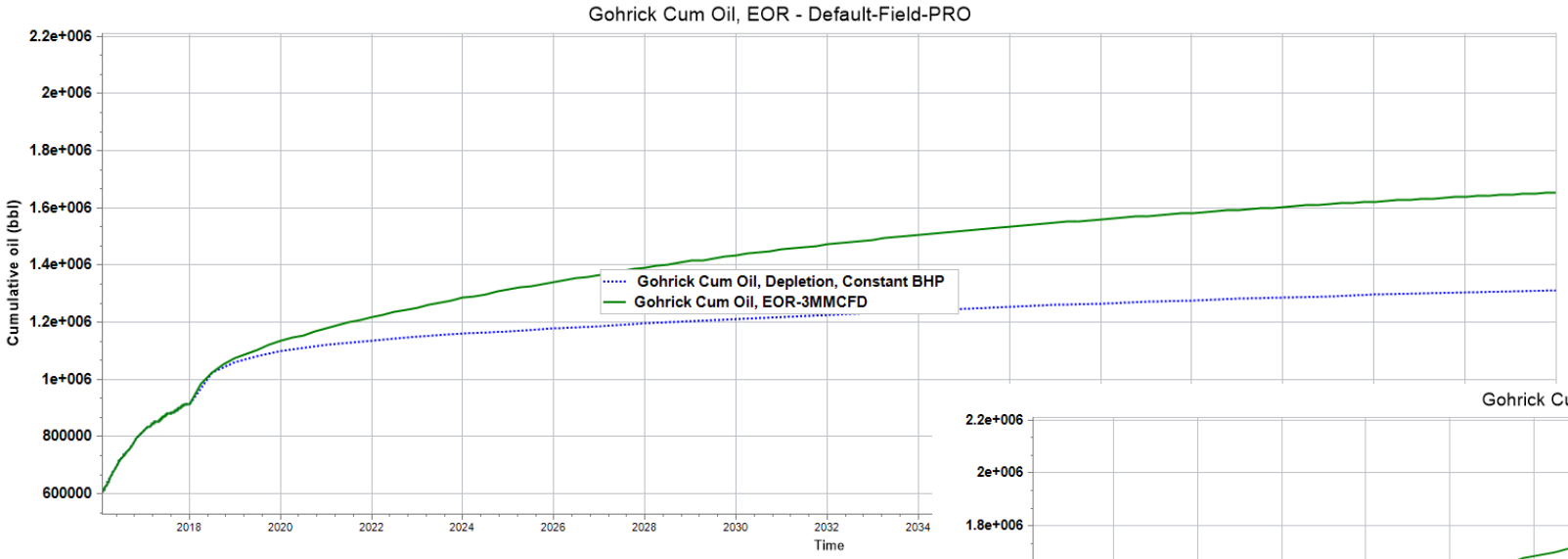


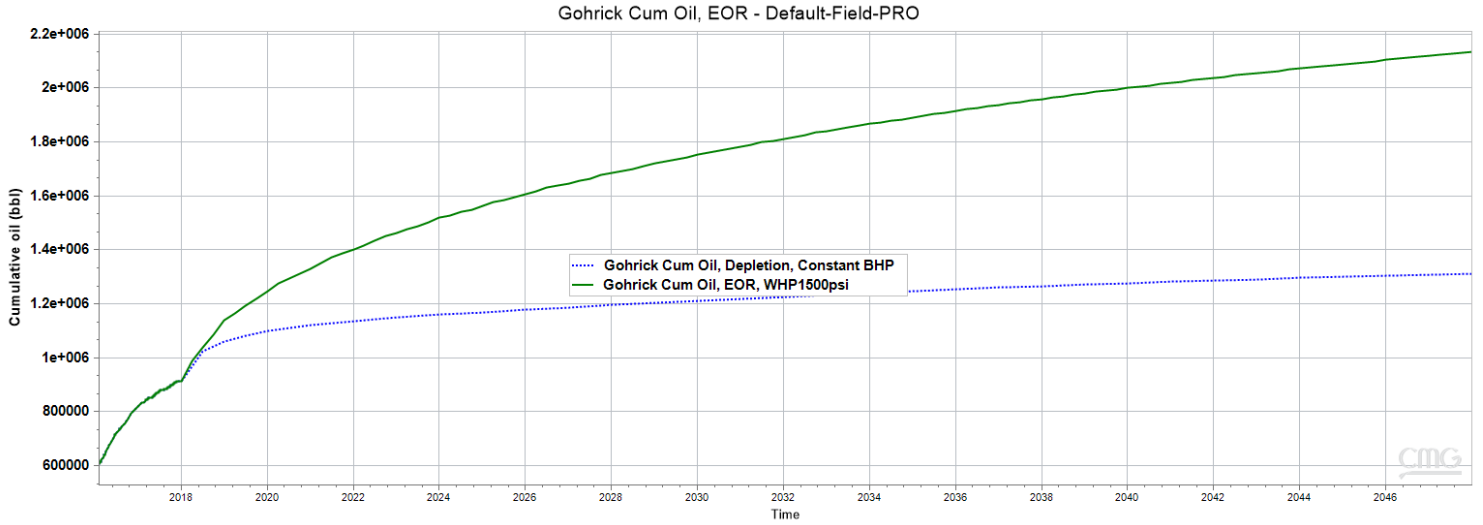




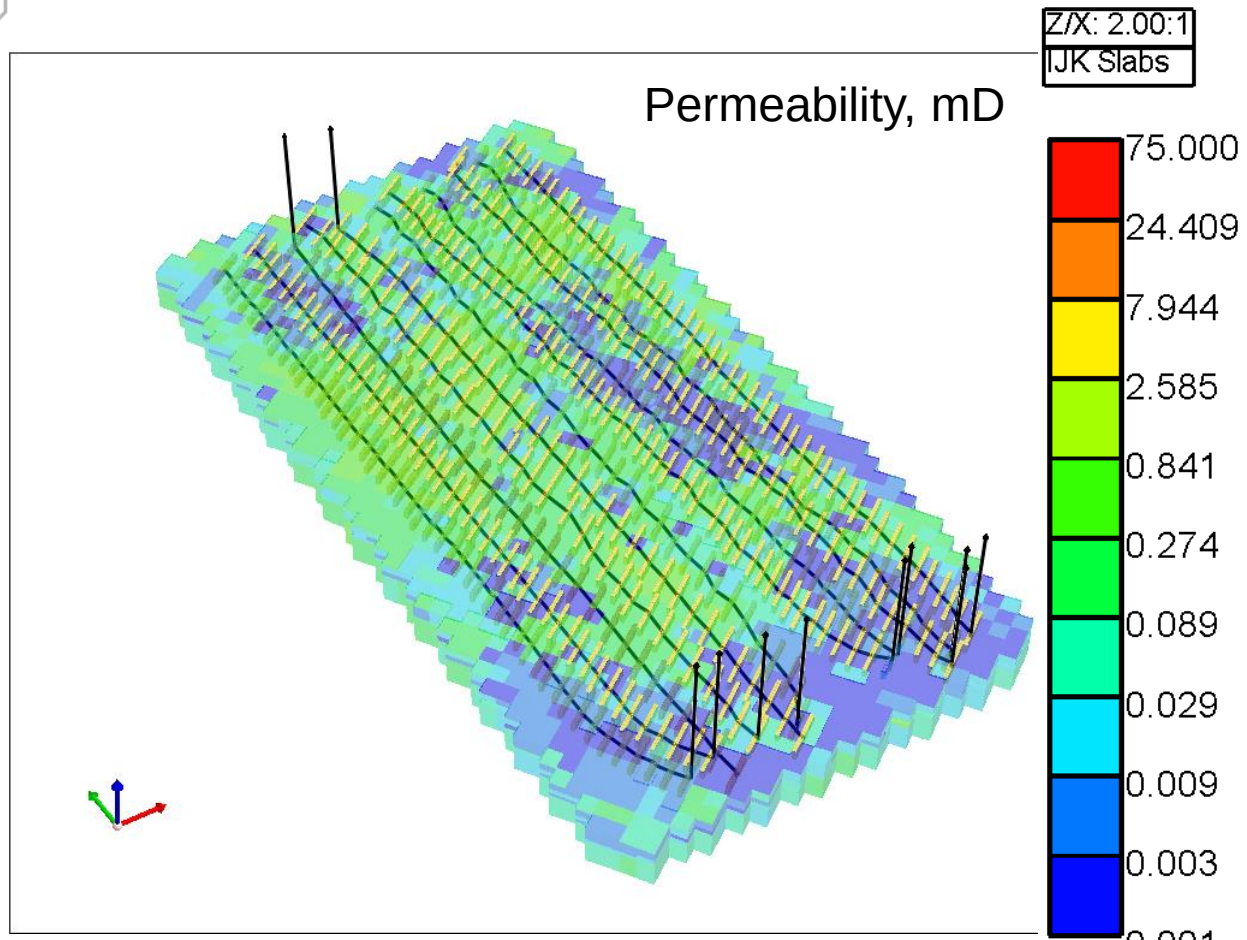
EXAMPLE SIMULATION RESULTS

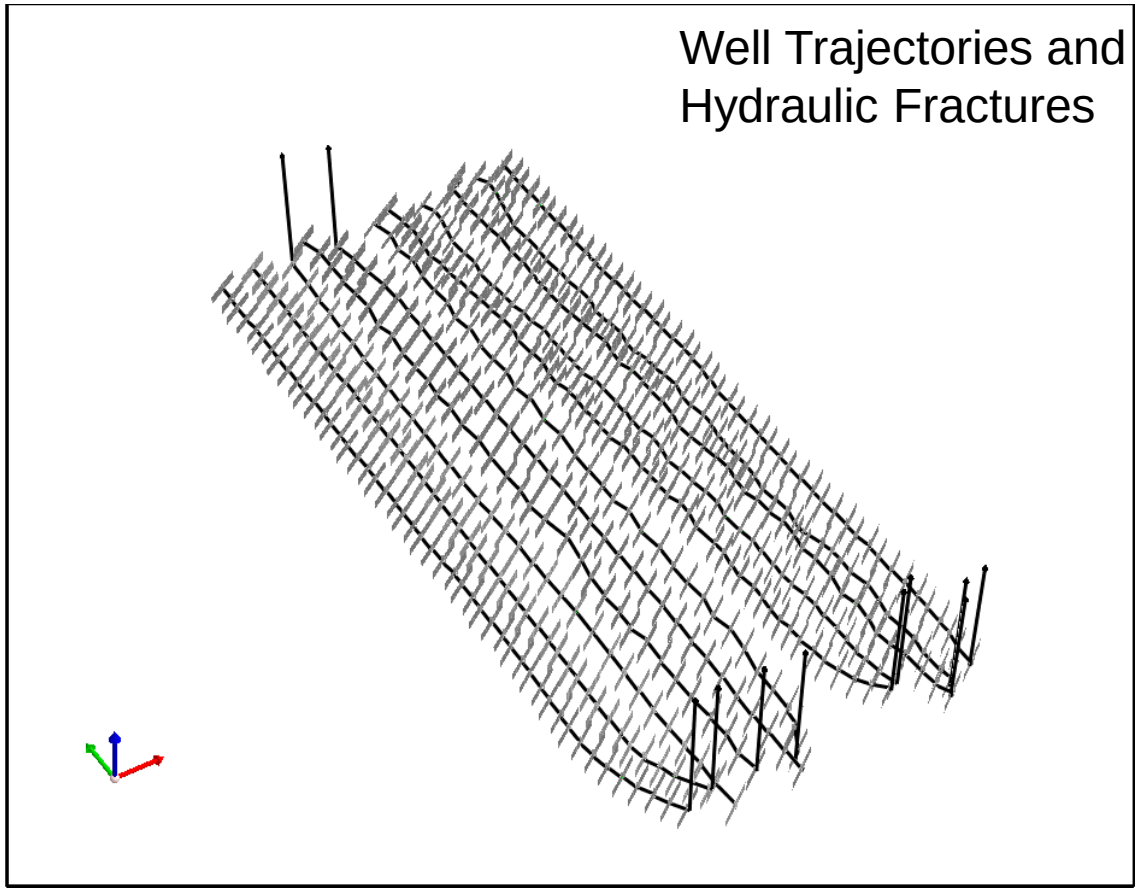
- **Predicted incremental recovery for five wells ranges from 26% to 63%.**





ONGOING EFFORT TO UPSCALE TO A DSU MODEL





PILOT PERFORMANCE ASSESSMENT

Determine effectiveness of CMWHP

- Reservoir surveillance and operational monitoring plan has been developed.
- Monitoring equipment has been deployed.
- Reservoir surveillance and monitoring activities:
  - Downhole and surface pressure monitoring
  - Daily gas analysis of offset wells
  - Fluid production monitoring
  - Tracer studies

PILOT PERFORMANCE ASSESSMENT

Initial Injection

- Two rental gas lift compressors
- Injection rate, pressure, and GC measured directly prior to injection

SURVEILLANCE INCLUDES PRODUCTION, BOTTOMHOLE PRESSURE, AND GAS COMPOSITION MONITORING

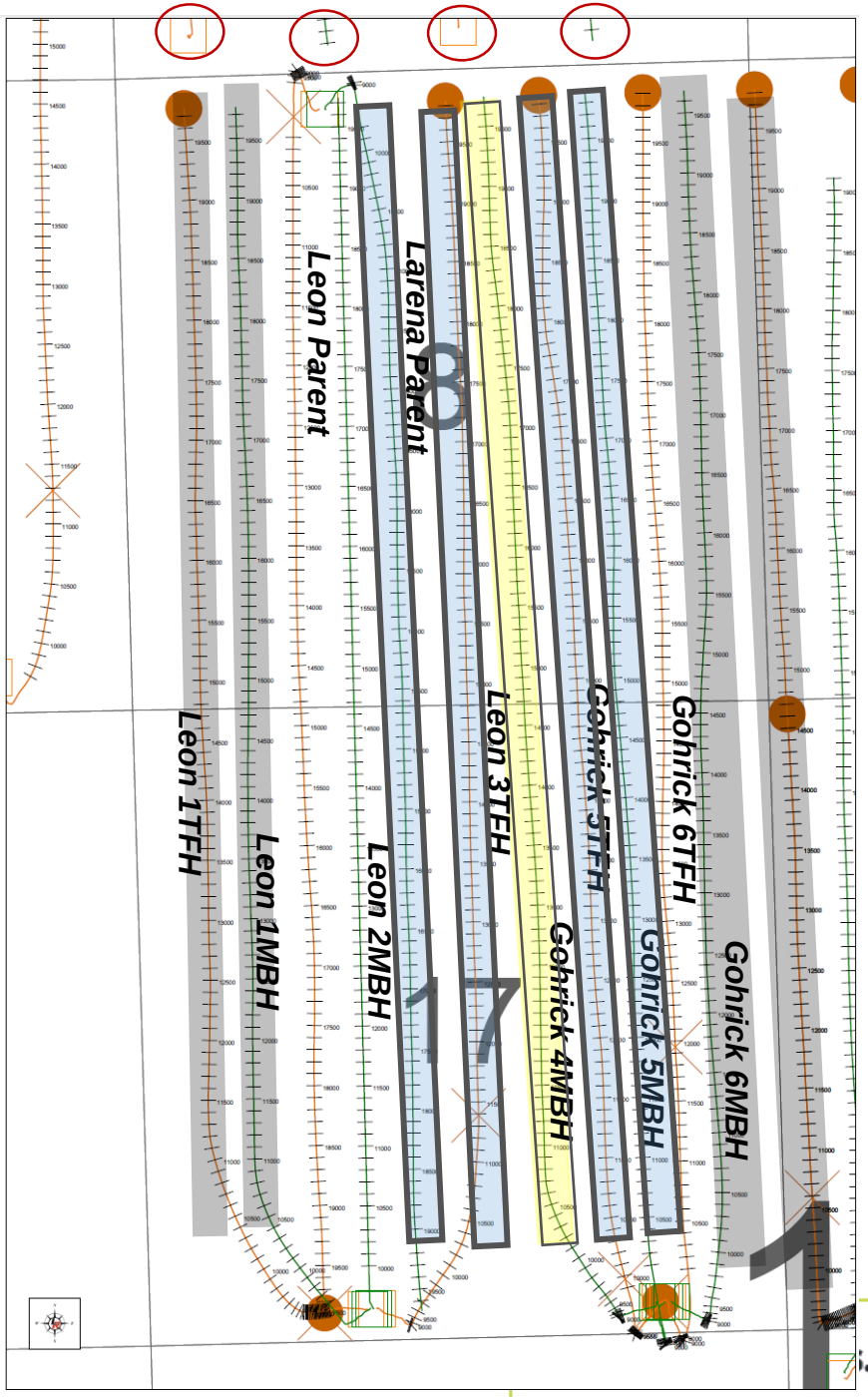
Surveillance Plan

✓Oil, gas, and water rates will be monitored continuously from Liberty operated wells.

✓The four wellbores immediately offset the injector well will have daily samples for GC.

✓The four wellbores immediately offset the injector (pattern allowing) will be equipped with bottomhole pressure gauges.

✓The offset operator to the north has been contacted and has agreed to provide operational information.



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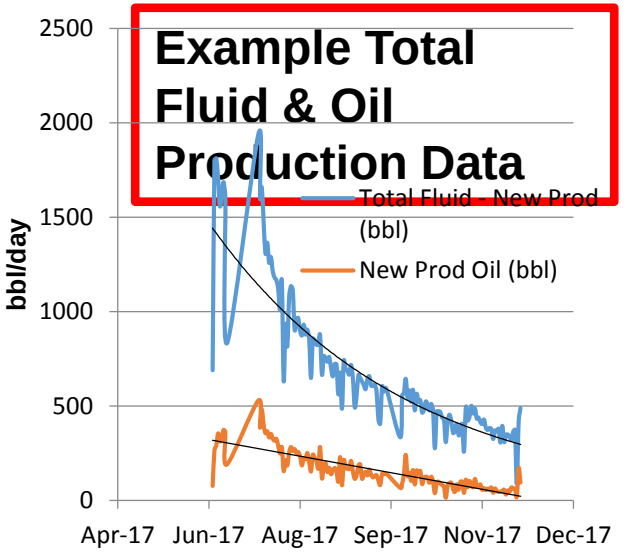
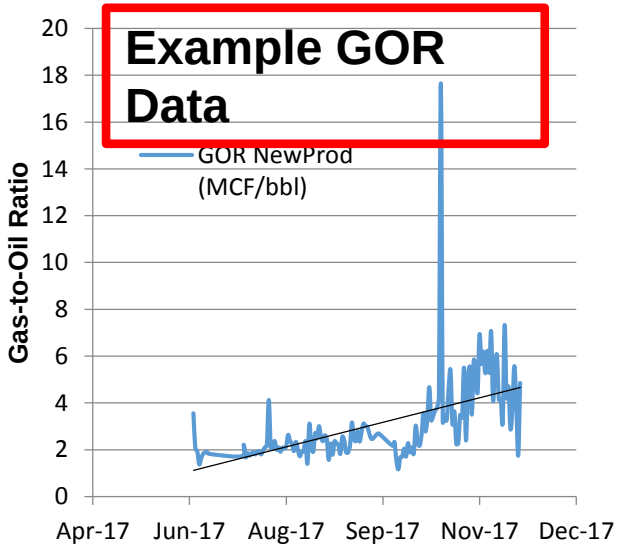
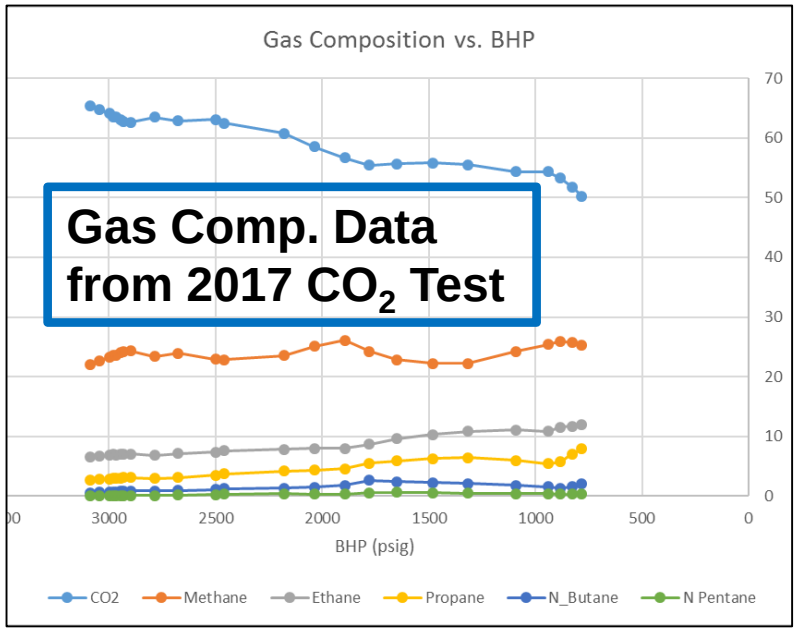
HOW DO WE ASSESS PILOT PERFORMANCE?

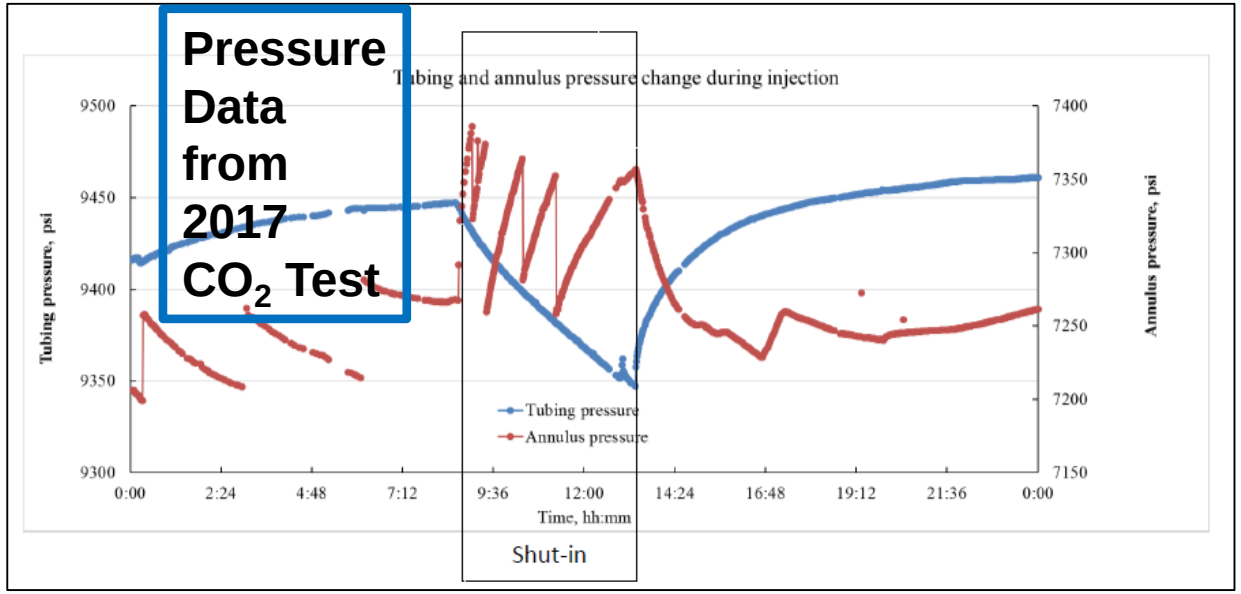
Short Term:

- Changes in pressure
- Changes in oil productivity
- Changes in GOR
- Changes in rich gas composition







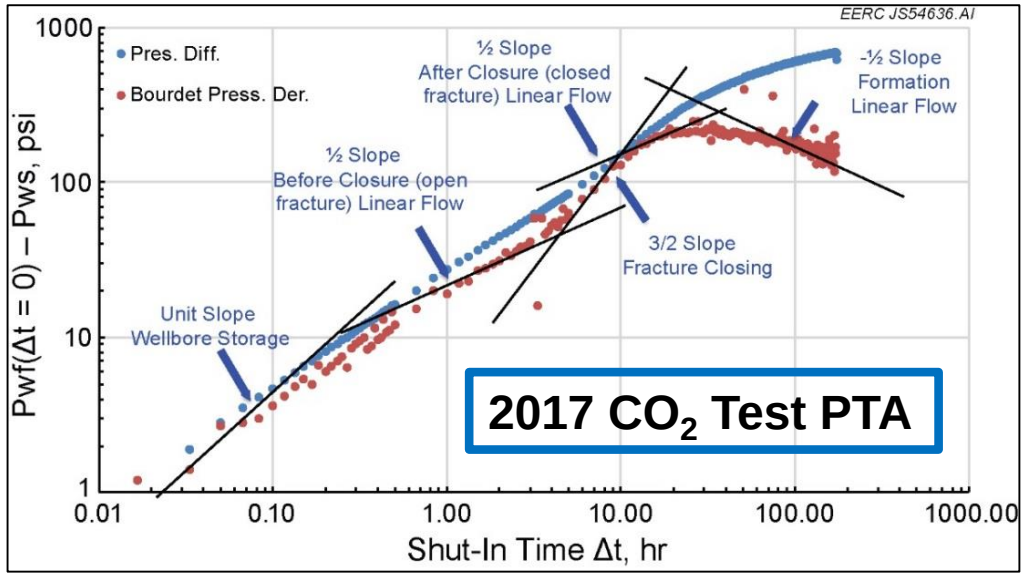


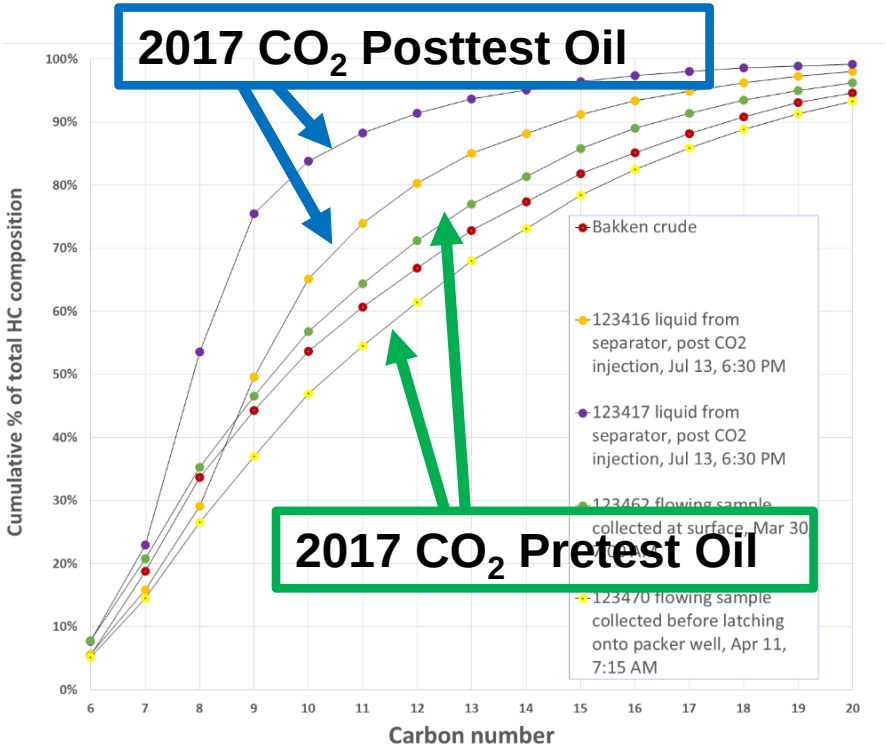
Example Data taken from Williams County Bakken Wells.

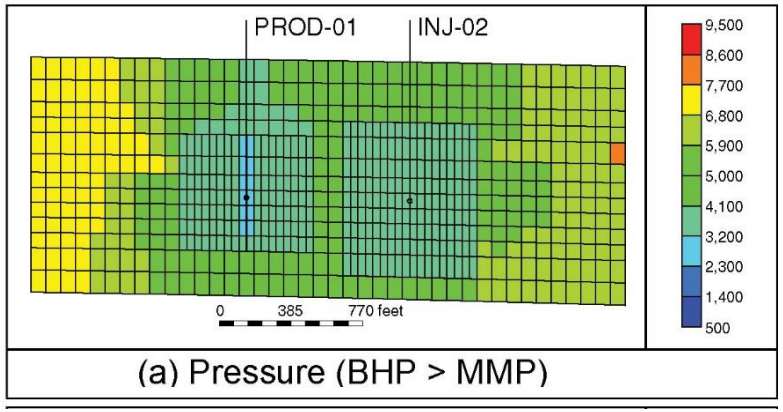
HOW DO WE ASSESS PILOT PERFORMANCE?

Long Term:

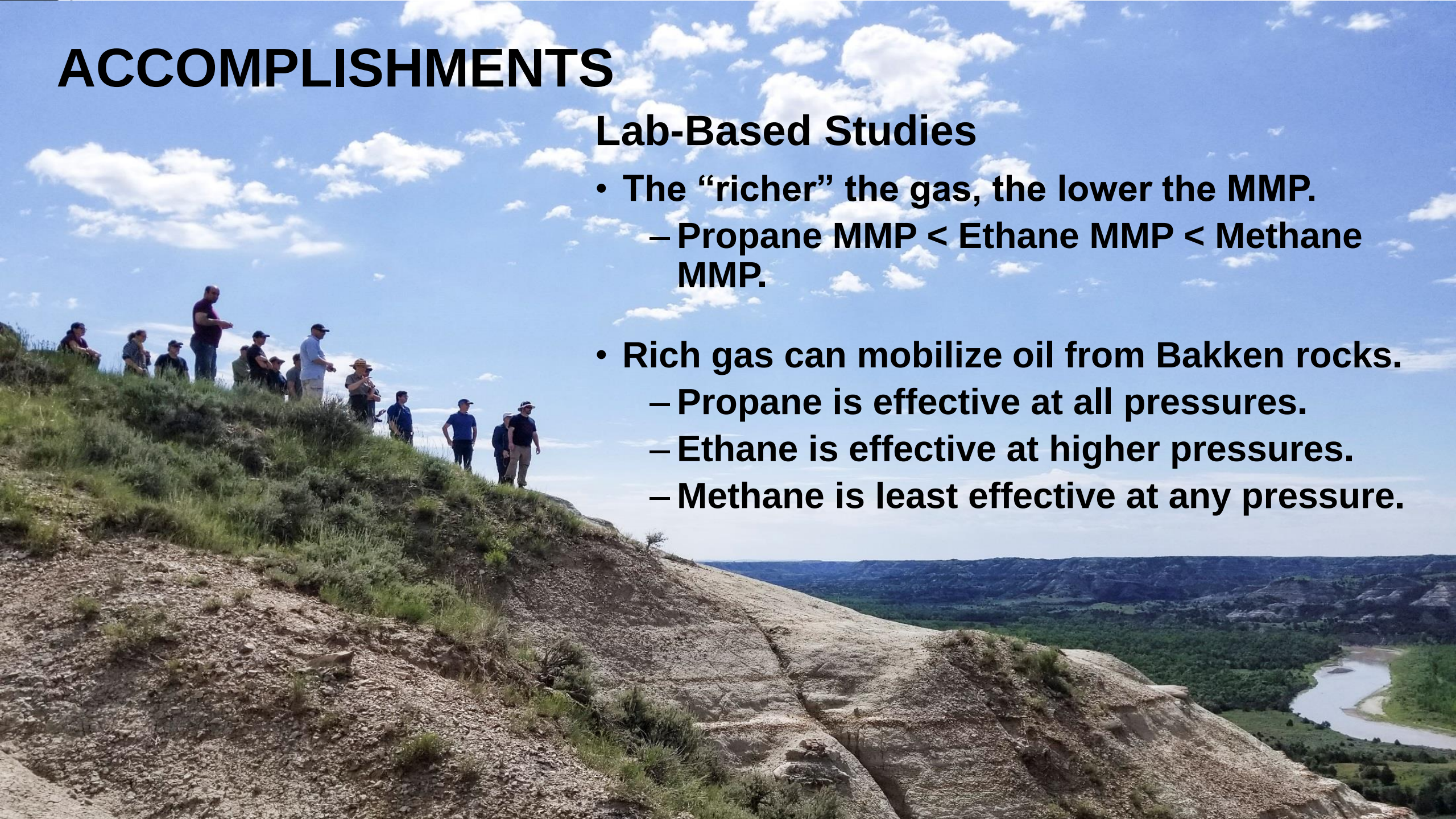
- Changes in oil production rate
- Changes in produced gas composition
- Changes in molecular weight distribution in produced oil
- Pressure Transient Analysis of data from the memory gauges
- Iterative modeling







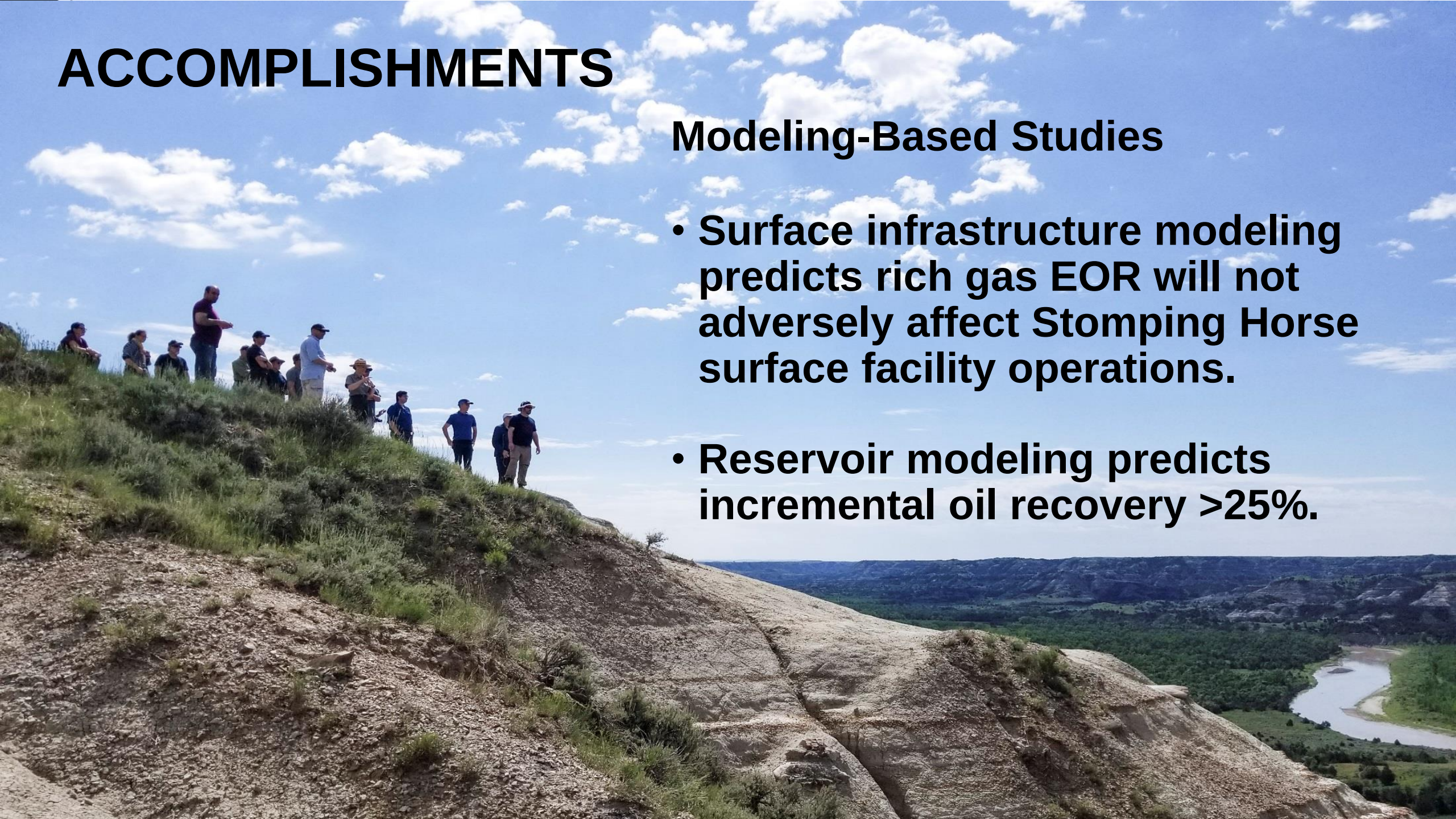
ACCOMPLISHMENTS



Lab-Based Studies

- The “richer” the gas, the lower the MMP.
  - Propane MMP < Ethane MMP < Methane MMP.
- Rich gas can mobilize oil from Bakken rocks.
  - Propane is effective at all pressures.
  - Ethane is effective at higher pressures.
  - Methane is least effective at any pressure.

ACCOMPLISHMENTS



Modeling-Based Studies

- **Surface infrastructure modeling predicts rich gas EOR will not adversely affect Stomping Horse surface facility operations.**
- **Reservoir modeling predicts incremental oil recovery >25%.**

ACCOMPLISHMENTS

Field Test Activities

- Initial injection started July 2018.
- Reservoir modeling predicts incremental oil recovery >25%.

LESSONS LEARNED

- Research gaps/challenges
  - Managing injection conformance in the reservoir.

- Unanticipated research difficulties
  - Working with rich gas mixtures in the lab.
  - Use of jet pumps as the lift mechanism for wells complicates fluid composition interpretation and design/interpretation of tracer studies.

LESSONS LEARNED

- Technical disappointments
  - Challenges in procuring desired compression equipment led to delays in injection.

- Changes that should be made next time
  - Too early to tell…

SYNERGY OPPORTUNITIES

- Methods and insights developed by this project can be directly applicable to projects in many North American tight oil formations.
  - Eagle Ford Shale Laboratory (EFSL)
  - Tuscaloosa Marine Shale Virtual Laboratory
  - Improved modeling workflows and enhancements to existing software packages

CONTACT INFORMATION

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Assistant Director for Subsurface Strategies
jsorensen@undeerc.org


THANK YOU!
Critical Challenges.
Practical Solutions.

APPENDIX

BENEFIT TO THE PROGRAM

- Program goal being addressed:
  - Enhanced resource production and environmentally prudent development of resources are priorities for the National Energy Technology Laboratory (NETL) Strategic Center for Oil and Gas. To support NETL in its goals, the Energy & Environmental Research Center (EERC), in partnership with Liberty Resources and the North Dakota Industrial Commission (NDIC), are conducting a feasibility and implementation study for the use of captured rich gas as an injection fluid for enhanced oil recovery (EOR) operations in tight oil reservoirs of the Bakken Petroleum System.
- Project benefits statement:
  - This project will provide the necessary technical support and develop lessons learned to demonstrate how re-injecting captured rich gas (mixture of methane, ethane, and potentially other hydrocarbons) into a Bakken reservoir can be used for EOR, thereby increasing ultimate recovery of the resource, and reducing greenhouse gas (GHG) emissions associated with flaring. It is anticipated that the scientific understanding gained from these research activities will lead to commercial deployment of rich gas EOR in the Bakken within the next decade, and perhaps sooner.

PROJECT OVERVIEW – GOALS AND OBJECTIVES

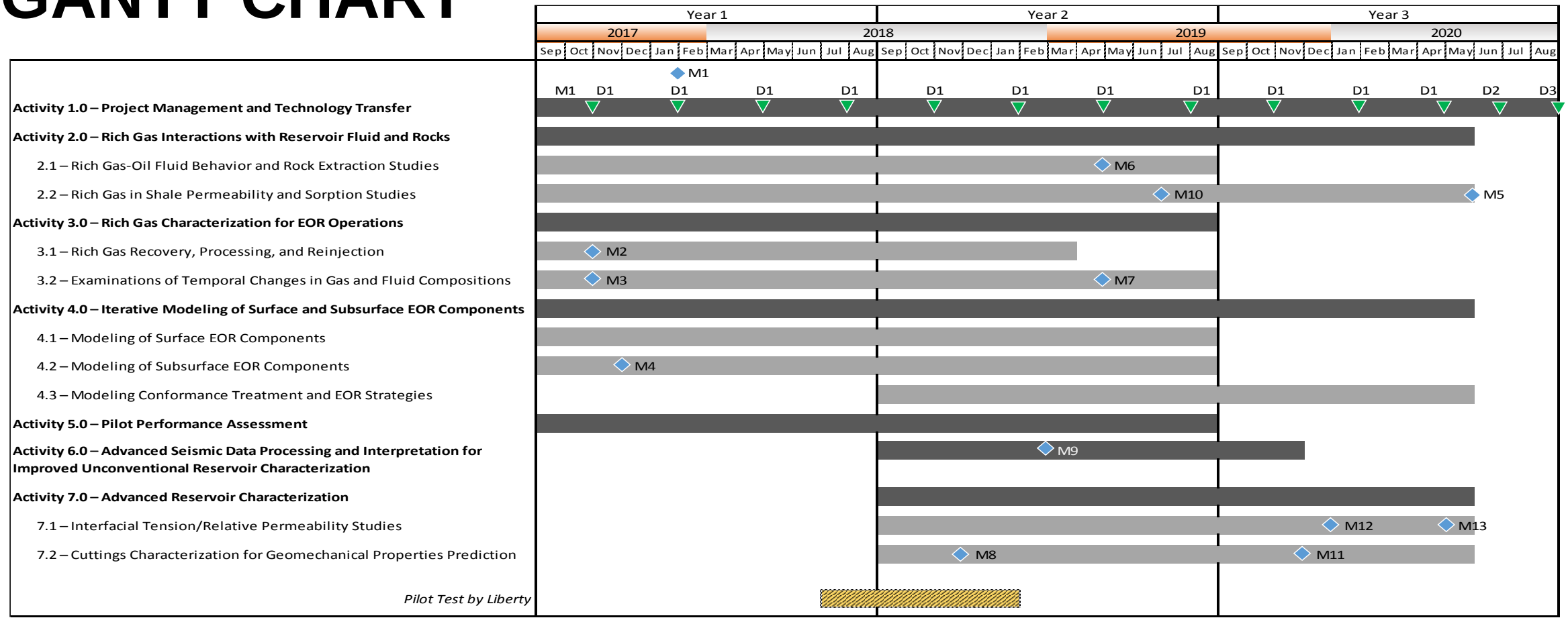
- Goals:
- To develop knowledge that will determine the feasibility of re-injecting captured rich gas into a Bakken petroleum system reservoir to enhance oil recovery. Specific research objectives related to this goal are as follows:
  - These goals relate to the Program goals in that:
    - Tight oil plays are found throughout North America.
    - Methods and insights gained in this project can be applied to many, if not all, of these formations.
    - Understanding the movement of rich gas within and/or through these tight formations is critical to understanding their roles in enhanced oil recovery.
- Success criteria
  - The laboratory-, modeling-, and field-based activities have utility in guiding the further use of rich gas for EOR in tight oil formations. This will be evidenced if efforts by industry result in the pursuit of additional field-based rich gas injection tests and/or the deployment of commercial-scale rich gas EOR operations in the Bakken petroleum system.

ORGANIZATION CHART

- **EERC Project Team**
- James Sorensen, EERC Assistant Director of Subsurface Strategies, will be the subtask manager and principal investigator on this program. Other key personnel include Dr. Steven Hawthorne (EERC leader in hydrocarbon elution experiments and oil property testing leader), Bethany Kurz (leader of the EERC applied geology laboratory and natural materials analytical laboratory), Larry Pekot (EERC modeling leader), John Hamling (EERC leader of injection test design and monitoring activities), John Harju (EERC Vice President for Strategic Partnerships), and Edward Steadman (Vice President for Research).

- **Project Partners (providing cash & in-kind contributions)**
  - North Dakota Industrial Commission-Oil & Gas Research Program (cash cofunding)
  - Liberty Resources (in-kind contributions, including providing a well for the injection test and field activities in support of the injection test)

GANTT CHART



Deliverables	Milestones	
D1 – Quarterly Progress Report	M1 – Conduct Project Kickoff Meeting	M8 – Cuttings Sample Collected
D2 – Draft Final Report	M2 – Complete Initial Assessment of Test Site Rich Gas Quality and Quantity	M9 – Complete Seismic Data Gathering
D3 – Final Report	M3 – Finalize Fluids Sampling Collection and Analysis Plan	M10 – Initial Magnetic Balance Sorption Results Available
	M4 – Complete Initial Reservoir Geocellular Model	M11 – Complete XRD/XRF
	M5 – Complete Rich Gas in Shale Permeability Studies	M12 – Complete IFT/Contact Angle
	M6 – Complete Minimum Miscibility Pressure and Rock Extraction Studies	M13 – Complete Relative Permeability
	M7 – Complete Temporal Changes in Gas and Fluid Composition Studies	

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APPENDIX B

STOMPING HORSE BAKKEN ENHANCED OIL RECOVERY PROJECT – SCIENCE AND TECHNOLOGY IN ACTION

Energy & Environmental Research Center (EERC)

STOMPING HORSE BAKKEN ENHANCED OIL RECOVERY PROJECT – SCIENCE AND TECHNOLOGY IN ACTION

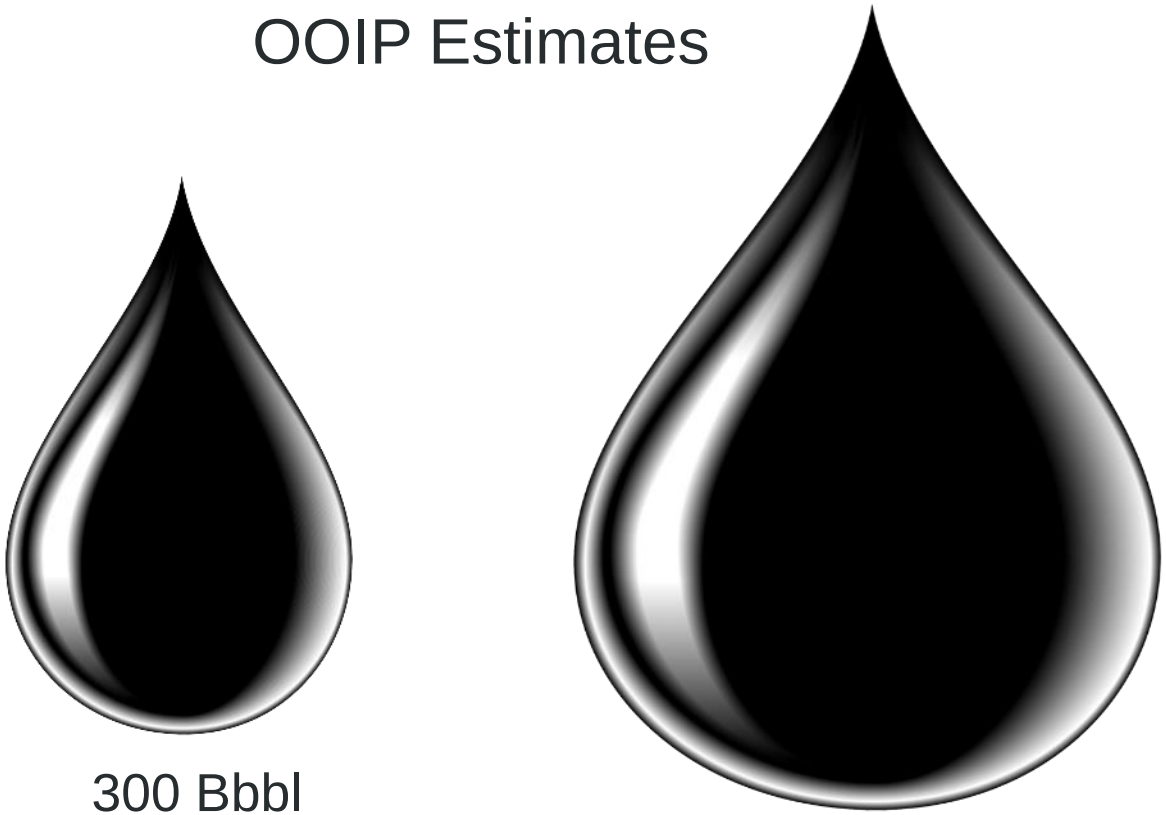
James Sorensen
Assistant Director – Subsurface Strategies
Energy & Environmental Research Center

2018 North Dakota Petroleum Council Annual Meeting
Fargo, North Dakota
September 25, 2018

Critical Challenges. Practical Solutions.

WHY DO WE CARE ABOUT EOR IN THE BAKKEN?

OOIP Estimates



300 Bbbl
(Flannery and Kraus, 2006)

900 Bbbl
(Continental Resources, 2011)

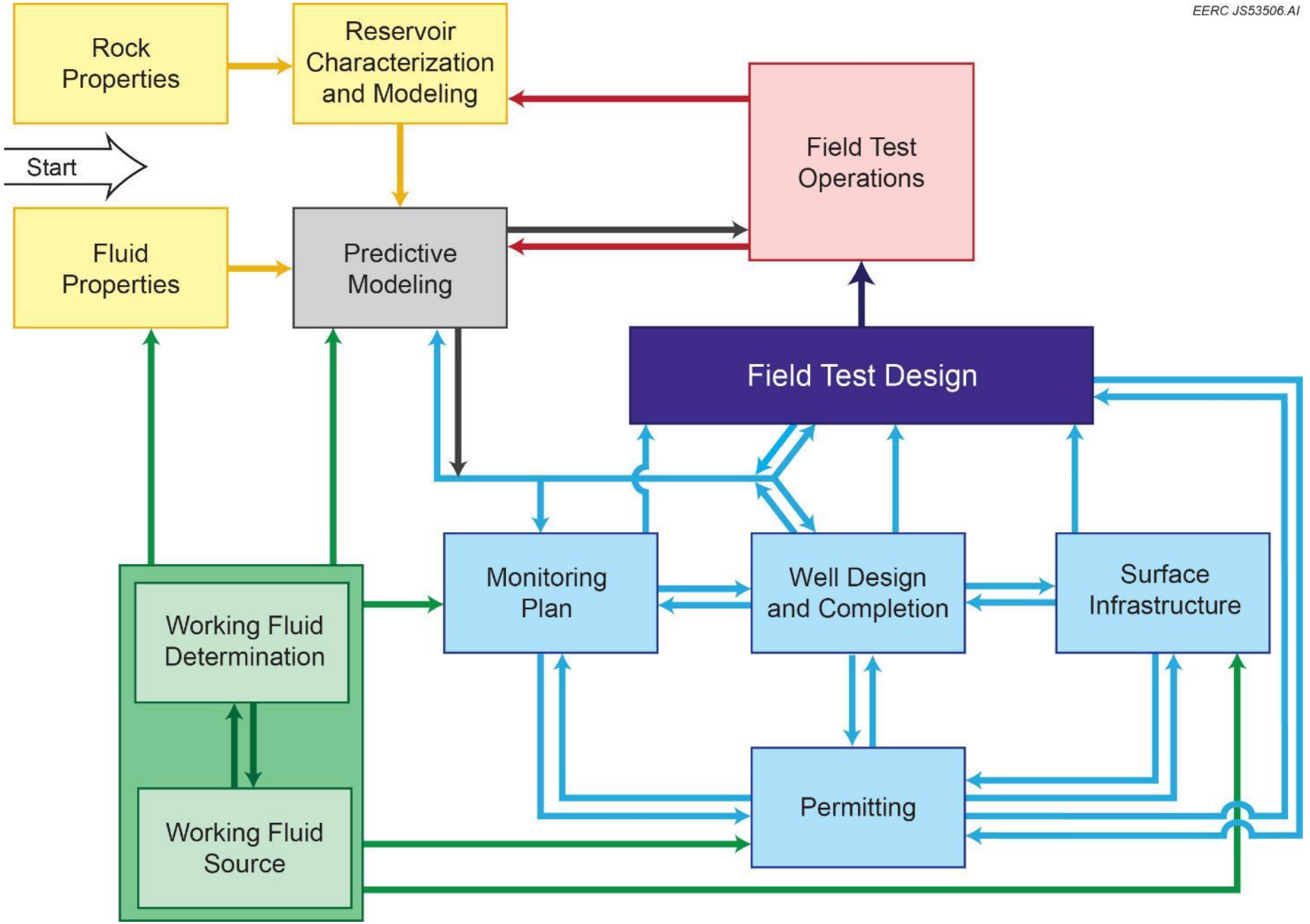
Technically Recoverable Reserve Estimates

7.4 Bbbl
(USGS, 2013)

24 Bbbl
(Continental Resource, 2011)

Business as usual leaves hundreds of billions of barrels in the ground.

What it takes to do a pilot EOR test in the field.



LIBERTY RESOURCES

NETL

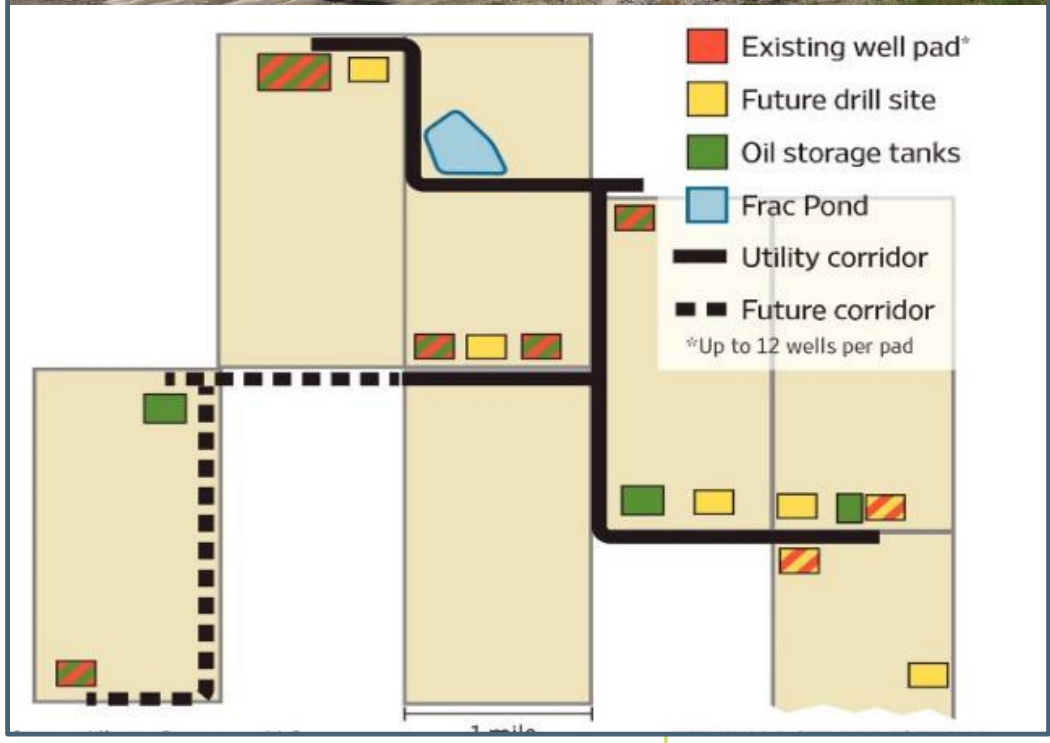
North Dakota oil & gas research program

EERC | UND

STOMPING HORSE OIL FACTORY

- A methodical, structured approach to oil field development
- Maximizing field and DSU productivity, ***<u>including the use of rich gas for EOR</u>***

- In 2017 US DOE-National Energy Technology Laboratory and the North Dakota Oil & Gas Research Program provided funding.



LIBERTY RESOURCES

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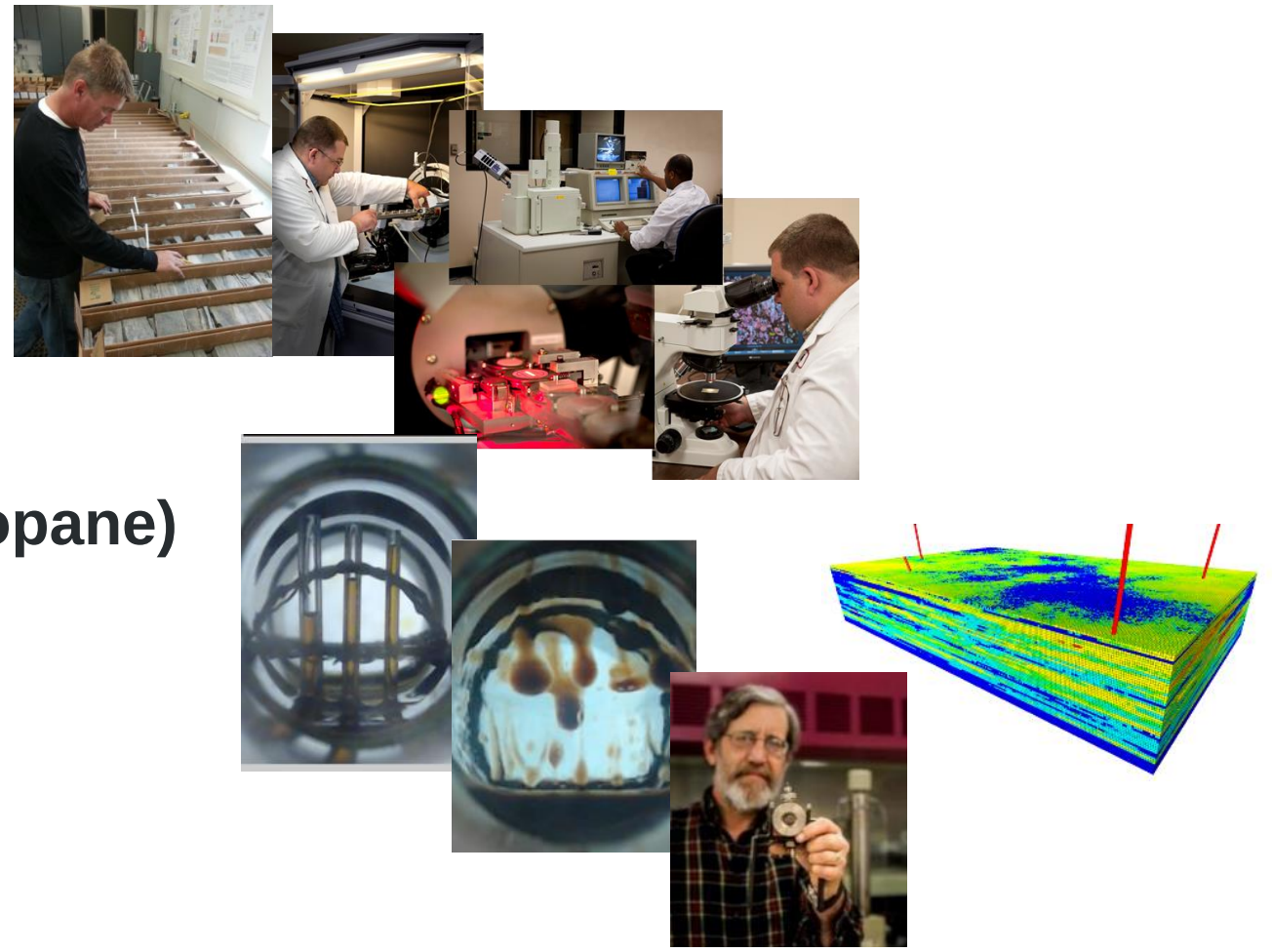
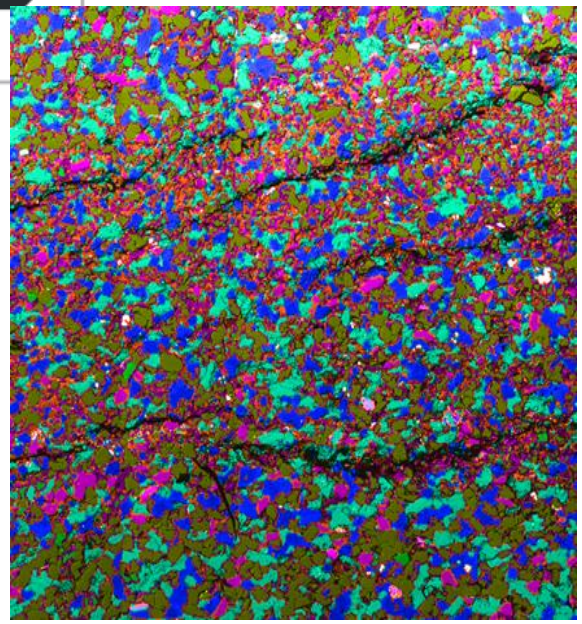
APPLIED SCIENCE & TECHNOLOGY

Laboratory and field studies to understand:

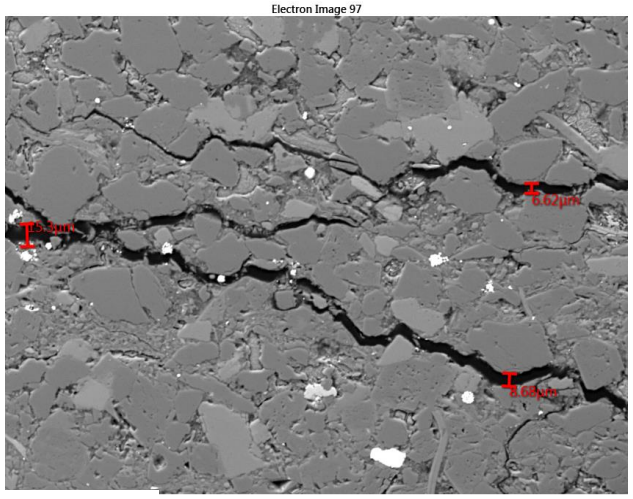
- **The rocks**
- **Reservoir fluid behavior**
- **Effects of working fluids**
  - **Rich gas (methane, ethane, propane)**
  - **Carbon dioxide (CO_2)**
- **Reservoir dynamics**



OIL STRANDED IN THE ROCKS

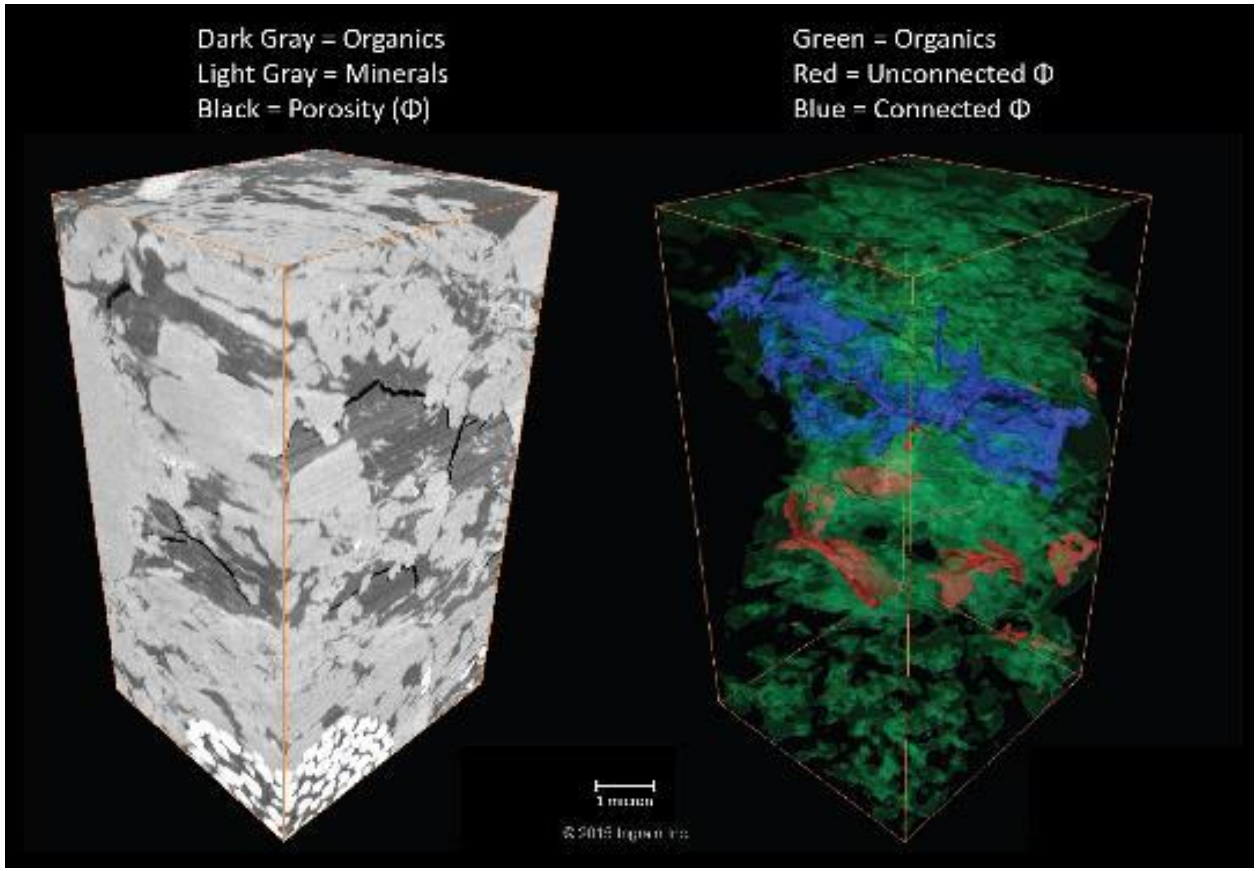


1 mm



100 µm

Microfracture networks make significant contributions to fluid mobility in the Bakken.



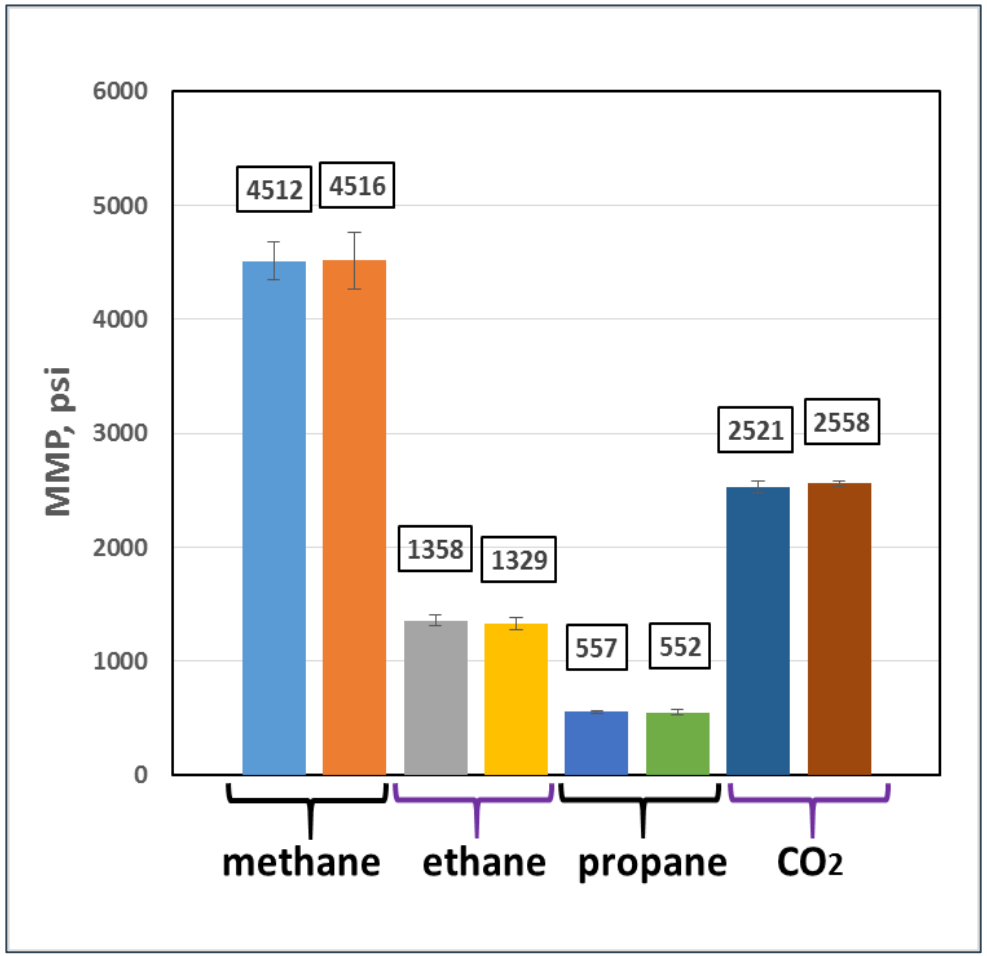
Rich gas (methane, ethane, propane) can mobilize oil from Bakken samples in the lab.

Contact time with rock surface area is key to success!

Minimum Miscibility Pressure (MMP) with Methane, Ethane, Propane, and CO_2

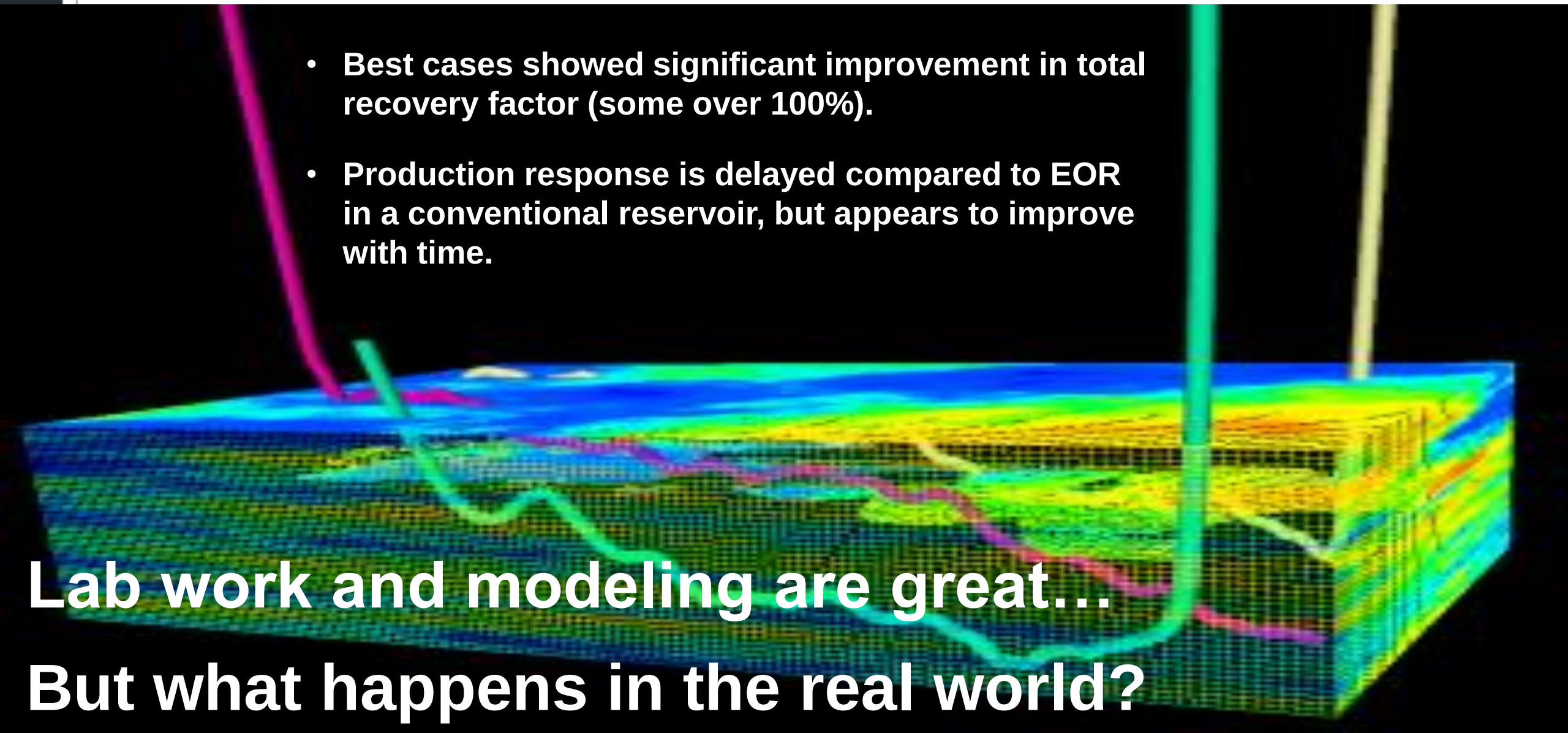
The richer the gas, the lower the MMP!!

Bakken Crude Oil (230° F)



MODELING BAKKEN EOR

- Best cases showed significant improvement in total recovery factor (some over 100%).
- Production response is delayed compared to EOR in a conventional reservoir, but appears to improve with time.

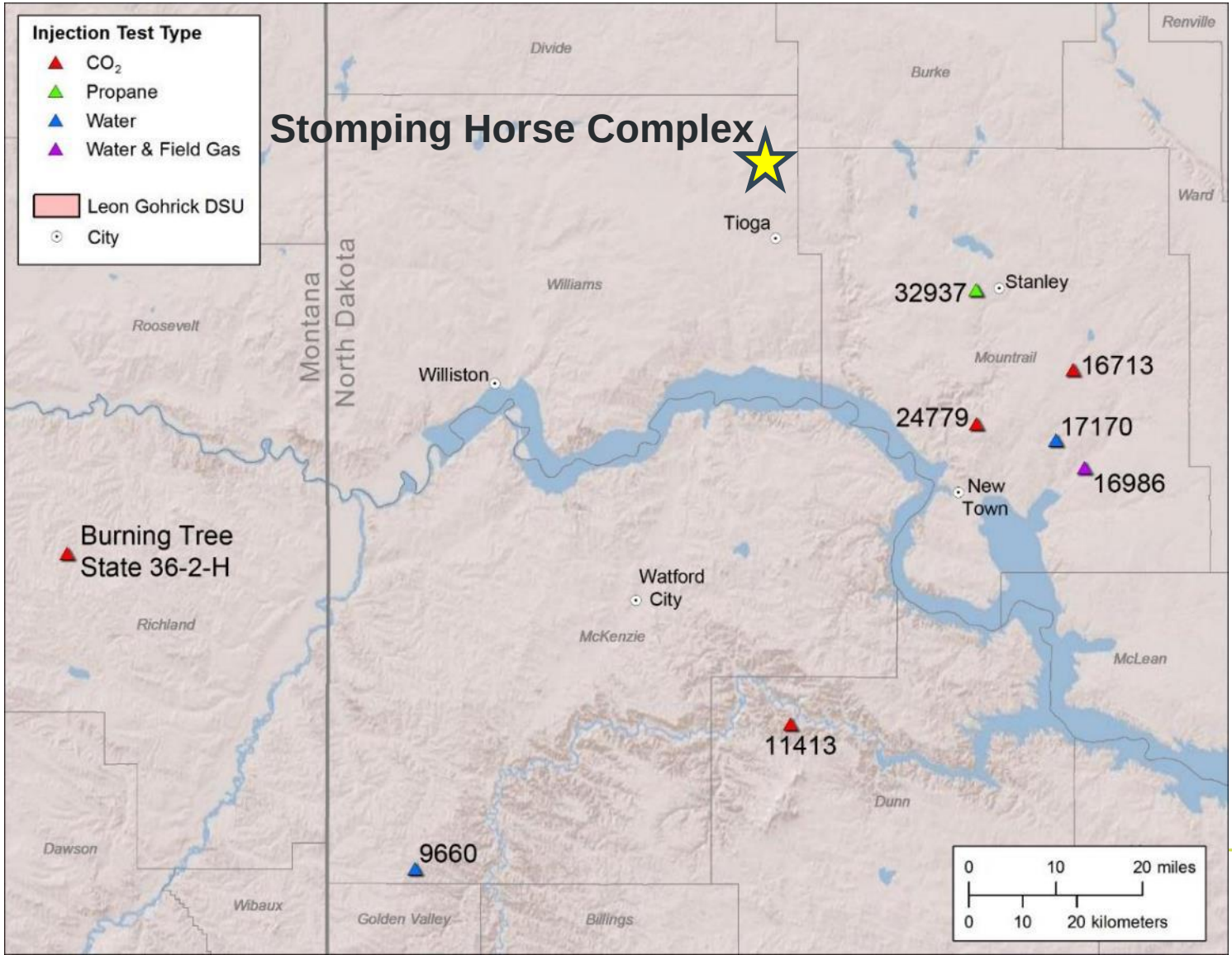


Lab work and modeling are great…

But what happens in the real world?

BAKKEN EOR PILOTS ARE AN INDUSTRY PRIORITY

- Seven EOR pilots in the Bakken since 2008, four since 2014.
- Four CO_2 tests; others used rich gas, propane, or water.
- Injectivity into hydraulically fractured wells is not a problem, ***but conformance is the primary challenge***.
- **Test at Stomping Horse designed to address conformance.**



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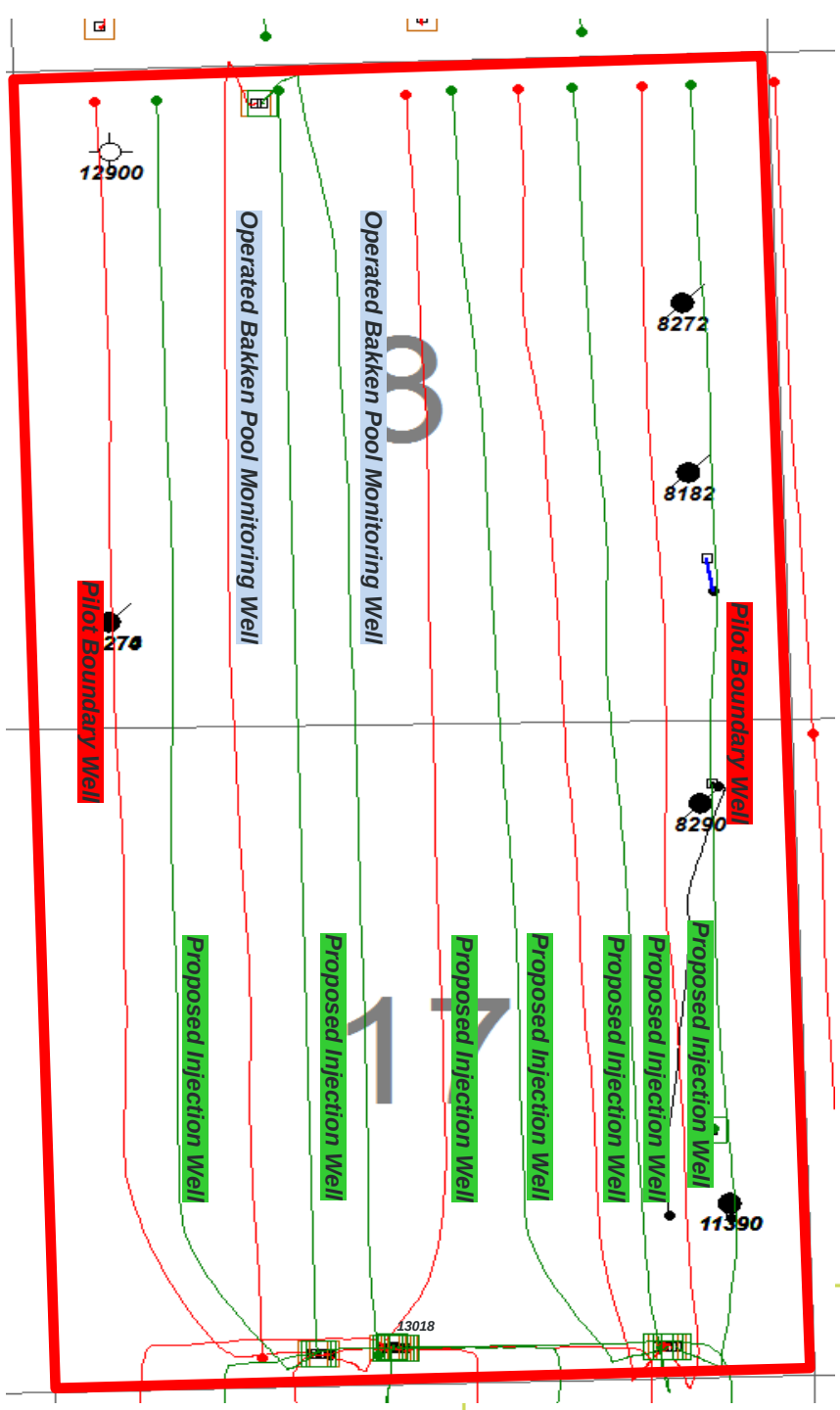
MANAGING CONFORMANCE AT STOMPING HORSE

- Liberty Resources EOR pilot using rich gas (methane, ethane, and propane) in a ***cyclic multi-well huff 'n puff*** scheme.
- Injection in the first well started in July 2018.
- Project scheduled to run through summer 2020.



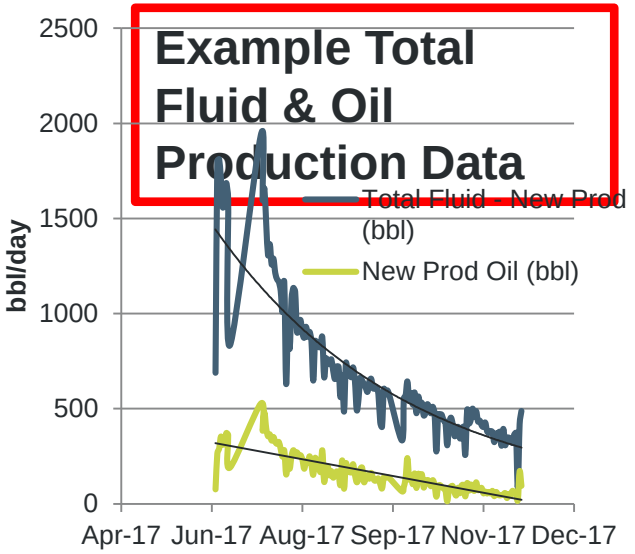
LIBERTY RESOURCES

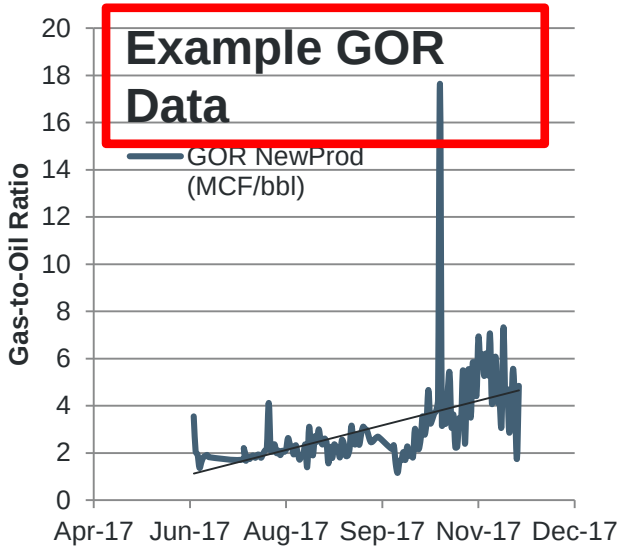
North Dakota oil & gas research program

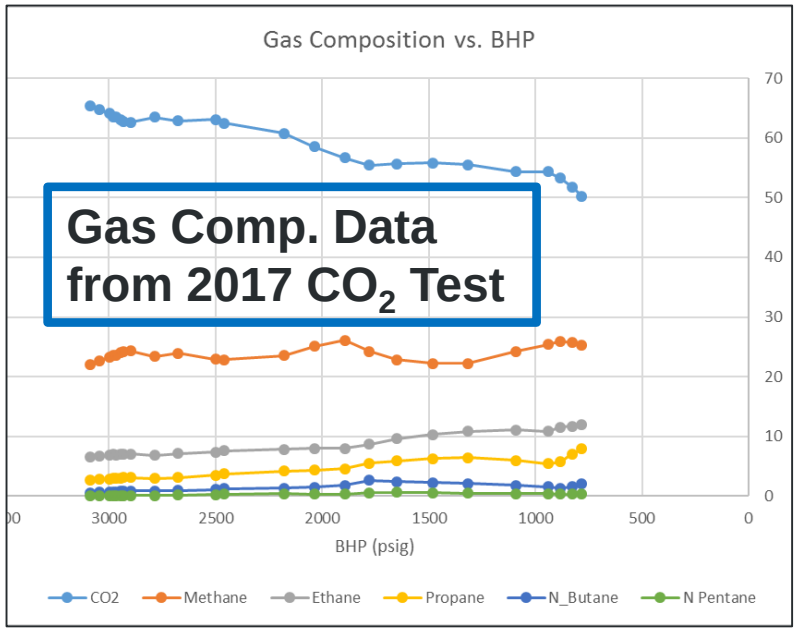
HOW DO WE ASSESS PILOT PERFORMANCE?

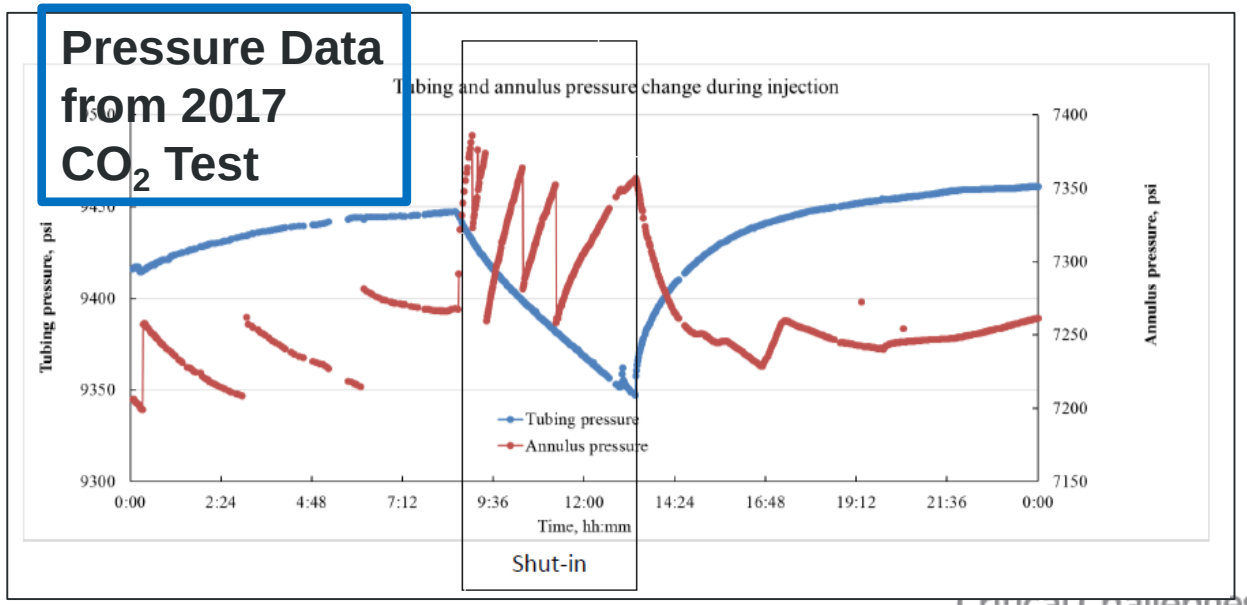
Short Term:

- Changes in pressure
- Changes in oil productivity
- Changes in GOR
- Changes in rich gas composition









Example Data taken from Williams County Bakken Wells.

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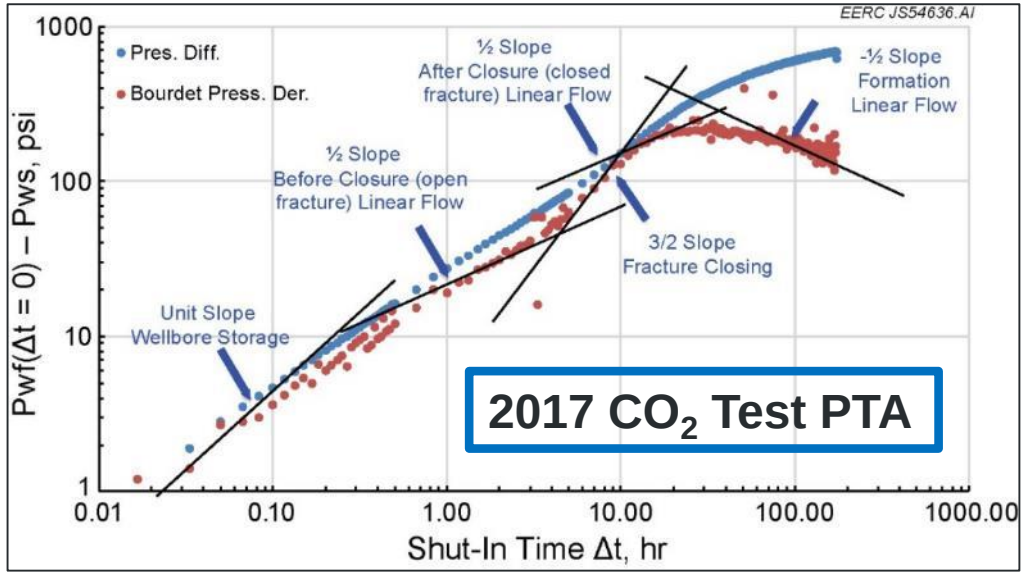
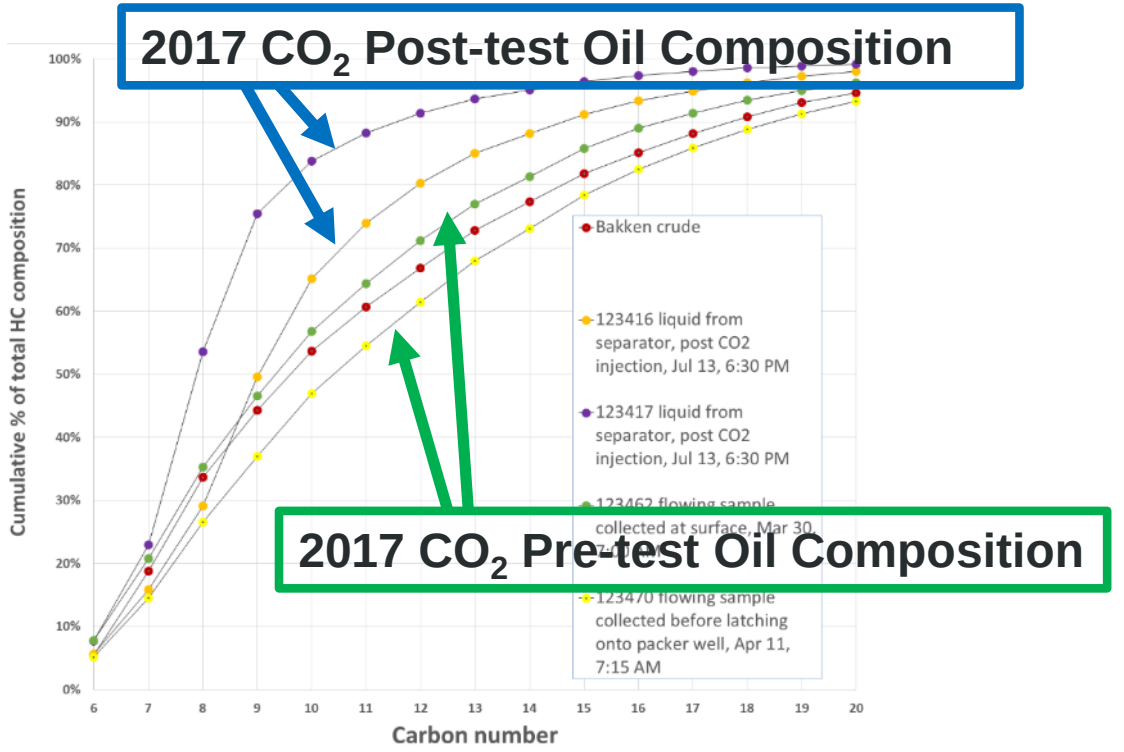
Critical Challenges. Practical Solutions.

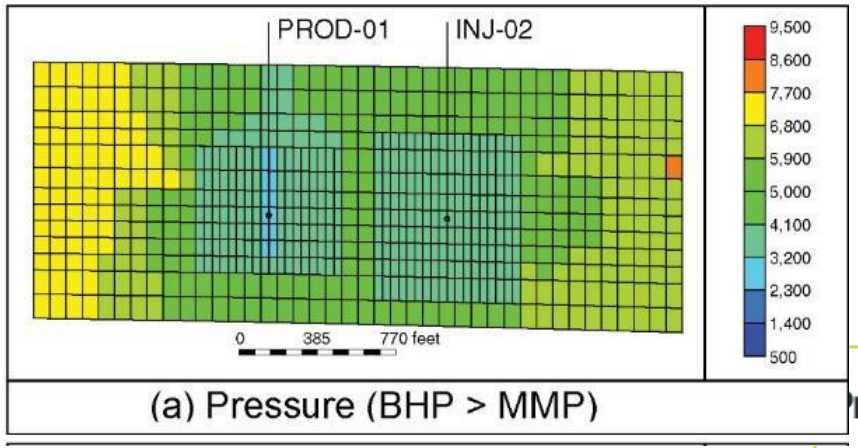
HOW DO WE ASSESS PILOT PERFORMANCE?

Long Term:

- Changes in oil production rate
- Changes in produced gas composition
- Changes in molecular weight distribution in produced oil
- Pressure Transient Analysis of data from the memory gauges
- Iterative modeling



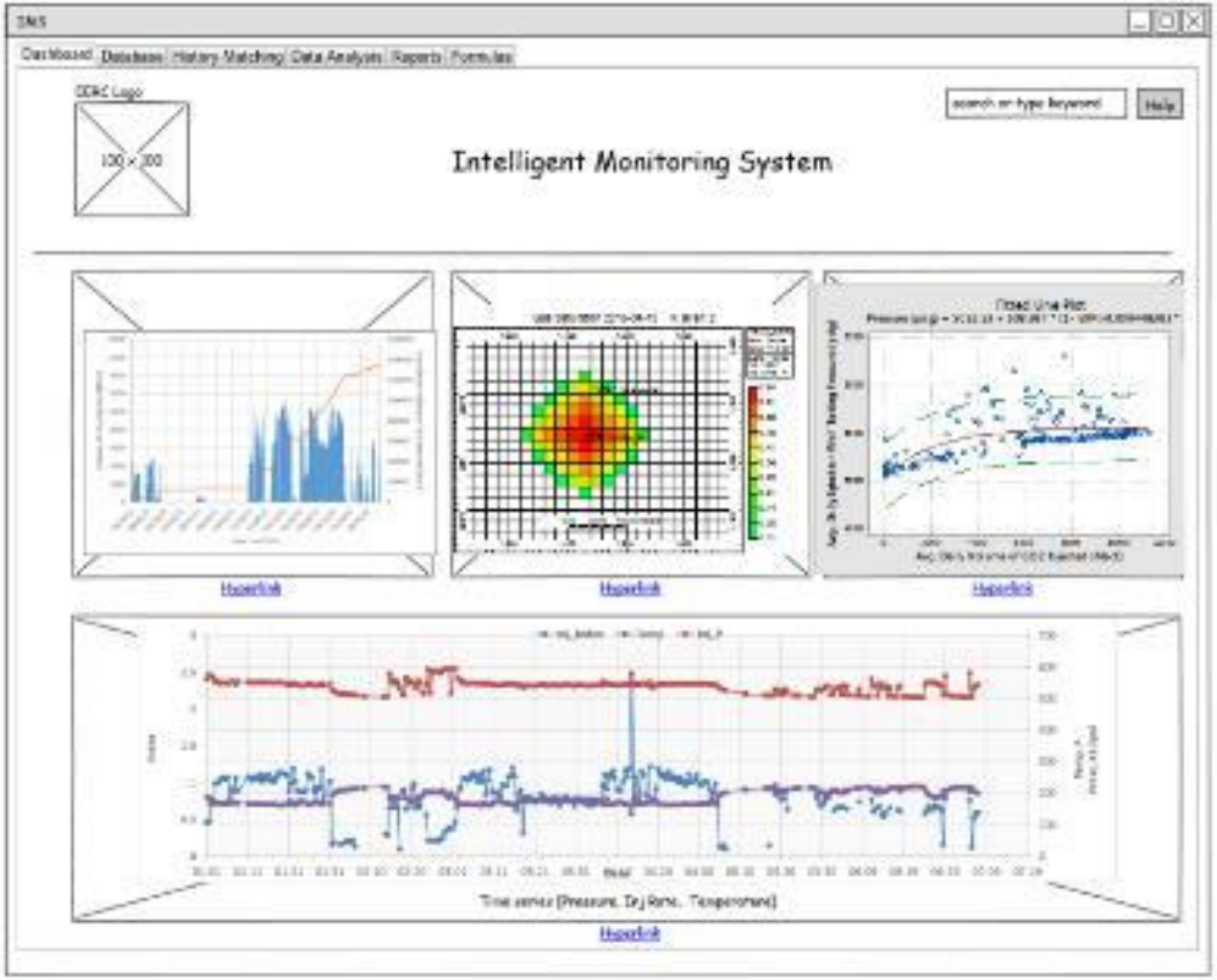




HOW DO WE ASSESS PILOT PERFORMANCE?

Intelligent Monitoring System (IMS)

- **Artificial Intelligence and Machine Learning can be used to streamline data analytics.**
- **Identify trends and correlations between operational elements and performance.**



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THE NUT WILL BE CRACKED!

Industry and government projects focused on EOR in unconventionals are moving forward and making progress.

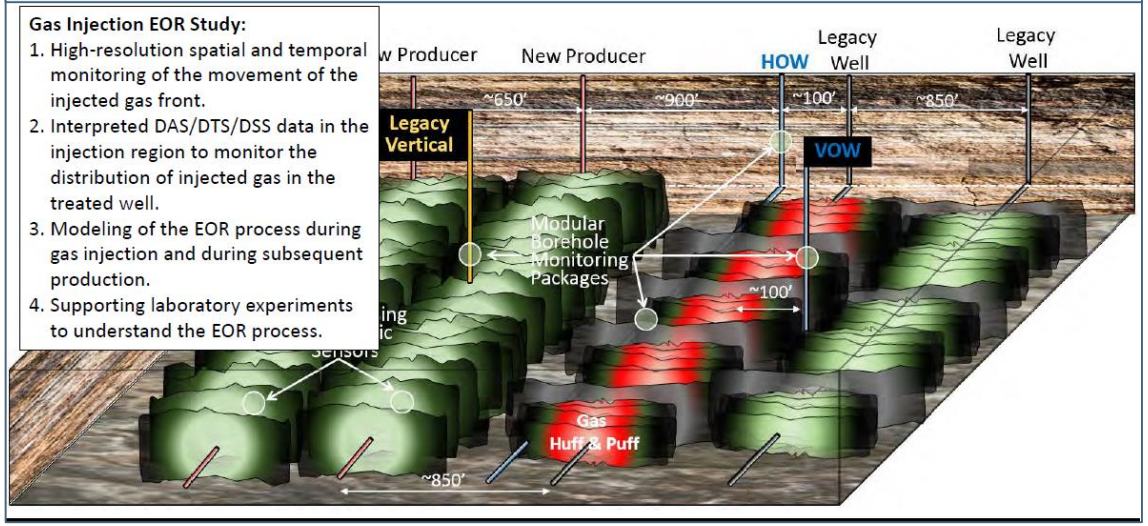
U.S. DEPARTMENT OF ENERGY | NATIONAL ENERGY TECHNOLOGY LABORATORY | gti | LAREDO PETROLEUM

Hydraulic Fracturing Test Site (HFTS)

DE-FE0024292

Gas Injection EOR Study:

1. High-resolution spatial and temporal monitoring of the movement of the injected gas front.
2. Interpreted DAS/DTS/DSS data in the injection region to monitor the distribution of injected gas in the treated well.
3. Modeling of the EOR process during gas injection and during subsequent production.
4. Supporting laboratory experiments to understand the EOR process.



The Eagle Ford Shale Laboratory: A Field Study of the Stimulated Reservoir Volume, Detailed Fracture Characteristics, and EOR Potential

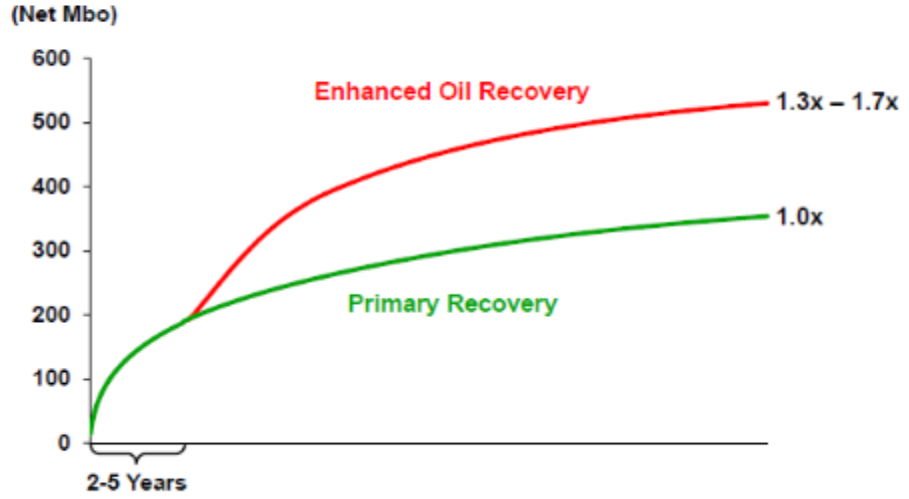
Award No. DE-FE0031579

Texas A&M University
Lawrence Berkeley National Laboratory
WildHorse Resource Development
Stanford University

U.S. DEPARTMENT OF ENERGY Fossil Energy OFFICE OF OIL & NATURAL GAS | NATIONAL ENERGY TECHNOLOGY LABORATORY

HAROLD VANCE DEPARTMENT OF PETROLEUM ENGINEERING TEXAS A&M UNIVERSITY | WildHorse Resource Development | BERKELEY LAB Bringing Science Solutions to the World | STANFORD UNIVERSITY

EOG Resources
Eagle Ford Enhanced Oil Recovery
Cumulative Oil Production per Well



eogresources

Bernstein_0516-9

THANKS!

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APPENDIX C

BPOP 2.0 UPDATE

Energy & Environmental Research Center (EERC)

BAKKEN PRODUCTION OPTIMIZATION PROGRAM (BPOP) 2.0 UPDATE

Presented to: Oil & Gas Research Council
Bismarck, North Dakota
August 20, 2018

Charles Gorecki
Director of Subsurface R&D

Critical Challenges. Practical Solutions.

AGENDA

- Budget
- BPOP 2.0 Members Meeting
- Final Report Review Process
- Rich Gas EOR with Liberty Resource
- Refrac Study
- Inyan Kara Modeling
- Industry Support Activities
  - Vapor Pressure
  - Remediation
  - Statistical Analysis of Production Data

BPOP 2.0

Sponsors	Current Budget	Expenses as of 8/15/18	Balance
NDIC Share – Cash	$6,000,000	$2,748,573	$3,251,427
Industry Share – Cash	$800,000	$457,193	$342,807
Marathon Oil Company – In-Kind	$7,280,000	$4,749,086	$2,530,914
Liberty Resources LLC – In-Kind*	755,639	755,639	$0
U.S. DOE – Cash	2,000,000	582,577	$1,417,423
Total	**$16,835,639**	**$9,293,068**	**$7,542,571**

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

ANNUAL MEMBERS MEETING

Over 30 participants attended meeting at the EERC on August 7–8, 2018. Presentations on key topics:

- Transportation and infrastructure (Kringstad)
- Rich gas EOR
- Produced water disposal
- Vapor pressure strategies
- Aromatic/aliphatic fingerprinting
- Technology trends

Bakken Production Optimization Program 2.0

EERC UNIVERSITY OF NORTH DAKOTA

BAKKEN PRODUCTION OPTIMIZATION PROGRAM 2.0 ANNUAL MEMBERS MEETING

Dress Code is Business Casual

AGENDA

DAY 1 TUESDAY, AUGUST 7, 2018 EERC – GRAND FORKS, ND

TIME	ACTIVITY	DISCUSSION LEADER(S)
12:00 Noon	Lunch provided at the EERC	
1:00 p.m.	Welcome	John Harju
1:05 p.m.	EERC Bakken Research – Where We've Come from and Where We're Going	Charlie Gorecki
1:40 p.m.	Transportation and Processing Infrastructure – View from the North Dakota Pipeline Authority	Justin Kringstad
2:10 p.m.	Networking Break	
2:30 p.m.	Panel on Bakken Rich Gas EOR – Pilot Testing at Stomping Horse	
	• Introduction and Project Overview	Jim Sorensen
	• Objectives, Approach, and Status of the Pilot Test Field Activities	Tammy Kaier, Liberty Resources
	• Laboratory Studies to Support Rich Gas EOR	Steve Hawthorne
	• Modeling and Simulation Efforts	José Torres
	• Member Time (30 minutes for Q&A)	
4:30 p.m.	The Future of the Bakken – View from the North Dakota Department of Mineral Resources Director's Chair	Lynn Helms
5:00 p.m.	Wrap-Up	
6:00 p.m.	Dinner – BBQ/Social at the EERC	

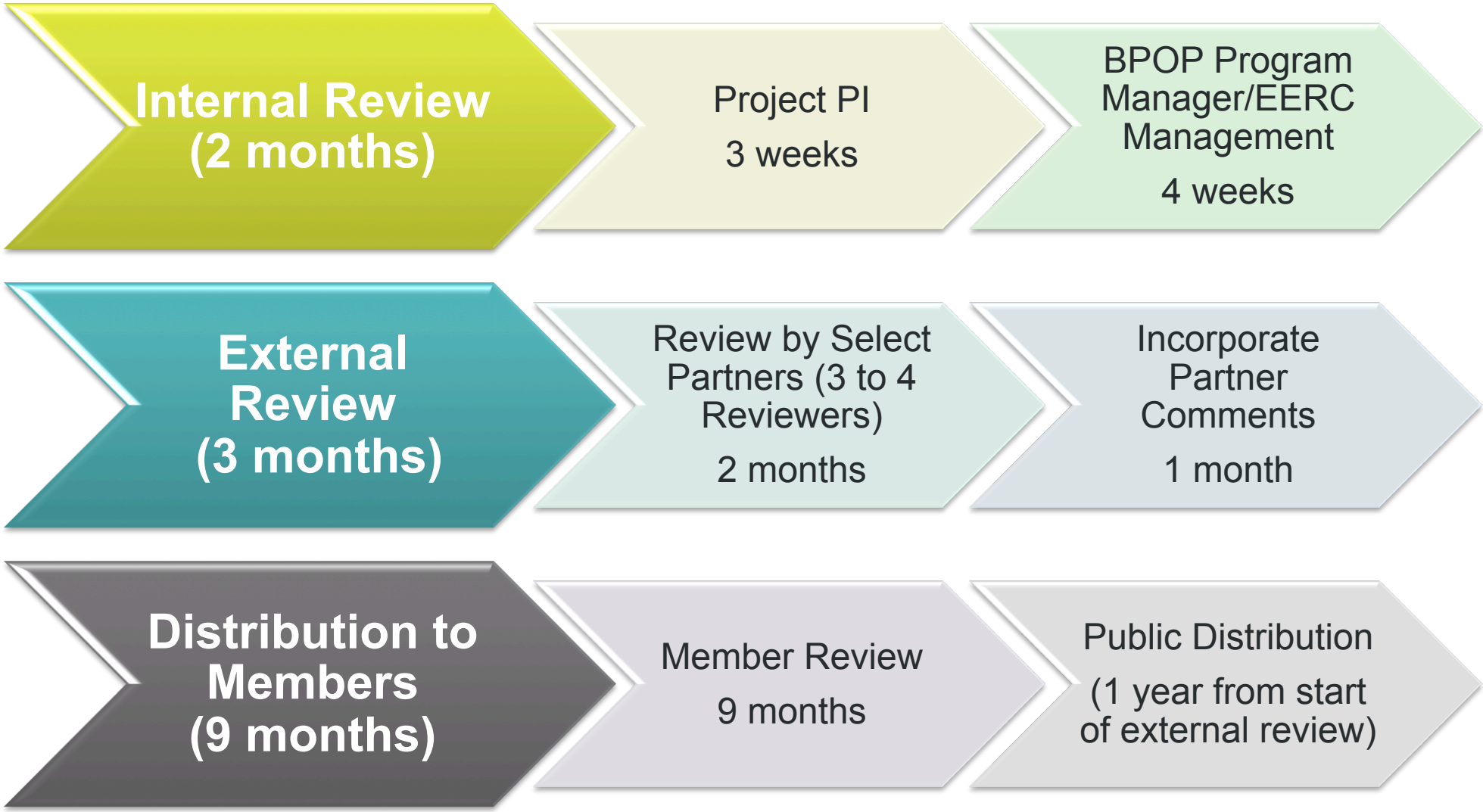
www.undeerc.org/Bakken/Bakken-Production-Optimization-Program.aspx

BAKKEN PRODUCTION OPTIMIZATION PROGRAM 2.0 ANNUAL MEMBERS MEETING

DAY 2 WEDNESDAY, AUGUST 8, 2018 EERC – GRAND FORKS, ND

ACTIVITY	DISCUSSION LEADER(S)
oduced Water	Beth Kurz
odeling	Chris Martin
ing and Potential Utility	Steve Hawthorne
d Technology Trends	
echnology Trends	Beth Kurz
roduction Data	Chantsa Dalkhaa
	Chantsa Dalkhaa
ne	
d at the EERC	

BPOP FINAL REPORT REVIEW PROCESS (DRAFT)



RICH GAS EOR – HIGHLIGHTS

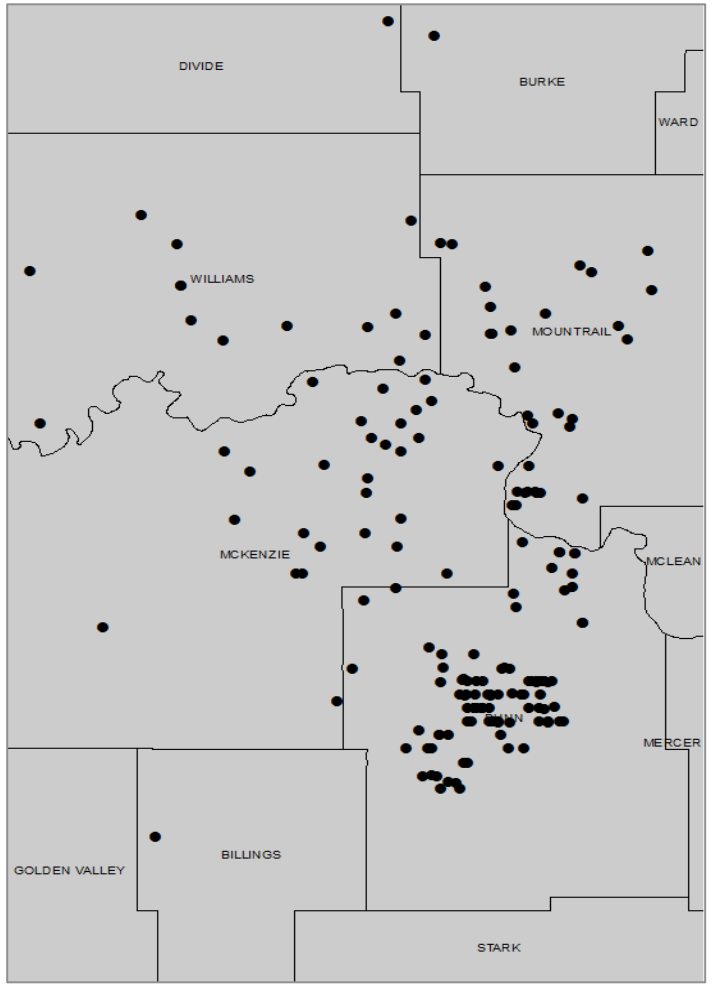
- **Lab studies of rich gas interactions with fluids and rocks**
  - The richer the gas, the lower the MMP.
- **Iterative modeling of surface and subsurface components.**
  - Surface infrastructure modeling predicts rich gas EOR will not adversely affect Stomping Horse surface facility operations.
  - Reservoir modeling predicts incremental oil recovery >25%.
- **Pilot performance assessment**
  - Initial “precharging” injection started July 17 using gas lift compressors capable of 1.4 MMscf/day and 1400 psi.
  - Operational and monitoring data being evaluated.

RICH GAS EOR – NEXT STEPS

- **Large-scale rich gas injection imminent**
  - Refurbished compressor expected delivery in late September 2018 (capable of 4200 psi and 3 MMscf/day).
  - Injection starting target for early October.
  - Pressures, rates, and injection/soak durations for the pilot will be determined based on learnings from the ongoing precharge injection activities.

REFRAC PERFORMANCE EVALUATION

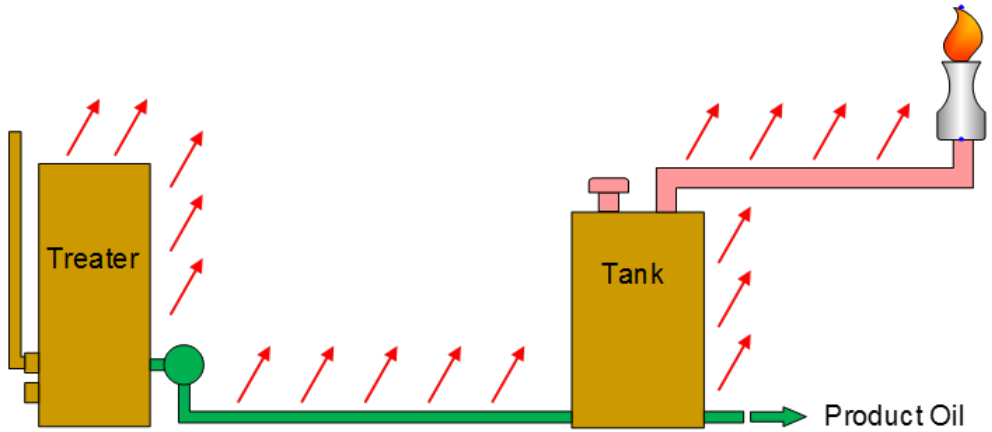
- **Evaluation of 168 refracs identified in ND (as of Sept 2017)**
- **Refrac production performance**
  - Average uplift in daily oil production of 350 stb/day during 30 days following refrac.
  - Incremental EUR ranging from 80 to 260 Mstb.
  - Avg GOR decrease of 20% during first 30 days after refrac.
- **Results show some positive potential in Bakken refracs, but…**
- **Current refrac data set substantially influenced by wells of specific initial completion type (openhole, single stage).**
  - Inventory of remaining openhole single-stage wells is limited.
  - Risk increases with increasingly complex completions.



Surface location of refrac wells.

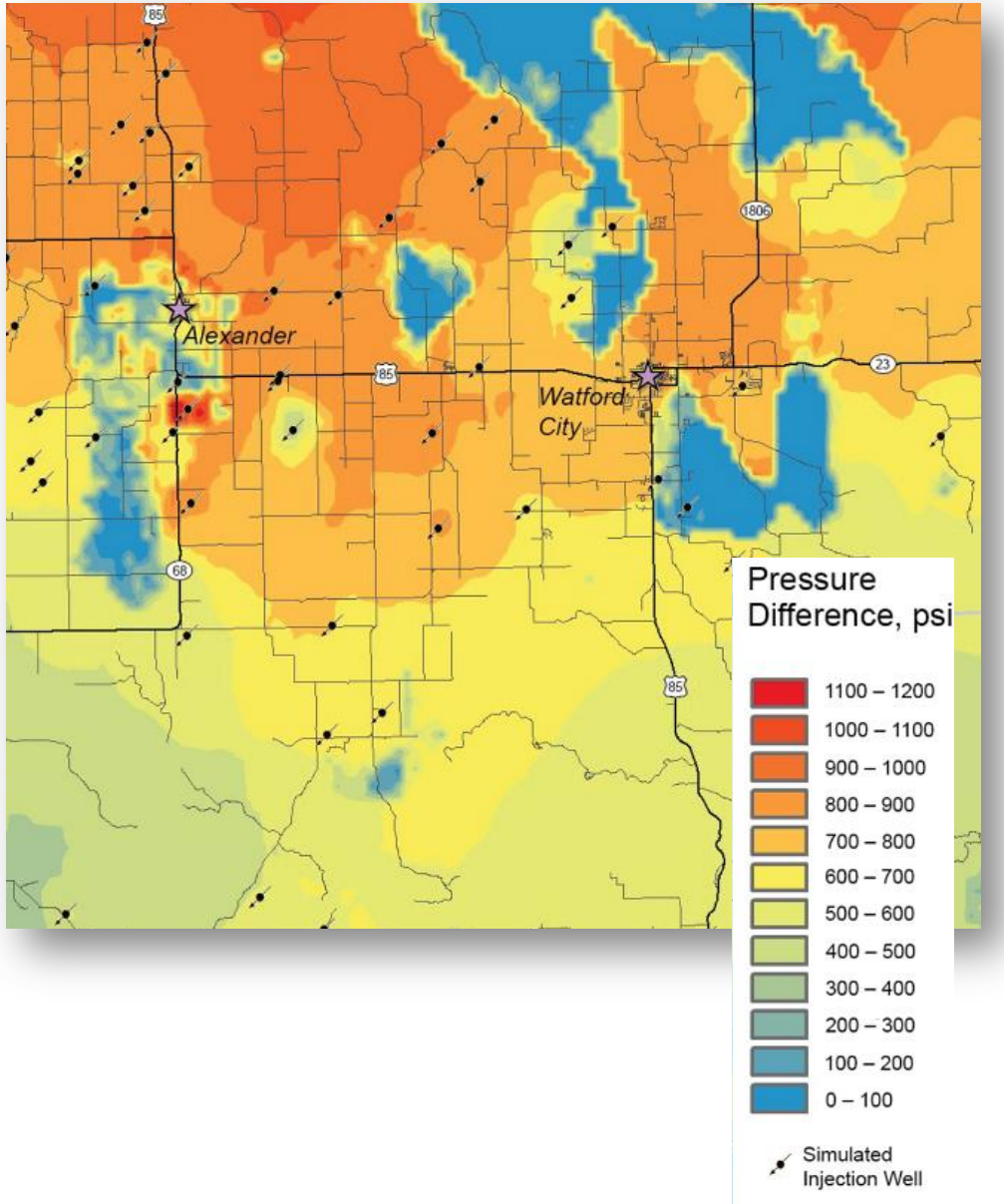
CRUDE OIL VAPOR PRESSURE MANAGEMENT

- **Impact**: determining optimal conditions for efficient operation will…
  - Help compliance with the state and midstream operators in cold weather.
  - Minimize hydrocarbon losses to gas stream in hot weather.
- **Activities**: worked with industry operators to gather data, develop computer models, and validate them with field data.
- **Next Steps**
  - Modeling activities are complete and being reviewed by participating BPOP members.
  - Final project summary being completed for distribution in upcoming weeks.



SALTWATER DISPOSAL (SWD) MODELING

- **Key Results:** modeling and simulation suggest a large overall storage potential in the formation; however, significant increases in pressure have been observed in certain areas of the formation.
  - Pressurization issues will likely increase as more SWD wells are installed and volumes of produce water requiring disposal continue to increase.
  - Pressurization of the Inyan Kara can be problematic when drilling new Bakken/Three Forks wells.
- **Next Steps: s**implistic models being developed to assist with estimating the zone of influence of SWD wells.
  - Could be used to assist in locating/siting SWD wells.



ANCILLARY ACTIVITIES

- **Statistical Analysis of Bakken Production Data**
  - 30 completion and geologic variables evaluated at 6- and 60-month cumulative oil production.
  - Quantified the relative effect of these variables on short- and long-term Bakken productivity.
  - Results summarized in presentation available on Members-Only Web site.
- **Remediation Support**
  - Providing information to the Hydrocarbon Remediation Task Force as subject matter experts.
  - Updated North Dakota Remediation Resource Manual to include brine and hydrocarbon impacts; being reviewed by BPOP members prior to distribution.

PROGRAM NEXT STEPS

- Input from member companies is being used to refine the focal points of our refrac efforts.
  - Refrac opportunities beyond barefoot completions?
  - Examine technical challenges relative to emerging technologies.
  - Compare and contrast refrac to infill drilling.

- A survey has been sent out to personnel at member companies to ensure BPOP is addressing the top priorities of the membership.


QUESTIONS?
Critical Challenges.
Practical Solutions.

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Critical Challenges.
Practical Solutions.

APPENDIX D

BPOP 2018 ANNUAL MEMBERS MEETING AGENDA

Bakken Production Optimization Program 2.0

EERC UNIVERSITY OF NORTH DAKOTA

BAKKEN PRODUCTION OPTIMIZATION PROGRAM 2.0 **ANNUAL MEMBERS MEETING**

Dress Code is Business Casual

AGENDA

DAY 1 TUESDAY, AUGUST 7, 2018 **EERC – GRAND FORKS, ND**

TIME	ACTIVITY	DISCUSSION LEADER(S)
12:00 Noon	Lunch provided at the EERC	
1:00 p.m.	Welcome	John Harju
1:05 p.m.	EERC Bakken Research – Where We've Come from and Where We're Going	Charlie Gorecki
1:40 p.m.	Transportation and Processing Infrastructure – View from the North Dakota Pipeline Authority	Justin Kringstad
2:10 p.m.	Networking Break	
2:30 p.m.	Panel on Bakken Rich Gas EOR – Pilot Testing at Stomping Horse	
	• Introduction and Project Overview	Jim Sorensen
	• Objectives, Approach, and Status of the Pilot Test Field Activities	Tammy Kaier, Liberty Resources
	• Laboratory Studies to Support Rich Gas EOR	Steve Hawthorne
	• Modeling and Simulation Efforts	José Torres
	• Member Time (30 minutes for Q&A)	
4:30 p.m.	The Future of the Bakken – View from the North Dakota Department of Mineral Resources Director's Chair	Lynn Helms
5:00 p.m.	Wrap-Up	
6:00 p.m.	Dinner – BBQ/Social at the EERC	

DAY 2 WEDNESDAY, AUGUST 8, 2018 **EERC – GRAND FORKS, ND**

TIME	ACTIVITY	DISCUSSION LEADER(S)
8:00 a.m.	Continental Breakfast at the EERC	
8:30 a.m.	Inyan Kara Modeling to Support Produced Water Management	Beth Kurz
9:00 a.m.	Surface Facility Vapor Pressure Modeling	Chris Martin
9:30 a.m.	Aromatic/Aliphatic Oil Fingerprinting and Potential Utility	Steve Hawthorne
10:00 a.m.	Networking Break	
10:20 a.m.	Panel on Bakken Production and Technology Trends	
	• Bakken Production and Technology Trends	Beth Kurz
	• Multivariate Analysis of Production Data	Chantsa Dalkhaa
	• Refracs	Chantsa Dalkhaa
11:15 a.m.	Open Discussion/Member Time	
12:00 Noon	Networking – Lunch provided at the EERC	