EERC

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www.undeerc.org

October 13, 2017

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

Dear Ms. Fine:

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

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

Sincerely,

Brian P. Kalk

Brian P. Kalk
Director of Energy Systems Development

BPK/rlo

Enclosure

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

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October 13, 2017

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

Dear Mr. Parker:

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

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

Sincerely,

Brian P. Kalk
Director of Energy Systems Development

BPK/rlo

Enclosure

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

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October 13, 2017

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

Dear Mr. Pospisil:

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

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

Sincerely,

B P Kalk

Brian P. Kalk
Director of Energy Systems Development

BPK/rlo

Enclosure

E-Mailed Report Only: Bryan Bugg, Liberty Resources

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October 13, 2017

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

Dear Mr. Swaren:

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

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

Sincerely,

Brian P. Kalk
Director of Energy Systems Development

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Enclosure

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

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October 13, 2017

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

Dear Ms. Erickson:

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

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

Sincerely,

Brian P. Kalk
Director of Energy Systems Development

BPK/rlo

Enclosure

E-Mailed Report Only: Kyrre Johansen, ConocoPhillips

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October 13, 2017

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

Dear Mr. Herman:

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

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

Sincerely,

Brian P. Kalk
Director of Energy Systems Development

BPK/rlo

Enclosure

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

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www.undeerc.org

October 13, 2017

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

Dear Mr. Lohnes:

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

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

Sincerely,

Brian P. Kalk
Director of Energy Systems Development

BPK/rlo

Enclosure

E-Mailed Report Only: Vicky Sand, Hess Corporation

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October 13, 2017

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

Dear Mr. Westler:

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

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

Sincerely,

Brian P. Kalk
Director of Energy Systems Development

BPK/rlo

Enclosure

E-Mailed Report Only: Brian Wold, WPX Energy

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October 13, 2017

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

Dear Dr. Longoria:

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

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

Sincerely,

Brian P. Kalk

Brian P. Kalk
Director of Energy Systems Development

BPK/rlo

Enclosure

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

BACKGROUND

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

The goals of BPOP 2.0 are to:

- Employ a “system of systems” approach to enhance overall production efficiency, recognizing that improved coordination among various design factors (reservoir management, well design, surface processing, gas management, waste management) can lead to significant improvements in resource recovery efficiency.

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

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

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

The anticipated outcomes of BPOP 2.0 are 1) increased well productivity and economic output of North Dakota’s oil and gas resources, 2) decreased environmental impacts of wellsite operations, and 3) reduced demand for infrastructure construction and maintenance. Specific results will include improved resource recovery efficiency, reduced land use impacts, increased royalties and tax revenue from harnessed associated gas and natural gas liquid streams, and increased revenue from added product streams captured earlier in the well life cycle.

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

ANNUAL REPORT

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

Expansion of Enhanced Oil Recovery Effort with Significant DOE Funding

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

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

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

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

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

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

Major Milestone for Liberty Resources EOR Pilot Operation

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

Refracturing Optimization Task

Refracturing (Refrac) Optimization Study Recently Engaged

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

Produced Fluid Characterization Task

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

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

Reservoir Performance Modeling Task

Novel Analysis of Bakken Petroleum System Reservoir Performance Completed

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

Water Injection Reservoir Assessment Task

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

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

Facility Process Optimization Task

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

The EERC has completed an initial analysis of a large set of operational data and crude oil vapor pressure data to identify trends and factors influencing crude oil vapor pressure. Results from this analysis were summarized and shared with the North Dakota Petroleum Council (NDPC) Technical Solutions Group in Dickinson, North Dakota, on September 7, 2017.

Summarized and presented an overview of data analysis and modeling activities regarding surface facility design and operations strategies to achieve crude oil vapor pressure targets.

Aromatic/Aliphatic Study Task

EERC Developing New Indicators of Oil Source Rock

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

Environmental Support Task

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

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

Program Management

The EERC continues to seek support for this program, and to date, additional cost share has been secured from the following Bakken producers: Petro-Hunt, Hess Corporation, ConocoPhillips, Oasis Petroleum, WPX Energy, Marathon Oil, and Liberty Resources. Statoil has notified us of its intent to join and has requested an invoice. Payment is anticipated in October 2017. In addition, the EERC has secured $2,000,000 from DOE to complement the ongoing work to determine the feasibility of reinjecting captured rich gas into a Bakken reservoir to enhance oil recovery. Liberty Resources is providing in-kind contributions that support this programmatic scope.

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

Table 1. BPOP 2.0 – Original Budget

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

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

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

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

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

QUARTERLY PROGRESS REPORT (July – September 2017)

ACCOMPLISHMENTS DURING REPORTING PERIOD

Enhanced Oil Recovery Task

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

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

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

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

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

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

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

  – Laboratory-based examinations of rich gas interactions with reservoir fluids and tight rocks (including oil-rich shales) will be used to determine the ability of various rich gas mixtures to mobilize oil in the tight reservoir rocks and shales of the Bakken petroleum system. During this quarter, minimum miscibility pressure (MMP) studies were conducted using different mixtures of rich gas (ethane, methane, and propane) in oil samples from Liberty Resources Stomping Horse complex in Williams County. Initial extraction studies on rocks from the Stomping Horse area were also conducted.

  – Evaluations of the changes in gas and fluid compositions over time in both the tight oil reservoir and surface infrastructure environments will be conducted as well as examinations of how those changes affect reservoir and process facility performance. Crude oil and produced water samples were collected from a newly completed and producing well in the Stomping Horse complex to determine baseline compositions. These samples were collected September 7–18, 2017, during the first 2 weeks of well production. Sampling will be repeated periodically throughout the first 12 to 18 months of production to provide a temporal aspect to well fluid.

  – Iterative modeling of surface infrastructure and reservoir performance will be conducted using the data generated by the various project activities to optimize future commercial-scale Bakken EOR design and operations. A static geomodel of the Bakken petroleum system in the Stomping Horse area was used to create an upscaled model of the specific drill spacing unit (DSU) that will be used for the pilot project. The DSU model was the basis for history-matching modeling that was performed using data provided by Liberty Resources. Simulation modeling of several potential injection and production scenarios was also conducted. A model of the surface operations and infrastructure of the Stomping Horse complex, including the County Line Gas Plant, was created using data provided by Liberty Resources.

- On September 21, Liberty Resources presented its application before NDIC (Case No. 26035) for an order granting temporary authority to use numerous wells located in the DSU (referred to as the “Leon-Gohrick DSU”), comprised of Sections 8 and 17, T.158N., R.95W., Williams County, as injection wells for an EOR pilot operation. The application is under consideration by NDIC, and it is anticipated that a decision may be rendered in the next quarter. It is anticipated that the pilot test will be initiated no later than early to mid-2018, pending approval from NDIC. An exhibit presented by Liberty Resources that contains detailed information about the plans for pilot testing is provided in Appendix C.

Refracturing Optimization Task

- A literature survey is under way to learn more about past and current research and practices on refrac, the candidate well selection process, techniques and approaches, key challenges faced, and lessons learned associated with the operation.

- Development of suggested guidelines for candidate selection in unconventional reservoirs is also under way based on the findings from the literature review.

- A data set of approximately 140 existing Bakken refrac wells was obtained from the North Dakota Pipeline Authority (NDPA). Well and production data regarding these refrac wells have been compiled to understand what types of wells have been selected for refrac in the Bakken so far. Analysis of production performance of the refrac wells in the data set was begun to review and interpret the refrac responses in the Bakken. Incremental rates and estimated ultimate recovery (EUR) are determined following the refrac operation on an individual well basis, and the analysis has been completed for half of the data set.

- A case study of the first well in Whiting Corporation's Refrac Pilot Project has been initiated, with production performance assessed. The response of the well to the refrac operation seems to be positive, with an increased oil production rate and contacting new additional reservoir volume following the operation. Additional analysis is ongoing.

- EERC staff traveled to Bismarck, North Dakota, on August 1, 2017, to participate in the North Dakota Legislative Management Energy Development and Transmission Committee meeting regarding oil well refrac potential in North Dakota.

Produced Fluid Characterization Task

- Coordination with BPOP program leads continued to identify key information and data needs to support ongoing and planned research efforts.

- Formal solicitation of key industry partners was begun for available fluid compositional data and access to future sample collection and analysis activities.

- Crude and produced water samples were collected from a newly completed and producing Liberty Resources well. These samples were collected September 7–18, 2017, during the first 2 weeks of well production. Sampling will be repeated periodically throughout the first 12 to 18 months of production to provide a temporal aspect to well fluid composition.

- Analysis of recently acquired cuttings and fluid samples has continued. Data will continue to be analyzed and used to support multiple activities conducted within the program.

- EERC staff traveled to the Dickinson, Kildeer, and Tioga areas to retrieve produced fluid samples on July 12–15, 2017.

Reservoir Performance Modeling Task

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

Water Injection Reservoir Assessment Task

- History-matching simulations were completed for all 103 saltwater disposal (SWD) wells involved in the reservoir model for the Inyan Kara Formation. Adjustments were made to reservoir permeability for both the whole model and surrounding wells located in particular areas. The simulated area covers approximately 1750 square miles, nearly all of which lies within McKenzie County.

- To evaluate the long-term injection capacity of the Inyan Kara Formation in the simulated area, six prediction cases were performed. Three cases were performed with semiclosed boundary conditions, and three cases were performed with open-boundary conditions. The semiclosed boundary condition can be interpreted as providing conservative results, while the open-boundary condition provides more optimistic results. However, the boundary conditions have relatively little effect on the injection capacity of the modeled area.

- The results of the prediction simulation cases are summarized and analyzed. The cumulative water injection at the end of the year 2050 indicate there remains a very large disposal capacity of approximately 4 to 5 billion barrels (5–6 times the current cumulative water injected) in the existing SWD wells.

- Pressure difference maps between the original pore pressure and the year 2017, and between 2017 and the year 2050 are investigated in this study. These maps suggest there is still a large portion (e.g., south half) of the simulated area that has room for pressure increase, even after more than 30 years of injection, although additional SWD wells would be required in those areas. Therefore, the total injection capacity of the simulated area should be larger than the predicted capacity estimated by using only the existing wells. The ability to economically access this additional capacity has not been addressed by this study.

- A draft of the final topical report is completed and is under technical review.

Facility Process Optimization Task

- Following the May 10 industry meeting focused on crude oil vapor reduction strategies, the EERC prepared and distributed a formal data request to gather information about operating conditions and crude properties.

- A large data set comprising operational data and crude oil vapor pressure data was reviewed and analyzed to identify trends and factors influencing crude oil vapor pressure. Results from this analysis were compiled into a PowerPoint presentation and shared with the NDPC Technical Solutions Group in Dickinson, North Dakota, on September 7, 2017. EERC personnel presented an overview of data analysis and modeling activities conducted to evaluate surface facility design and operations ability to meet crude oil vapor pressure targets. The Hydrocarbon Remediation Task Force presentation, "Summary of Hydrocarbon Information," is attached in Appendix A.

- Three facility configurations were identified for modeling, then development began for a site-specific facility model for each configuration. Facility layout drawings, operational data, and produced fluids data have been requested and will form the basis for subsequent simulations and field validation of the model.

- Work has begun on a process model and winter field trial focused on insulated tanks and different tank fill strategies as a method for reducing crude oil vapor pressure. Facility drawings and operational data have been requested. These data will form the basis for site-specific facility modeling and a winter field trial to evaluate strategy effectiveness.

Aromatic/Aliphatic Study Task

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

- The newly developed analytical method for quantitating aromatic and aliphatic hydrocarbon contents has now been applied to 70 different samples (ranging from Three Forks to Lower, Middle, and Upper Bakken samples) obtained from 13 wells. Final data reduction and quality vetting are under way.

- The collection of additional core samples for aromatic/aliphatic analyses in the Liberty Resources production areas has been approved by the North Dakota Geological Survey Core Library and is scheduled to occur in late September or early October.

- Several drill cutting samples from the Middle Bakken Formation from two Liberty Resources wells were obtained and are presently being analyzed for aromatic/aliphatic ratios. The cuttings were collected from the heel to the toe of the laterals, so should allow any changes in aromatic/aliphatic ratios throughout the laterals to be investigated. Additional attempts to remove diesel cutting fluids from drill cuttings in order to allow the rock drill cuttings to be used for aromatic/aliphatic analyses have not been successful. The operator of these wells has recently provided a sample of its diesel fluid, which will be used in an attempt to better “clean” the diesel fluid from drill cuttings and allow aromatic/aliphatic analyses to be performed.

- Four oily water samples with crude oil “shows” were obtained during the drilling of a well lateral in the Middle Bakken. The samples were extracted with methylene chloride to obtain the hydrocarbon fraction and are presently being analyzed for aromatic/aliphatic ratios. These samples should enable determination of the aromatic/aliphatic ratios in crude oil produced prior to hydraulic fracturing and will likely enable determination of the shale contributions to produced crude oil after hydraulic fracturing.

Environmental Support Task

- EERC staff continued to collaborate with NDPC members, NDDH staff, and representatives of the Northwest Landowner's Association (NWLA) during planning of additional educational events focused on hydrocarbon spill and hydrocarbon spills remediation.

- The first education day event was held in Bismarck, North Dakota, on July 17, 2017. EERC staff presented to the group regarding the chemistry of unrefined hydrocarbons (crude oil), analytical methods employed to characterize produced liquid hydrocarbons, and an introduction to a risk-based approach to remediating hydrocarbon spills. The NDPC Technology Solutions Group Meeting Presentation, "Overview of Facility Process Modeling and Data Analysis," is attached in Appendix B.

Program Management and Development

- EERC staff traveled to Bismarck, North Dakota, to attend the Oil & Gas Research Program meeting on August 9–11, 2017.

- EERC staff traveled to Bismarck, North Dakota, to attend the NDIC meeting on September 20–21, 2017.

- EERC staff traveled to Calgary, Alberta, Canada, to attend the Society for Organic Petrology 34th Annual Meeting on September 21–24, 2017.

- EERC staff traveled to Washington, D.C., to attend the National Petroleum Council meeting on September 24–26, 2017.

- EERC staff attended the NDPC Annual Meeting in Grand Forks, North Dakota, on September 27–28, 2017.

- EERC staff traveled to Pittsburgh, Pennslvania, to attend the Interstate Oil & Gas Compact Commission Annual Meeting on September 30 – October 4, 2017, also participating in the Environmental & Safety Committee meeting.

MEMBERSHIP AND FINANCIAL INFORMATION

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

Table 3. BPOP 2.0 – Original Budget

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

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

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

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

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

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

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

FUTURE ACTIVITIES

The planned activities for the next quarter are detailed below.

Enhanced Oil Recovery Task

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

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

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

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

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

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

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

Refracturing Optimization Task

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

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

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

Produced Fluid Characterization Task

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

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

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

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

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

Reservoir Performance Modeling Task

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

Water Injection Reservoir Assessment Task

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

Facility Process Optimization Task

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

Aromatic/Aliphatic Study Task

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

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

- Diesel fluid expected to be provided by the operator who supplied the drill cuttings will be analyzed for the individual aromatic and aliphatic hydrocarbons to determine whether differentiation from the native rock hydrocarbon compositions that can be exploited to allow diesel-based drill cuttings to be used for aromatic/aliphatic analyses.

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

Environmental Support Task

- The second education day event is scheduled for October 10, 2017, and will focus on the following topics:

  – Resources to be protected, the uses of these resources, and the pathways leading to these resources

  – Current NDDH standards used by existing programs

Program Management and Development

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

APPENDIX A

HYDROCARBON REMEDIATION TASK FORCE PRESENTATION – SUMMARY OF HYDROCARBON INFORMATION

Summary of Hydrocarbon Information

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

Chad Wocken, Principal Engineer
Brad Stevens, Senior Research Engineer

Critical Challenges. Practical Solutions.

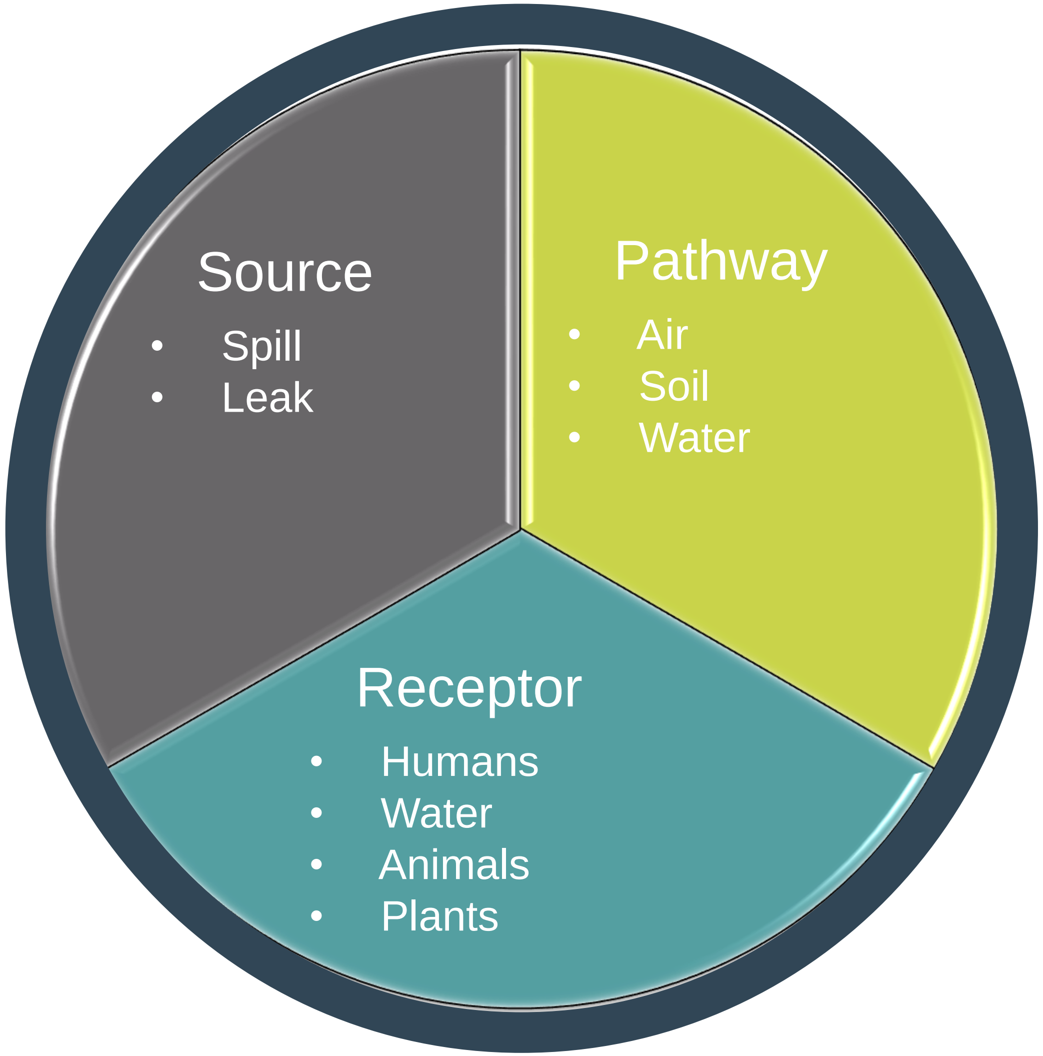
Overview/Outline

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

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

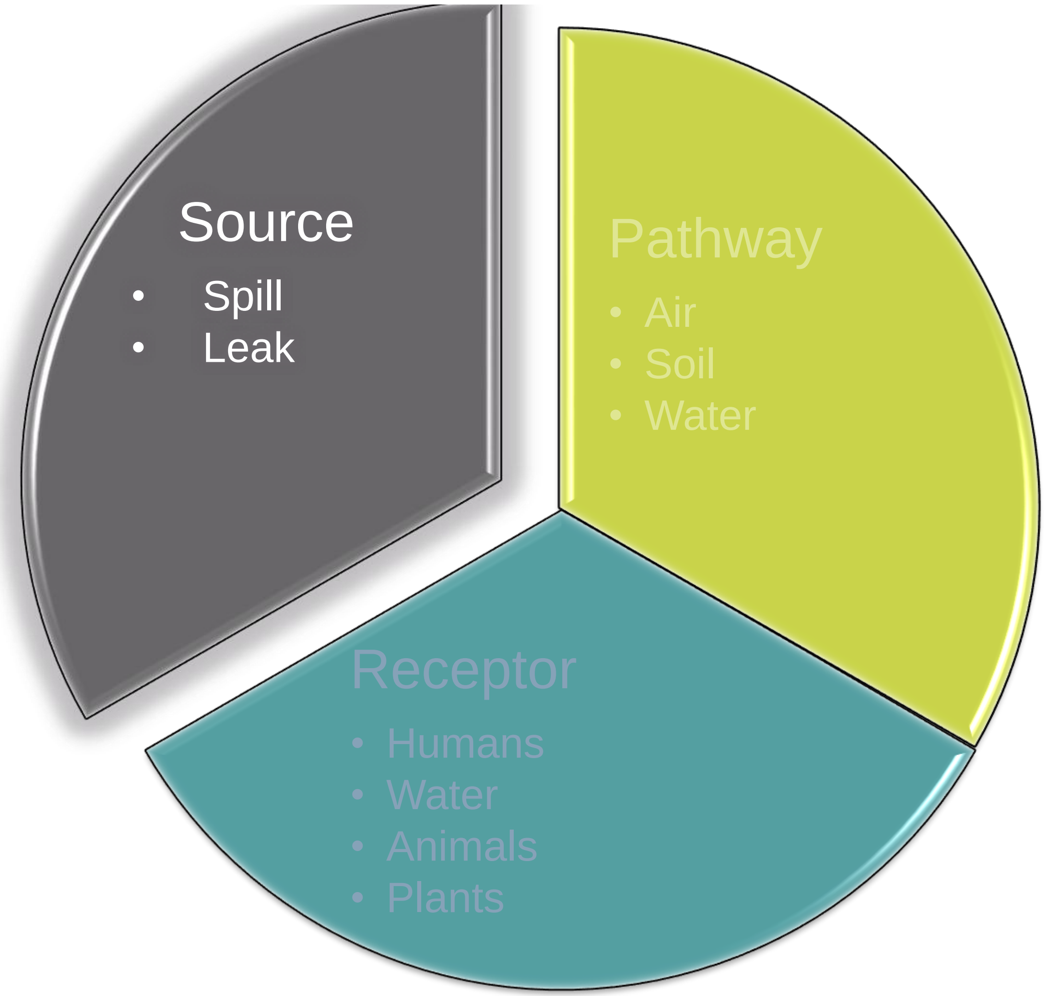
- Livestock and crop
- Water types and uses
- Review of North Dakota and other state regulations

Elements of a Spill

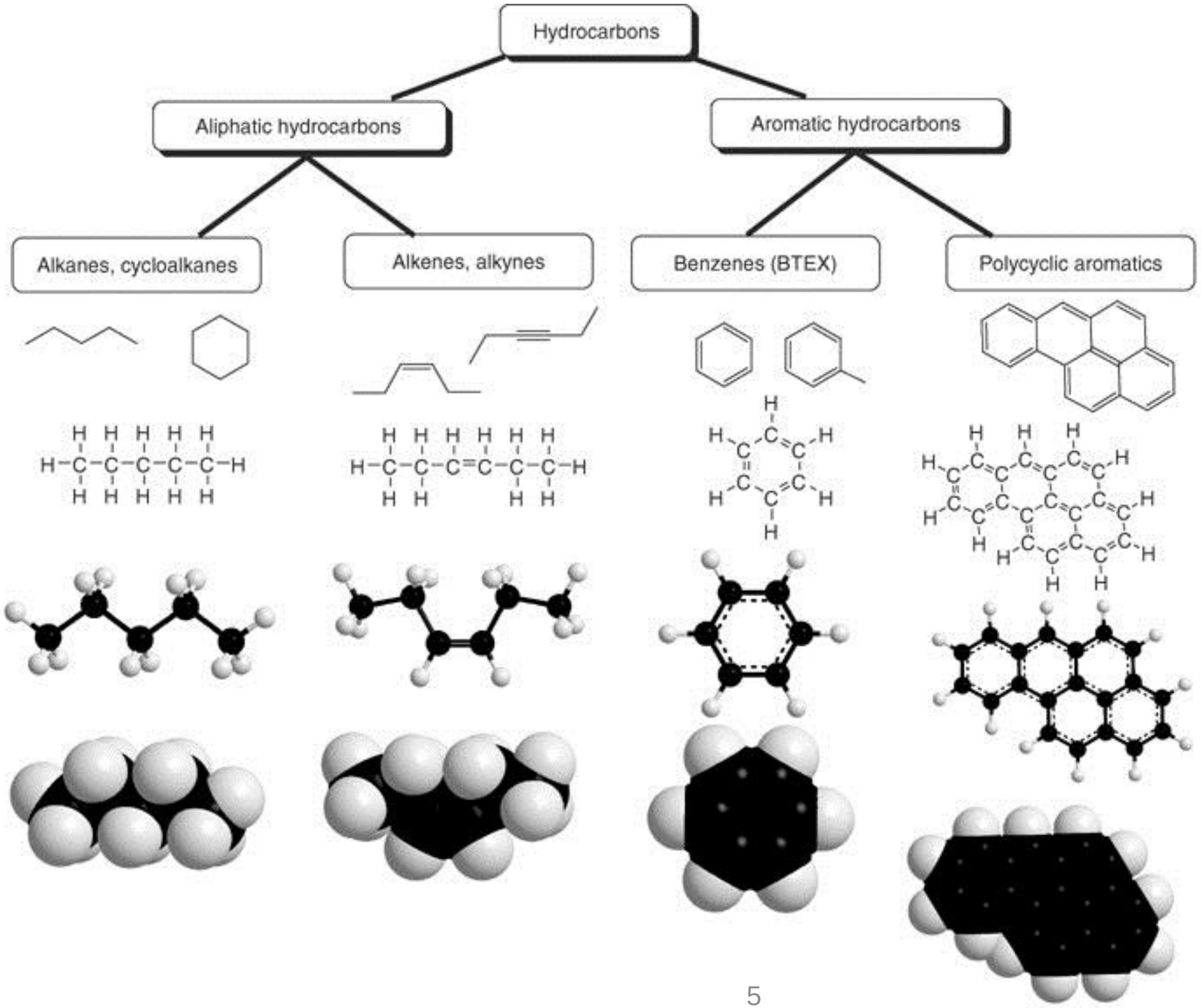


Crude Oil Chemistry

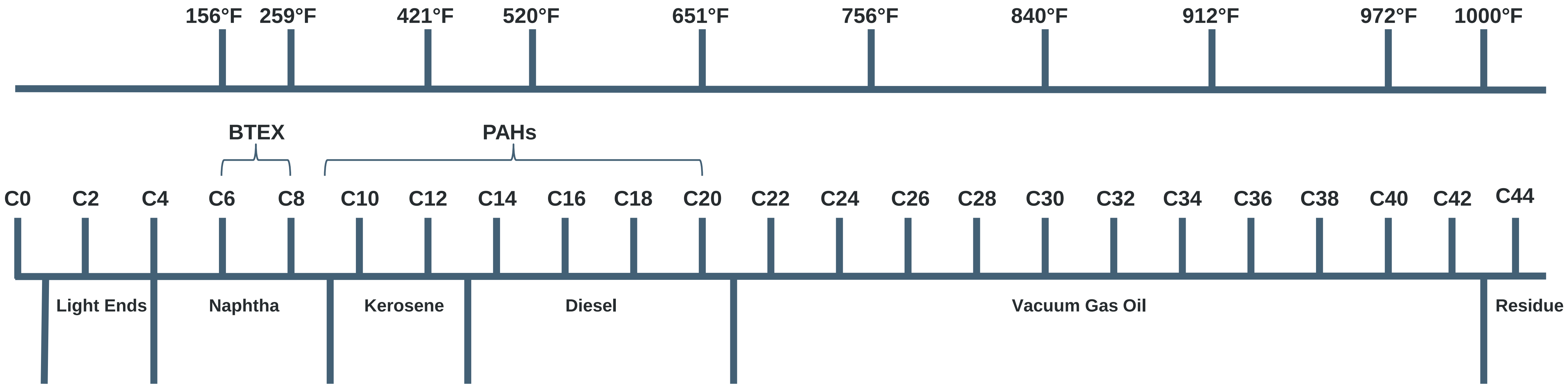
- Spills and leaks of unrefined hydrocarbon products:
  - Crude oil
  - Condensate
- Examples of sources:
  - Well-site equipment
  - Pipelines and gathering lines
  - Trucks, trains, etc.



Crude Oil – Complex Mixture of Hundreds of Chemicals



Carbon Number and Boiling Point

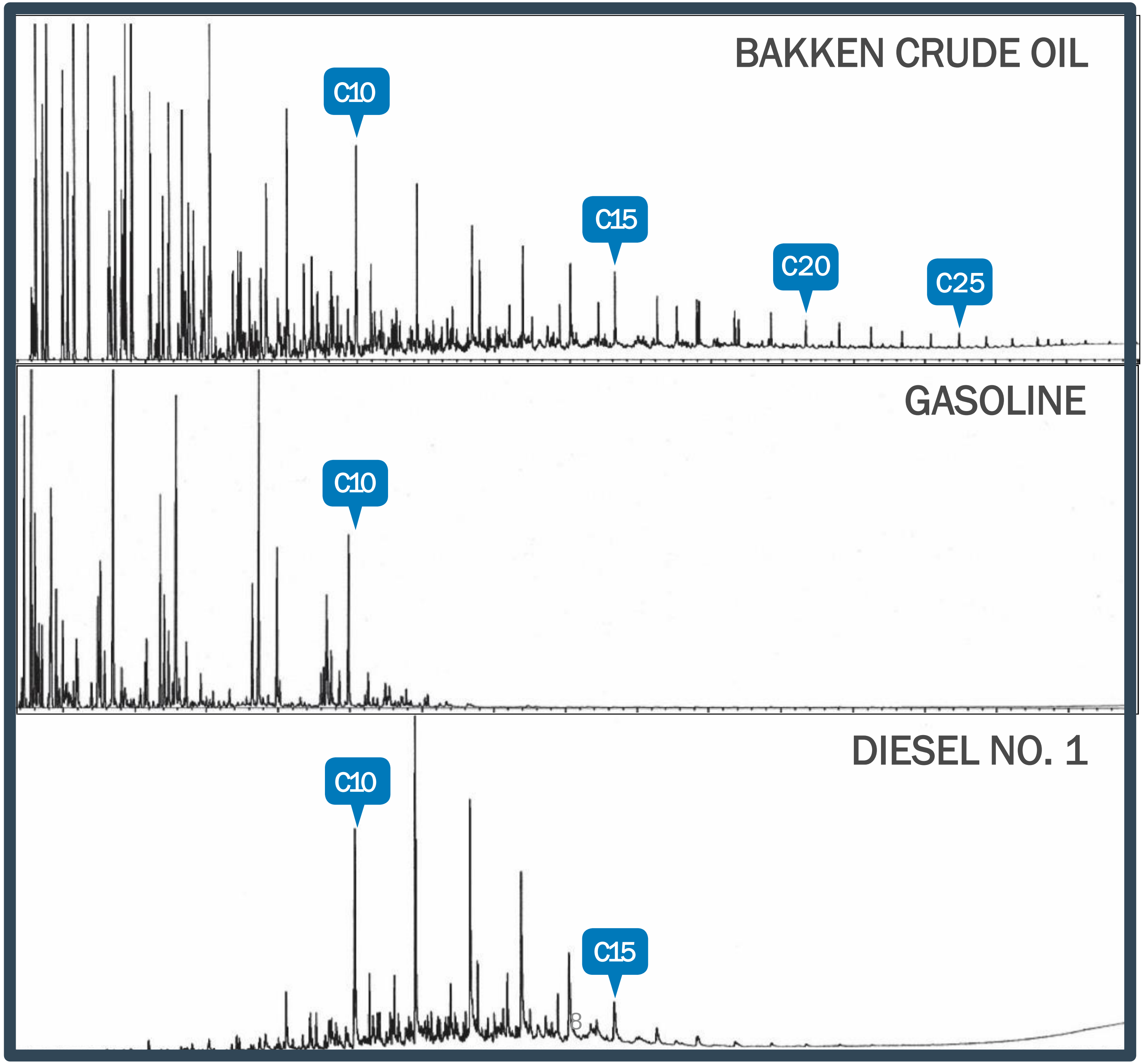


Crude Oil Properties

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

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

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


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

Comparison of HC Properties

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

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

Crude Oil Chemicals of Concern

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

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

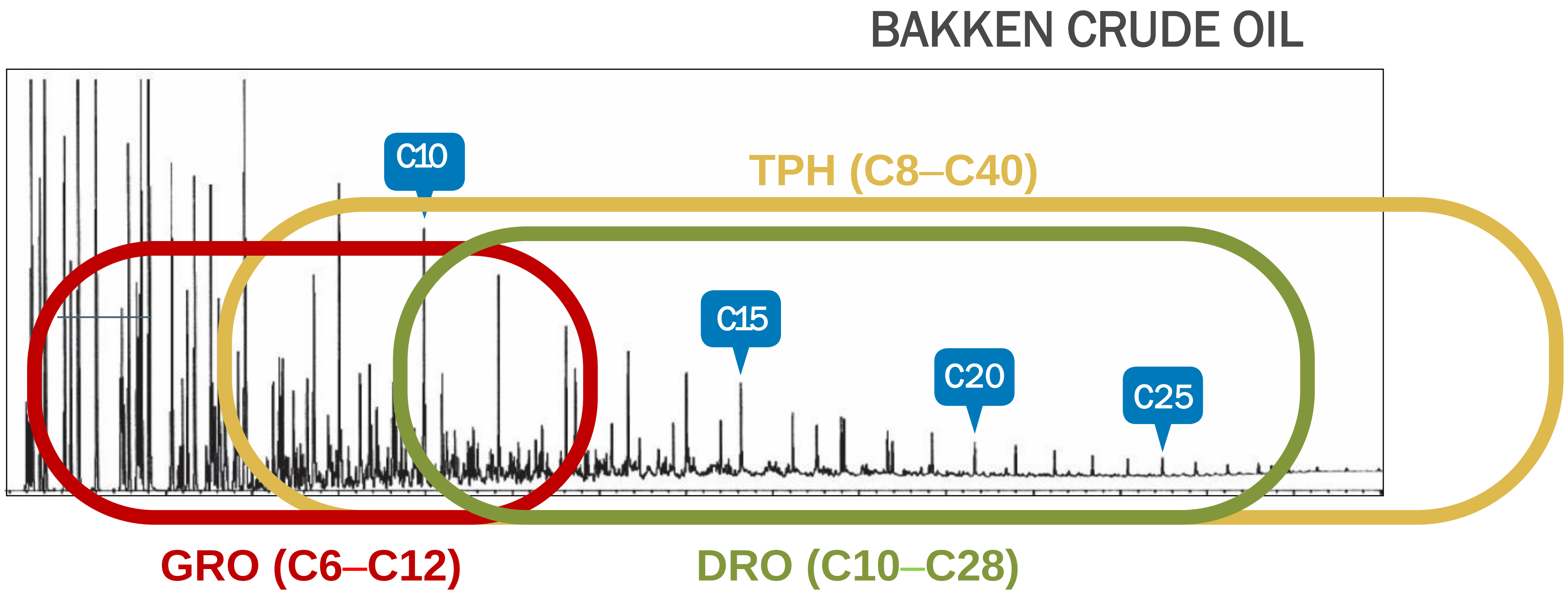
[1] API Publication No. 4709, Risk-Based Methodologies for Evaluating Petroleum Hydrocarbon Impacts at Oil and Natural Gas E&P Sites.
[2] Total Petroleum Hydrocarbon Criteria Working Group Series, Volume 2, Composition of Petroleum Mixtures, Thomas L. Potter, Kathleen E. Simmons, May 1998
[3] USGS, Fate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

Hydrocarbons Are Measured Using Multiple Analytical Methods

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

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

Comparison of TPH, GRO, and DRO Measurements



Summary of Fractionated Analytical Methods

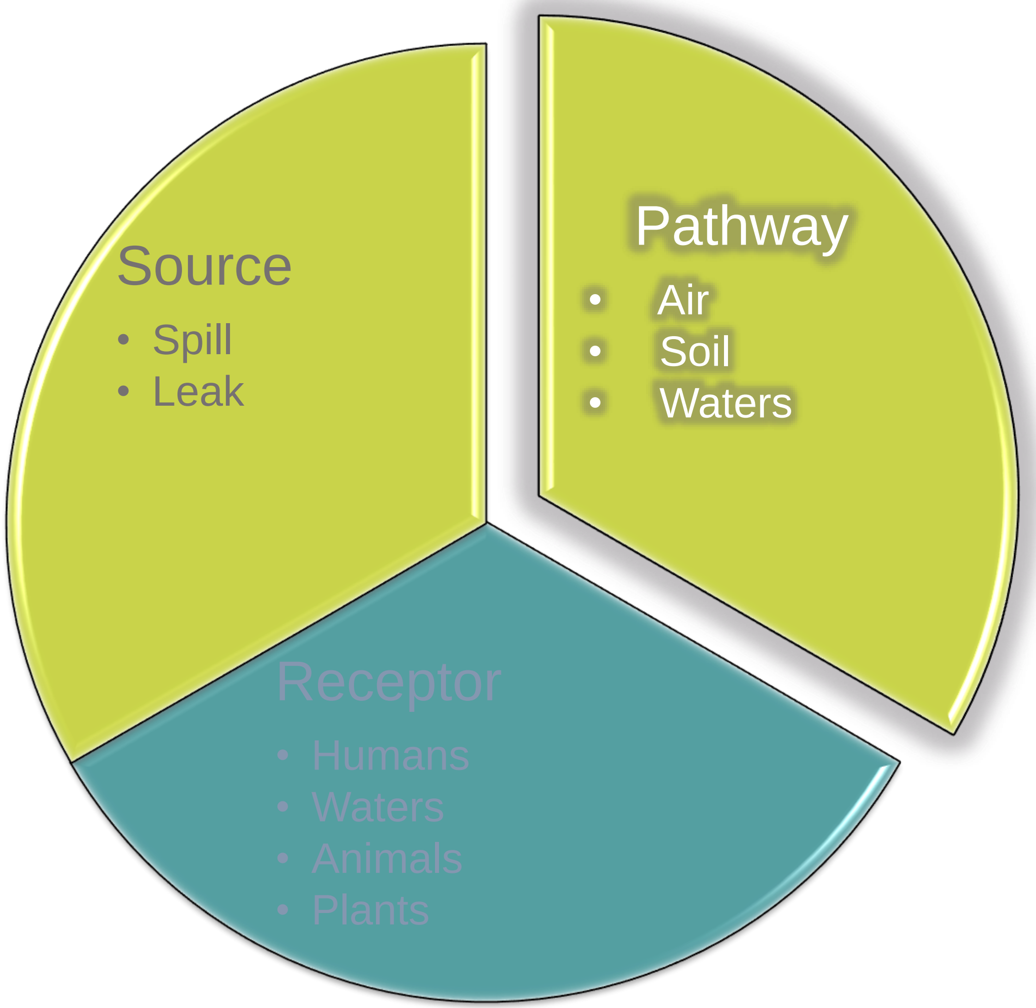
- Several analytical methods exist that provide greater detail about the types of hydrocarbons present in a crude oil:
  – Total Petroleum Hydrocarbon Working Group (TPHCWG)
    ♦ Fractionated method, identify groups of compounds with similar fate and transport properties
    ♦ Measured HCs in the range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

Crude Chemistry Review

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

Crude Oil in the Environment

- Typical pathways:
  - Air
  - Soil
  - Water

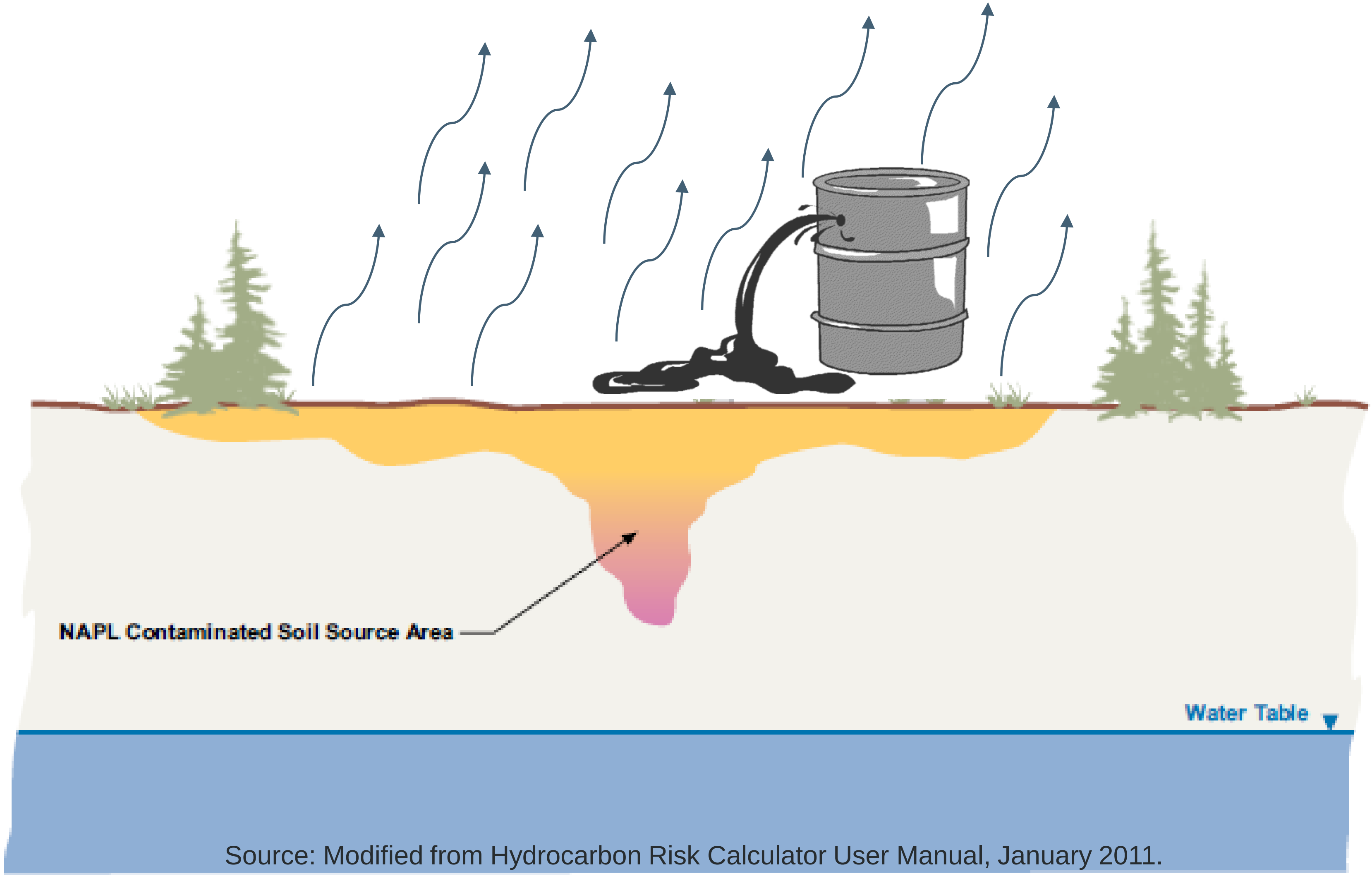


US Department of Health and Human Services Bulk Migration of Oil

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

Compounds Separate and Migrate Independently Driven by Their Respective Properties

- Volatility
- Solubility
- Sorption potential
- Biodegradation



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

Volatility

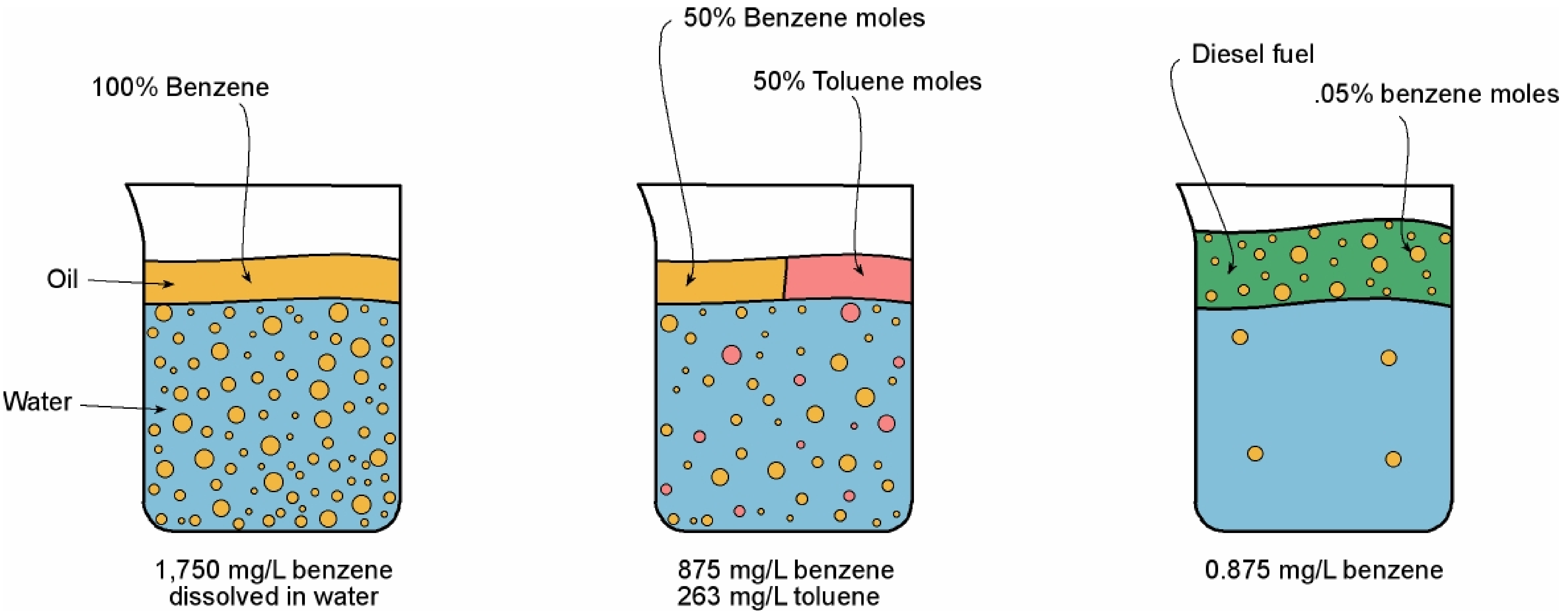
- Vapor pressure is the physical property used to represent volatility
- Vapor pressure
  - $>10^{-2}$ mmHg, hydrocarbon is likely in air phase
  - Between 10^{-2} and 10^{-7}mmHg, hydrocarbon in both vapor and liquid phase
  - $<10^{-7}$ mmHg, hydrocarbon is likely in liquid phase
- Volatilization impacted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

Solubility

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

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

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



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

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

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

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

Biodegradation

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

Biodegradation – Chemical Composition

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

Biodegradation – Environmental Factors

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

Comparison of Key Chemical Properties

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

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

Crude Oil in the Environment Review

Volatility

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

Solubility/Soil Sorption

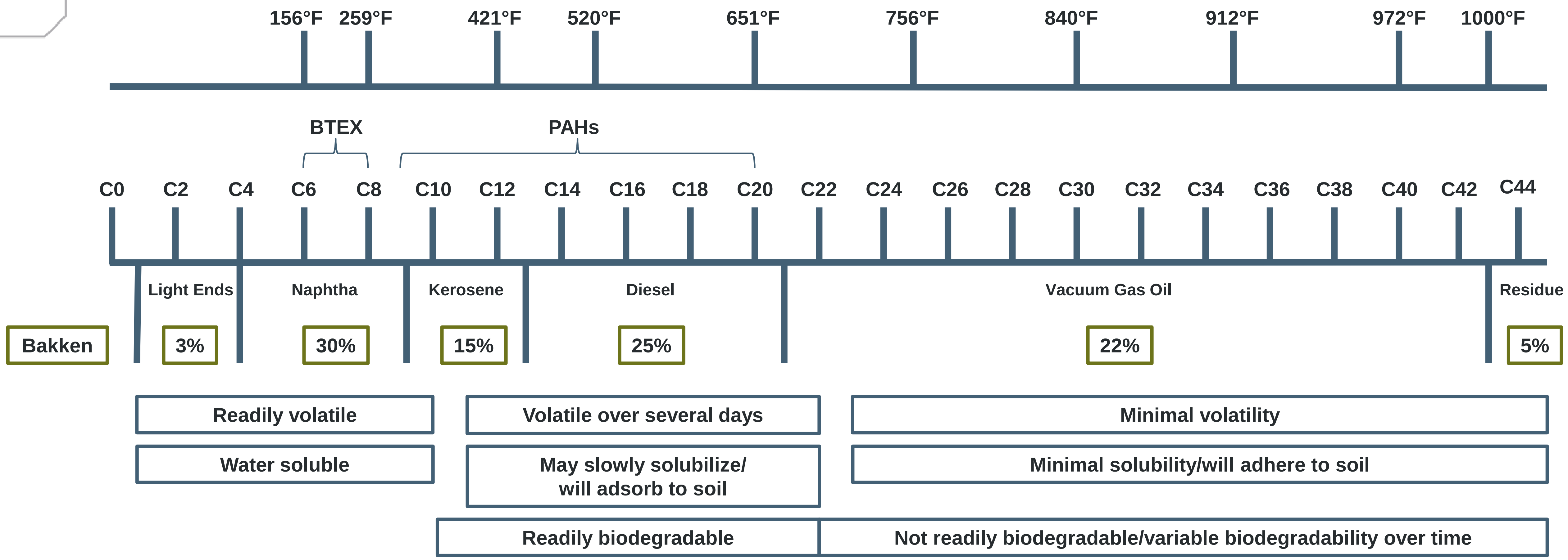
- Less than 5% of crude oil will dissolve in water.[2]
- C1–C10 has some water solubility.[1]
- C11–C22 may slowly dissolve in water, and will adsorb to soil.[1]
- C23+ minimal solubility, will adhere to soil.[1]

Biodegradability

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

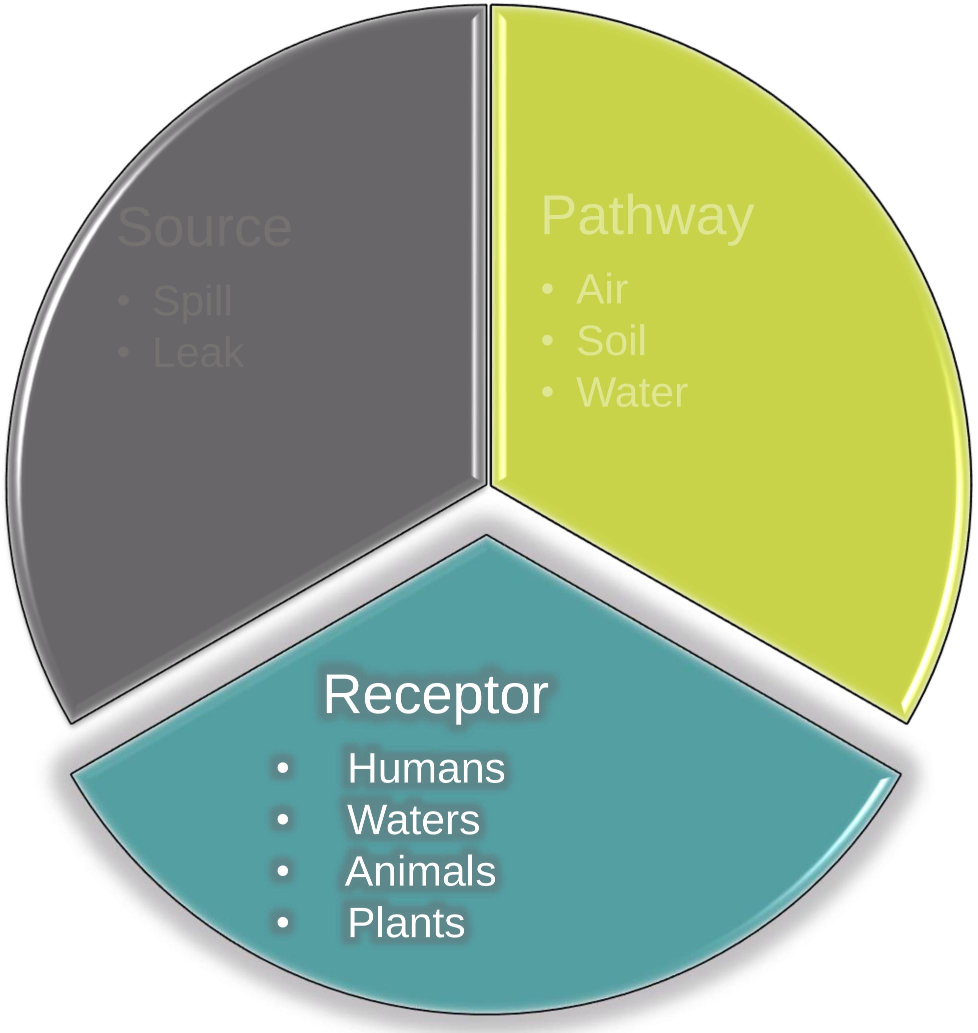
[1] Massachusetts Department of Environmental Protection, Bakken Crude Oil Spills – Response Options and Environmental Impacts.
[2] USGS, Fate and Transport of Petroleum Hydrocarbons in Soil and Ground Water at Big South Fork Nation River and Recreation Area, 2002–2003.
[3] Dr. Ben Thomas testimony to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

Carbon Number and Boiling Point

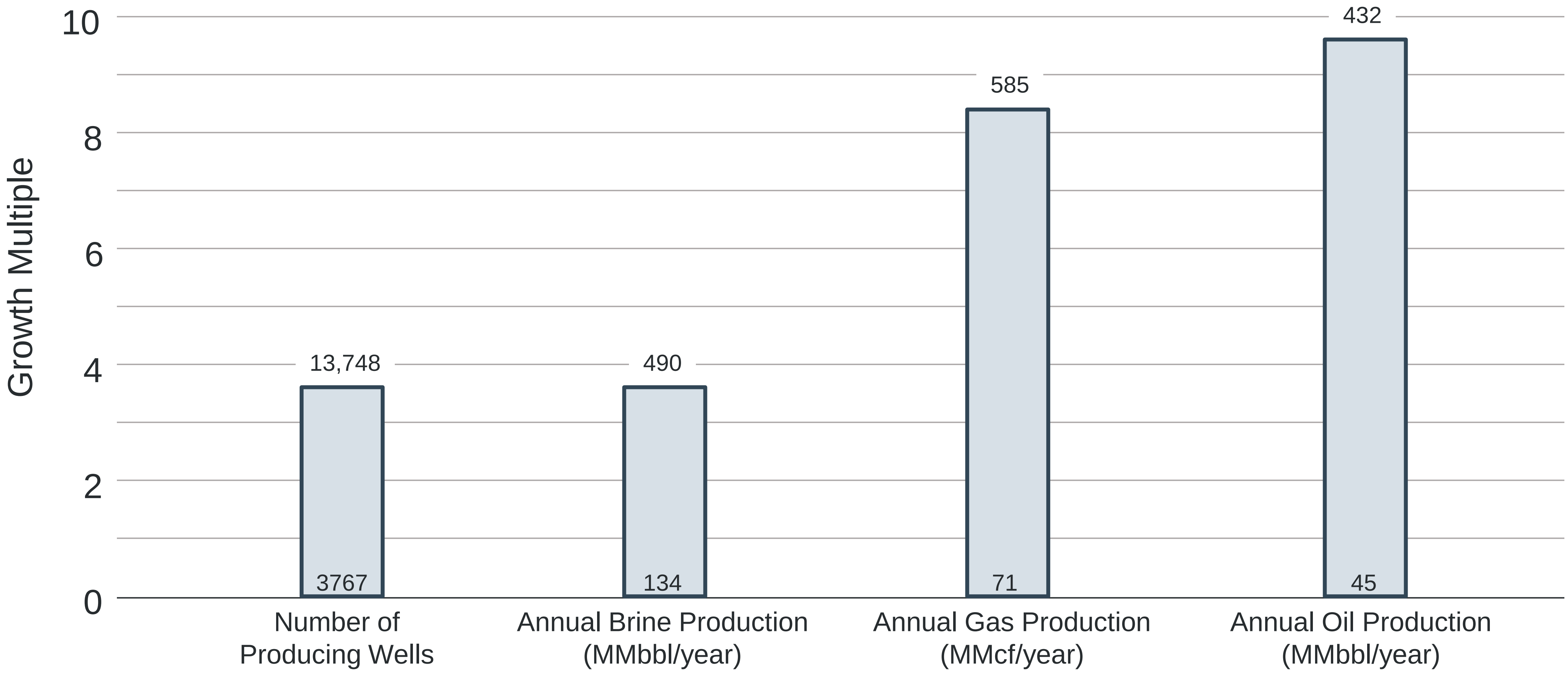


Crude Oil Releases and Risk-Based Decision Making

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

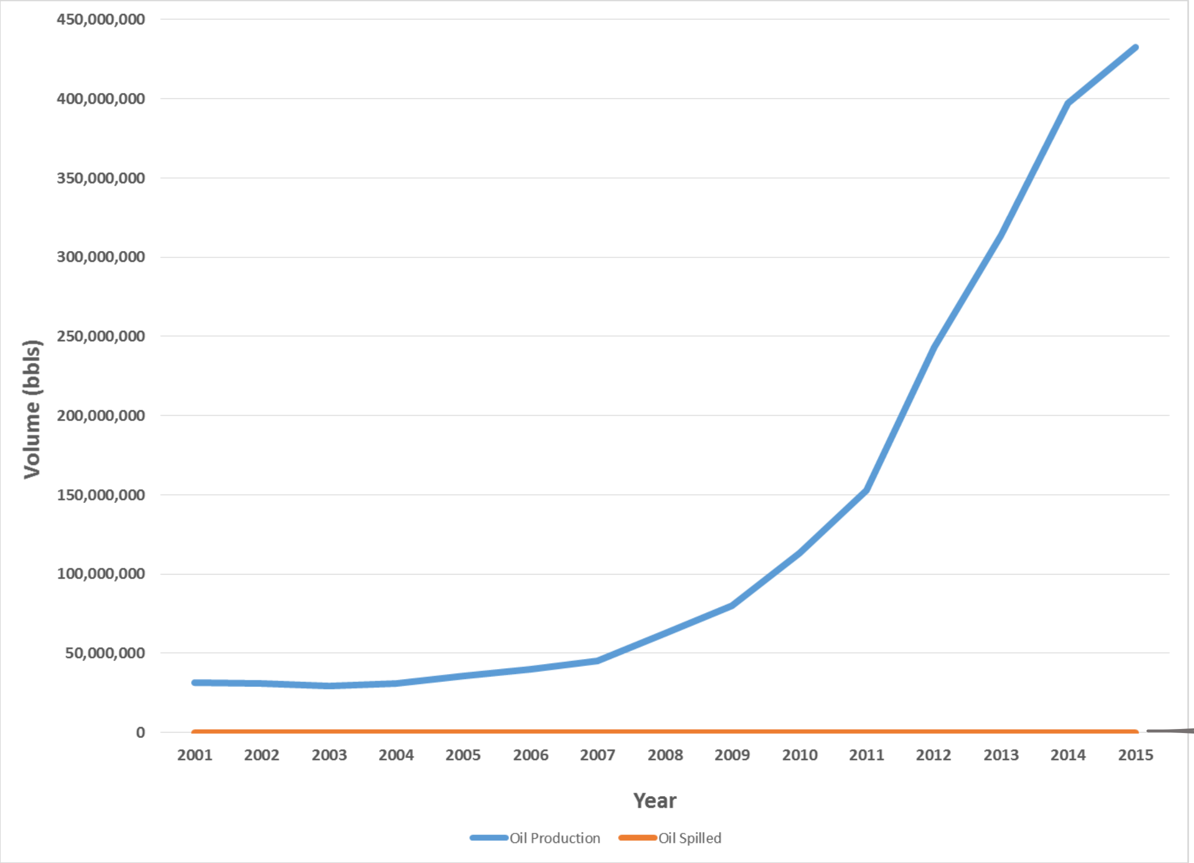


Background: Bakken Development by the Numbers 2007 vs. 2015

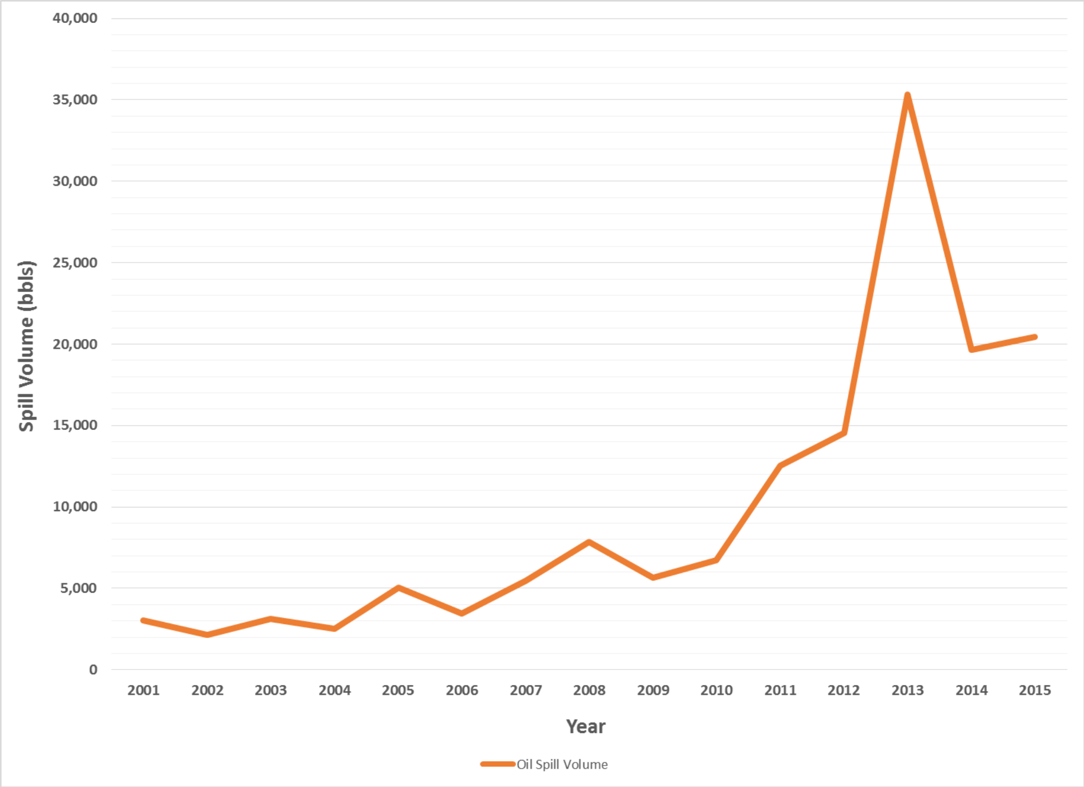


Notes: bbl = barrel
cf = cubic feet
MM = million

Crude Oil (2001–2015)

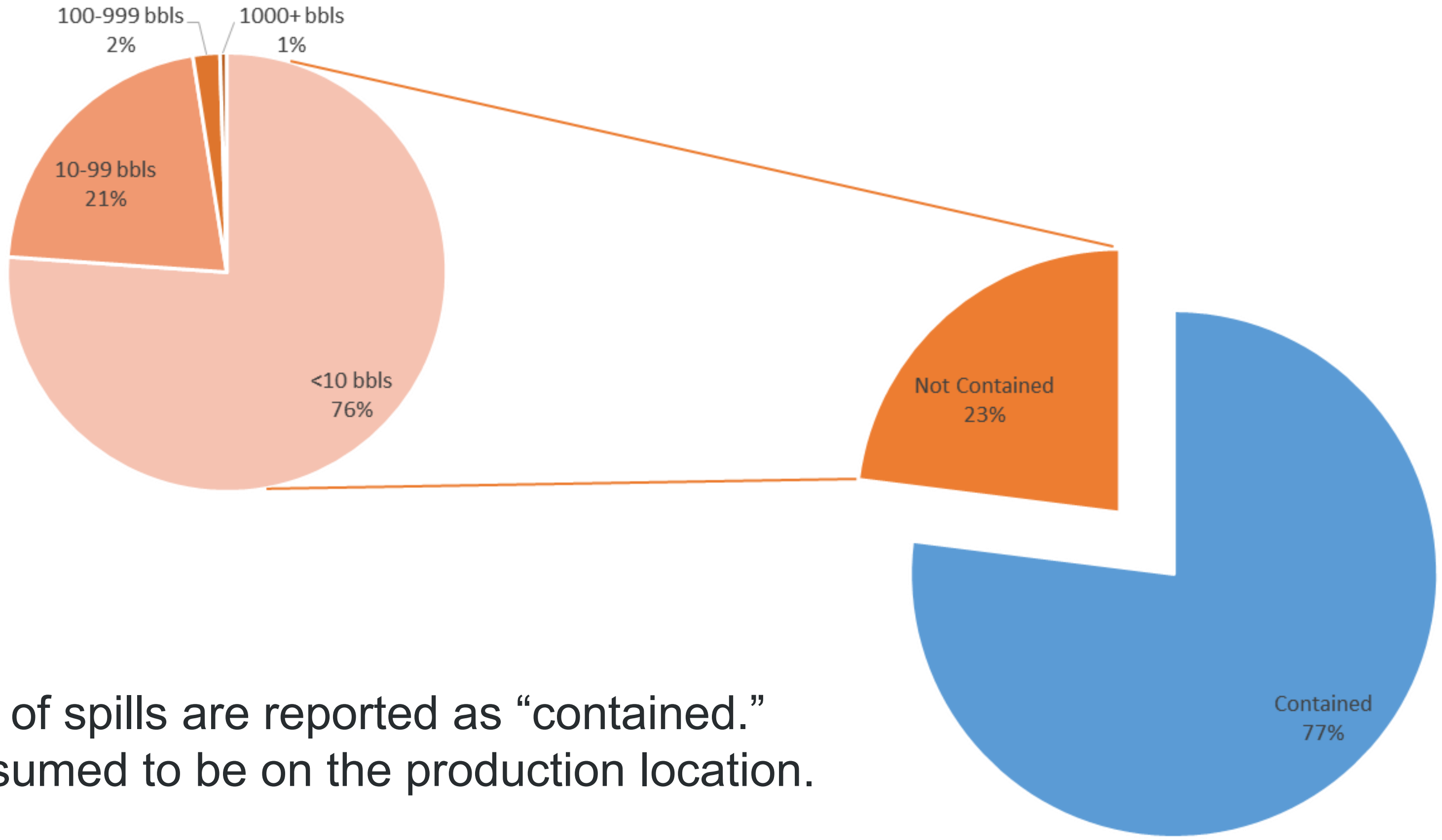


- From 2001 through 2015, roughly 6400 spills reported the release of nearly 148,000 barrels of oil.
- In 2015, approximately 20,000 barrels of oil were spilled of the approximately 432,000,000 barrels of oil produced.



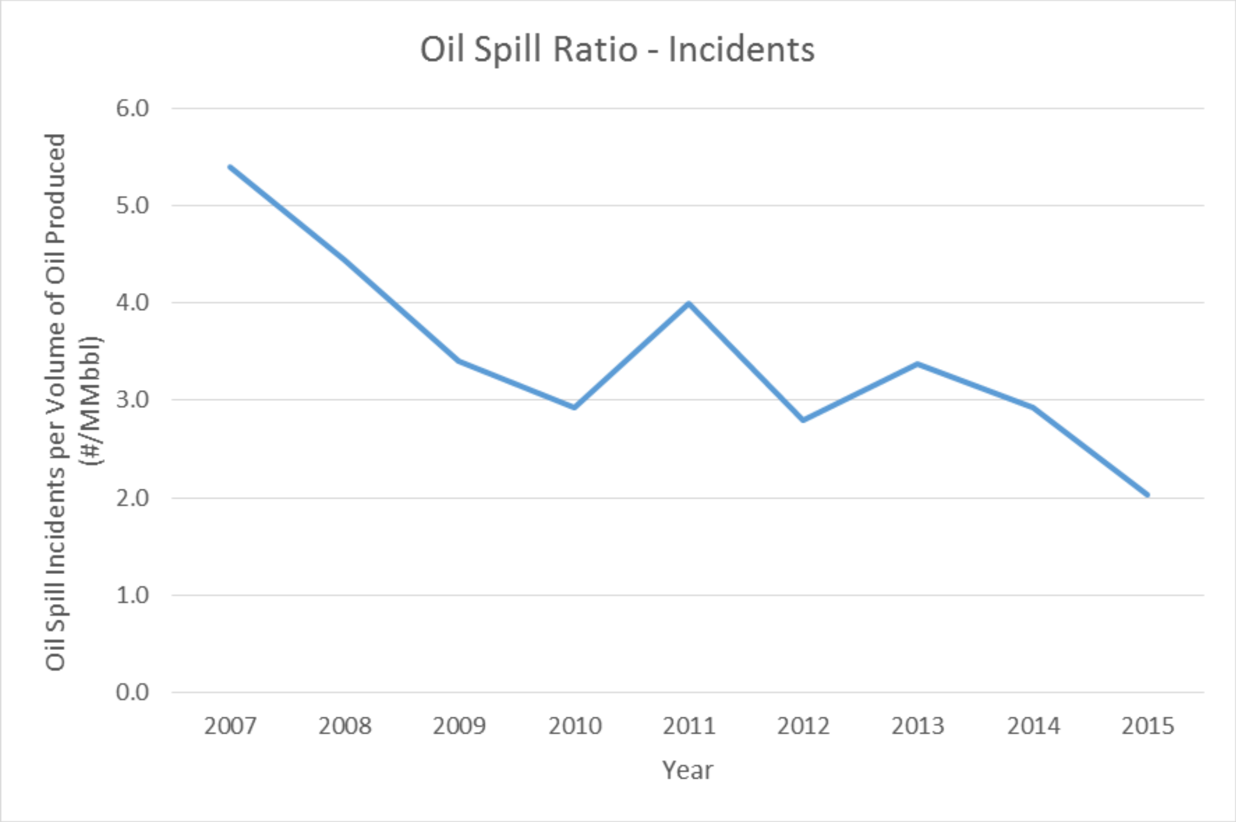
- On average, 0.009% of the oil volume produced annually is spilled.
- In other words, for every 10,000 barrels produced, 9,999 barrels are delivered to their destination and one barrel is spilled.

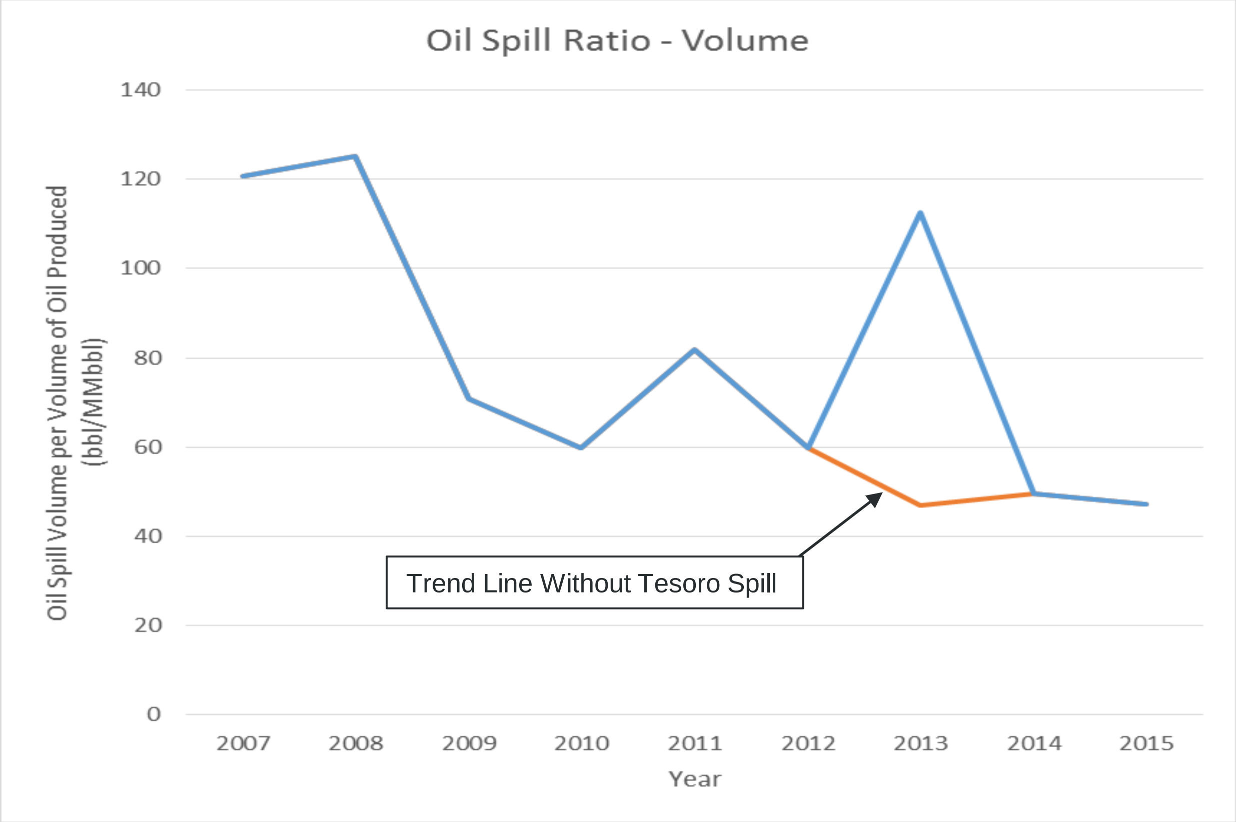
Crude Oil Spill Incidents (2015)



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

Crude Oil Spill Ratios

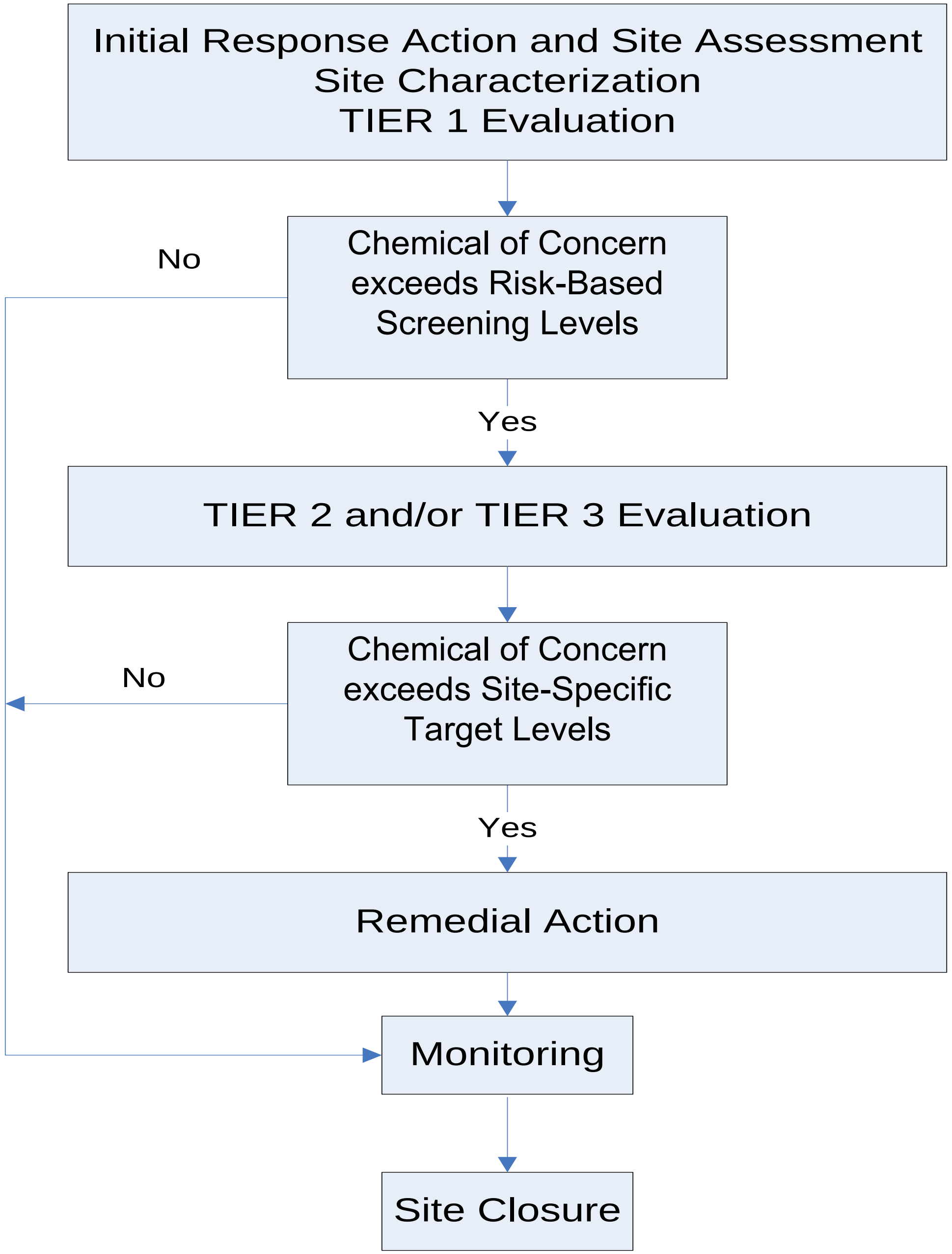




Notes: bbl = barrel
MMbbl = million barrels

Risk-Based Decision Making and Corrective Action

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



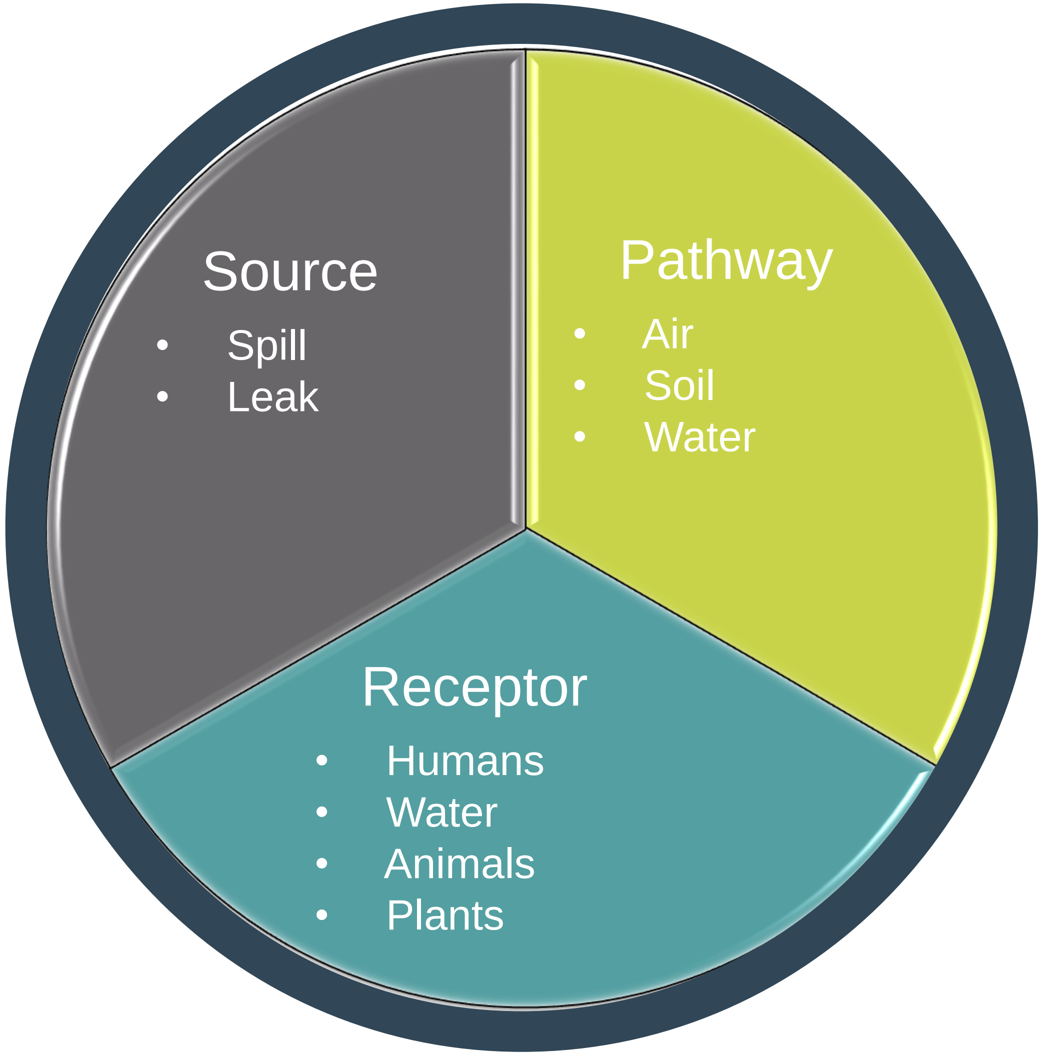
Modified from ASTM E1739 – 95

Risk-Based Corrective Action

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

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

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



Risk-Based Decision Making Review

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

Questions?

Critical Challenges. Practical Solutions.

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APPENDIX B

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

Overview of Facility Process Modeling and Data Analysis

NDPC Technology Solutions Group Meeting

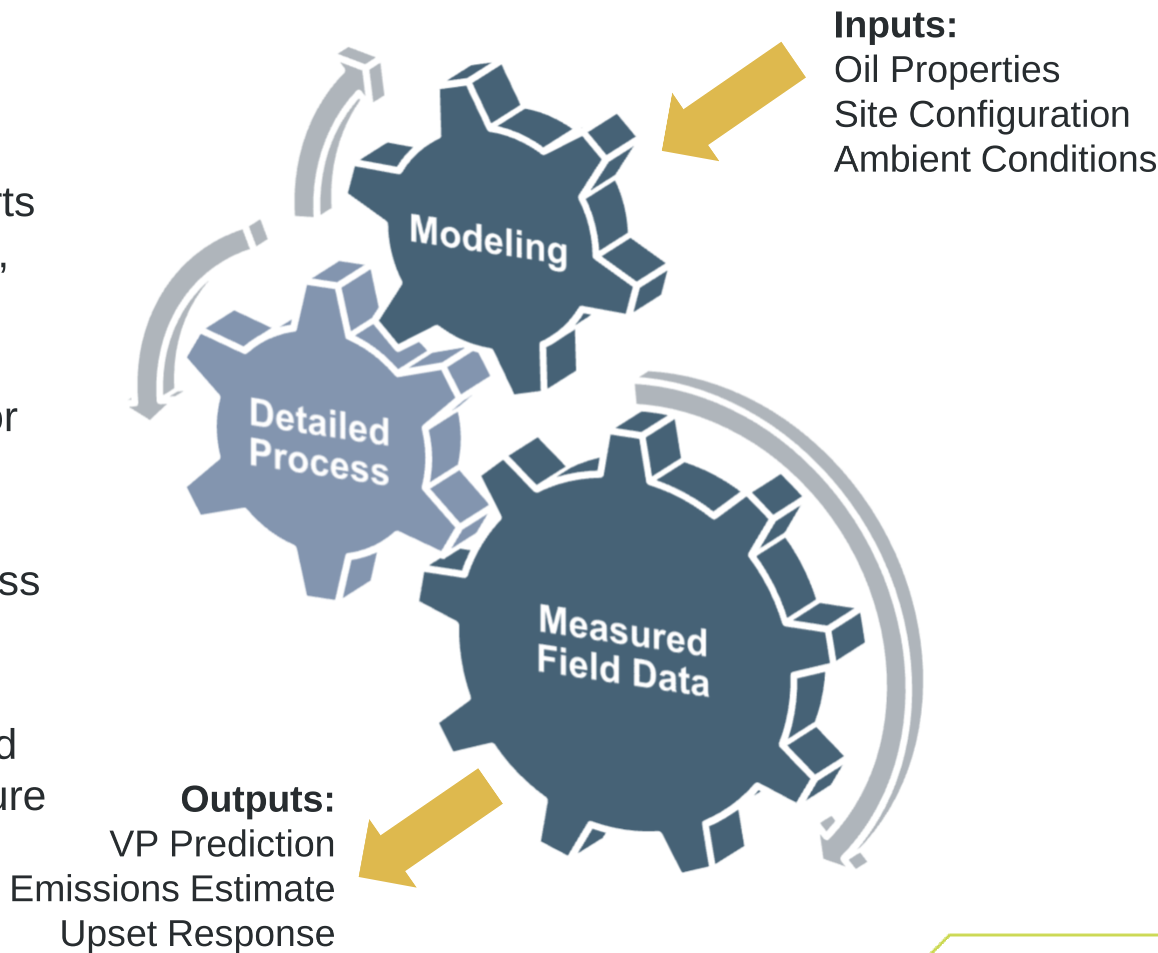
September 7, 2017

Dickinson, ND

Critical Challenges. **Practical Solutions.**

Background

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



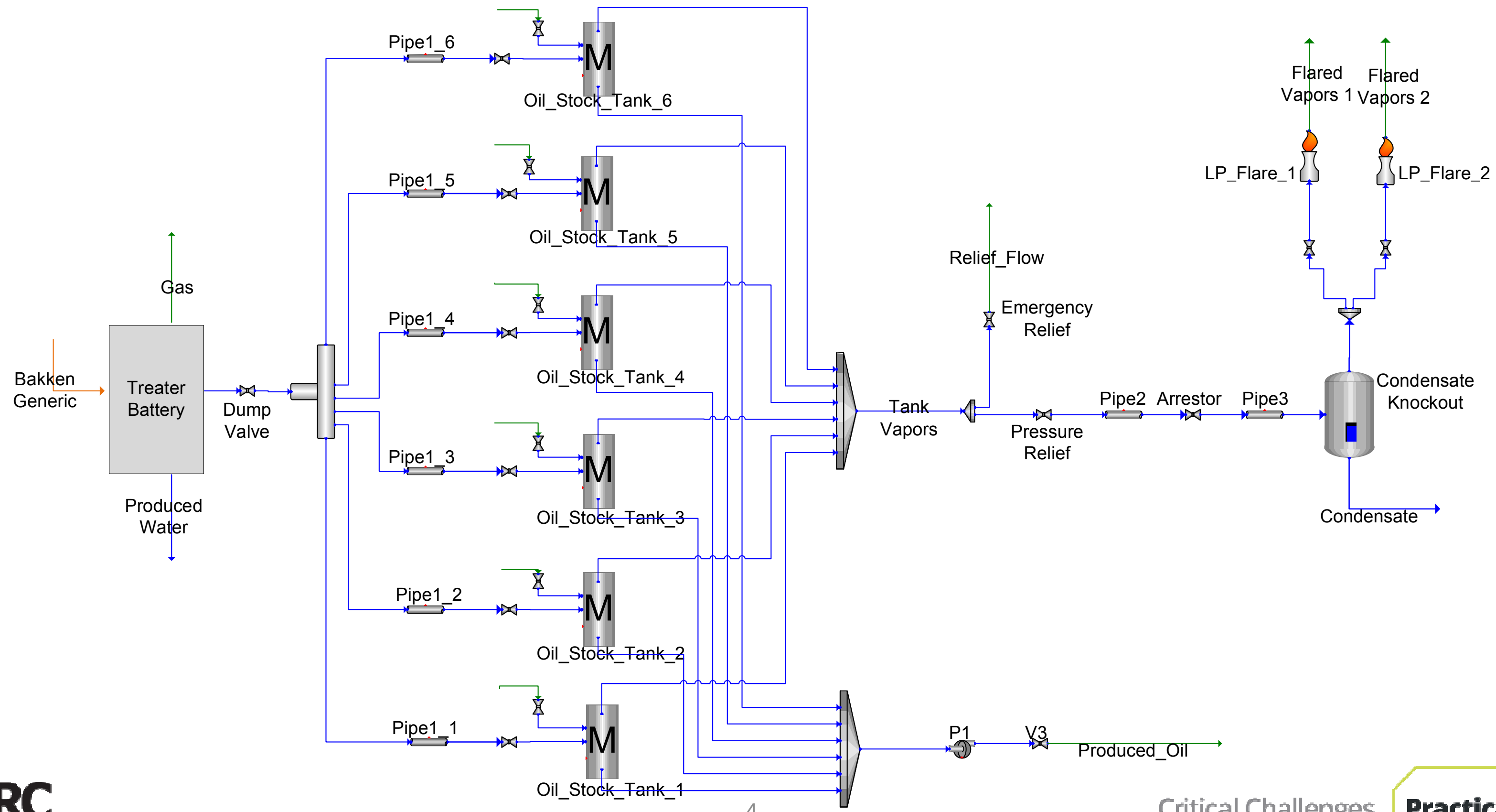
Model Summary

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

Bakken Production Optimization Program

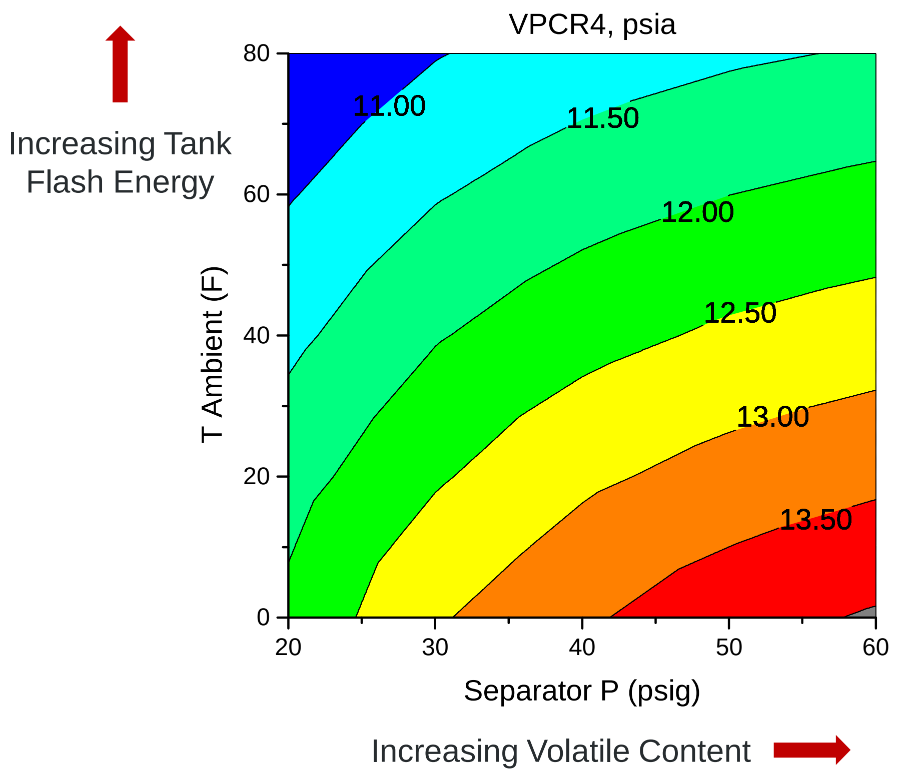
- More details available in the EERC’s write-up of this work under its Bakken Production Optimization Program (BPOP).
- BPOP website: https://www.undeerc.org/Bakken/Bakken-Production-Optimization-Program.aspx
- Direct paper link: https://www.undeerc.org/Bakken/pdfs/CLM-BPOP%20Process%20ModBrief%20R4-Mar17.pdf

Process Diagram



Process Modeling Recap

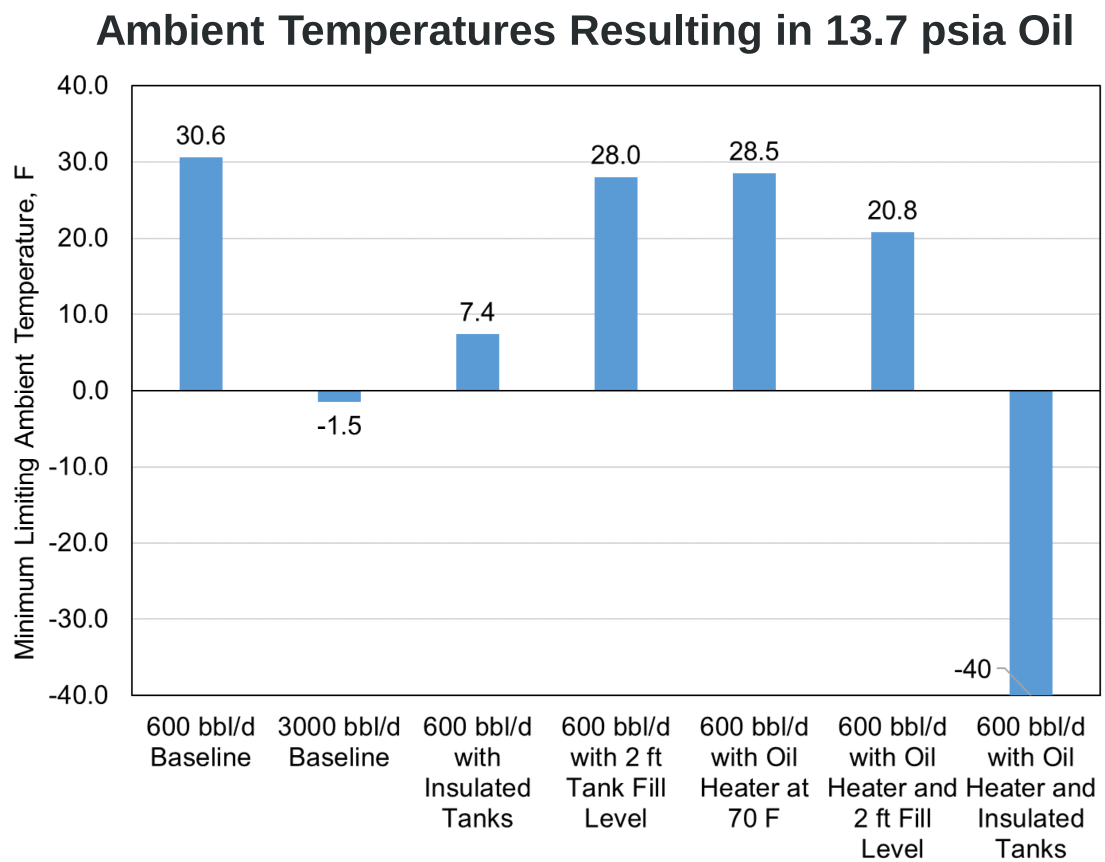
- Modeling showed two key sensitivities: volatile content of oil sent to storage and the available energy for the atmospheric flash in the tanks.
- Volatile content was largely dictated by upstream treater conditions (oil makeup was not included as a parameter).
- Atmospheric flash energy was impacted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



Cold Weather Modification Ranking

Different upgrade scenarios were modeled to estimate cold weather resiliency.

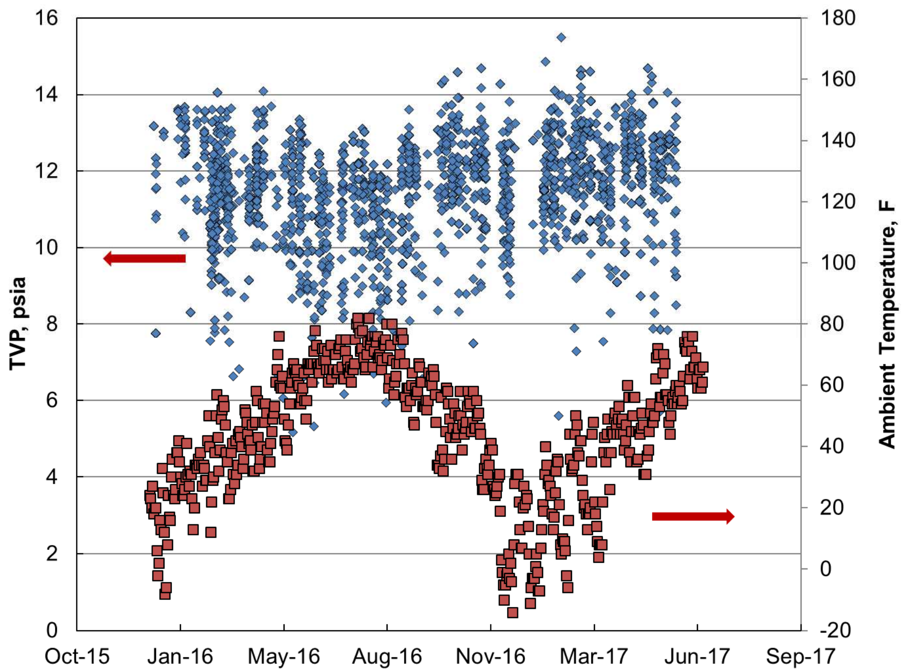
- Oil throughput was a significant factor for heat loss. The higher throughput site had a greater degree of cold weather protection.
- Modifying tank level and/or inline heat input resulted in only modest improvements.
- More significant improvements came with insulation and the most resilient configuration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



Analysis of Historical Vapor Pressure Data

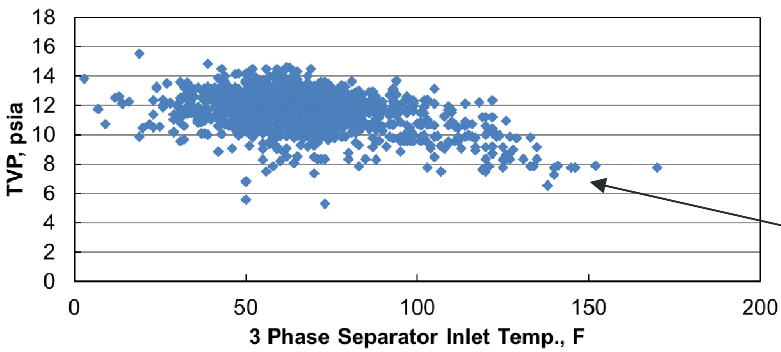
Shared Producer Data Set

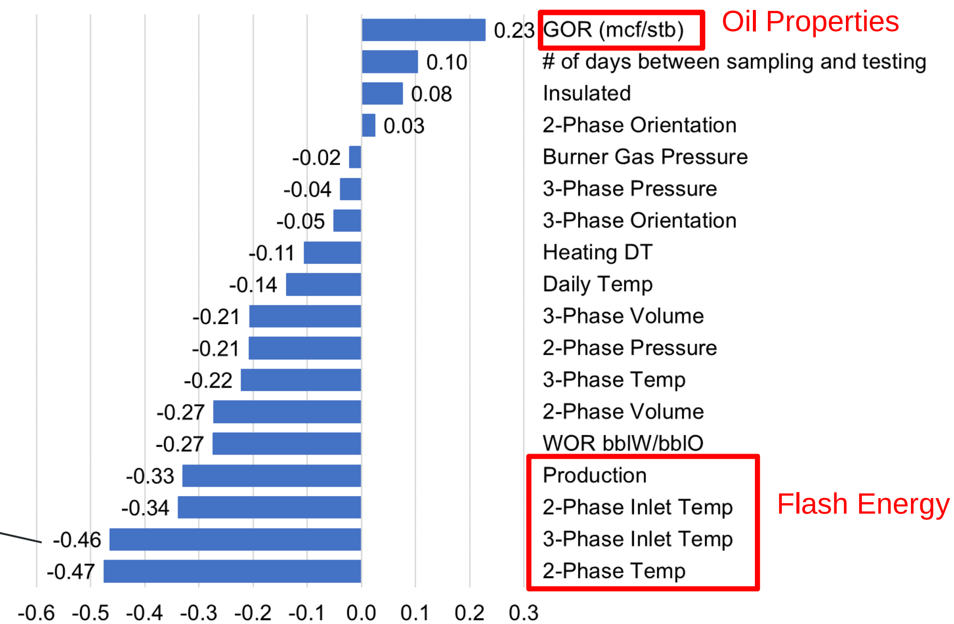
- Over 3000 individual readings covering 1.5 years.
- Consistent sampling protocol (open bottle); quarterly readings.
- Corresponding information:
  - Configuration
  - Temps. and Pressures
  - Production
  - Field



Vapor Pressure Correlation Coefficients

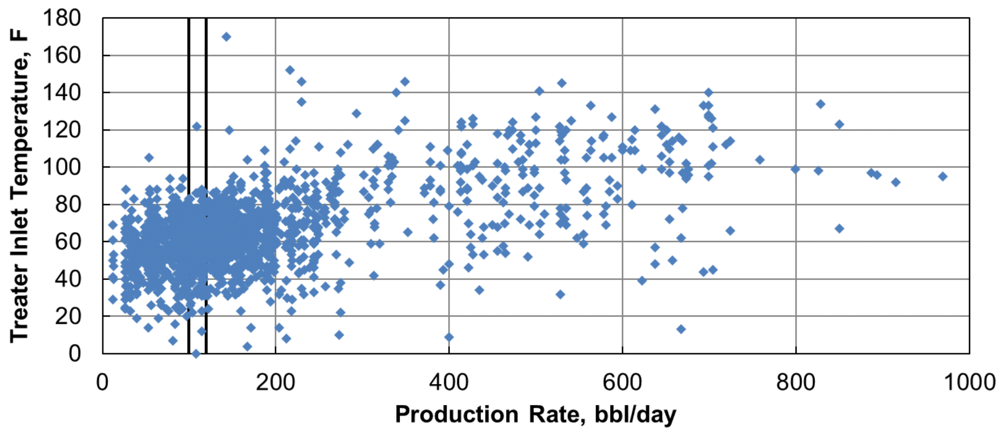
- Correlations with VP were tested for each parameter of a complete data subset, i.e. only using entries having all values populated.

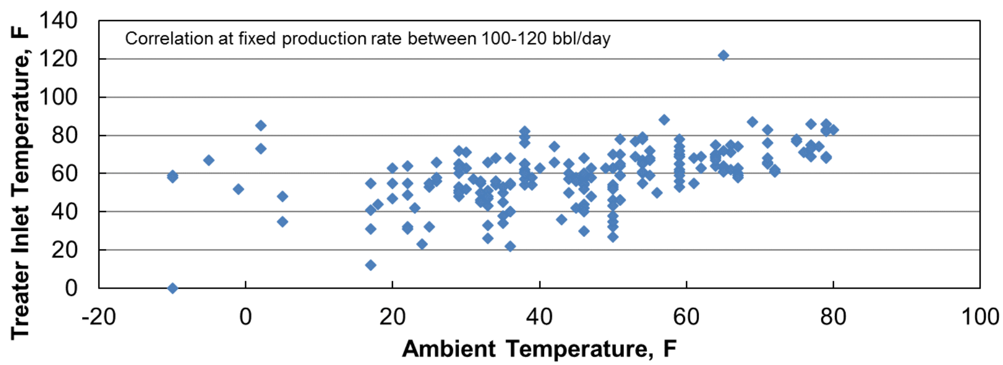




Flash Energy Correlation

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



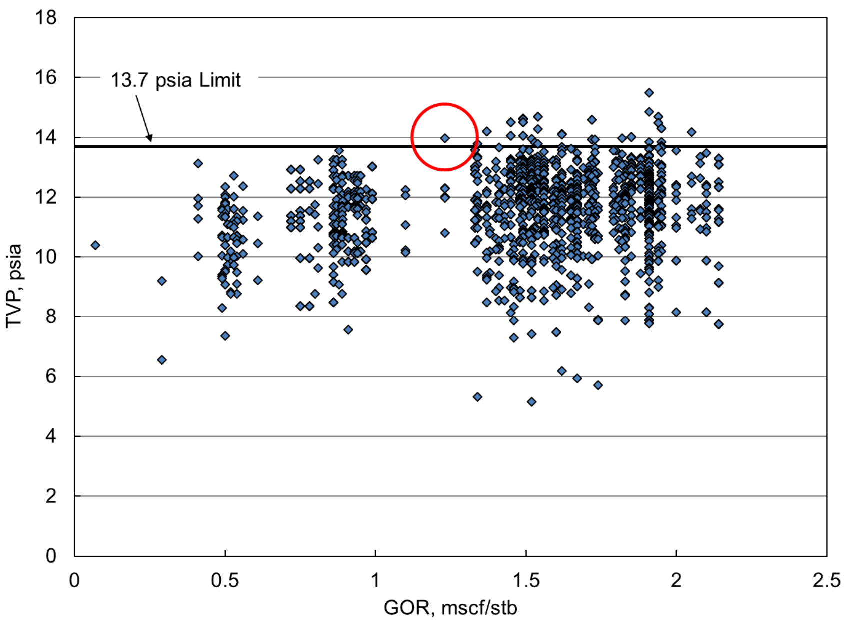


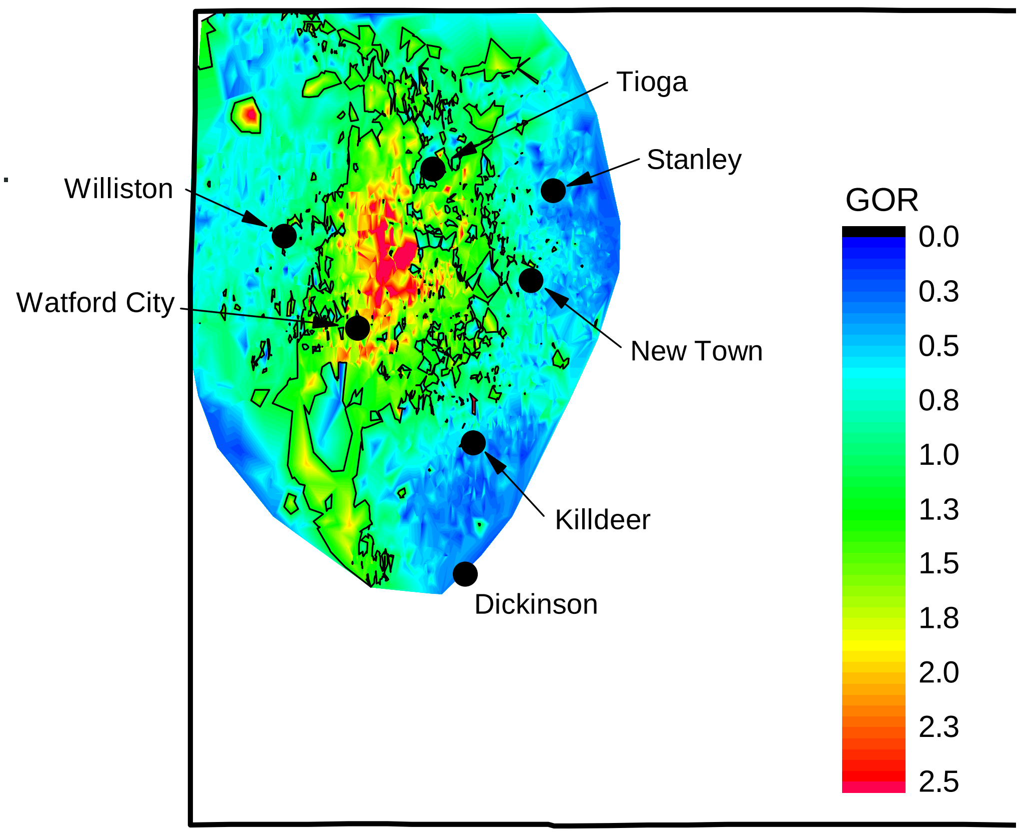
EERC

Critical Challenges. Practical Solutions.

Oil Properties

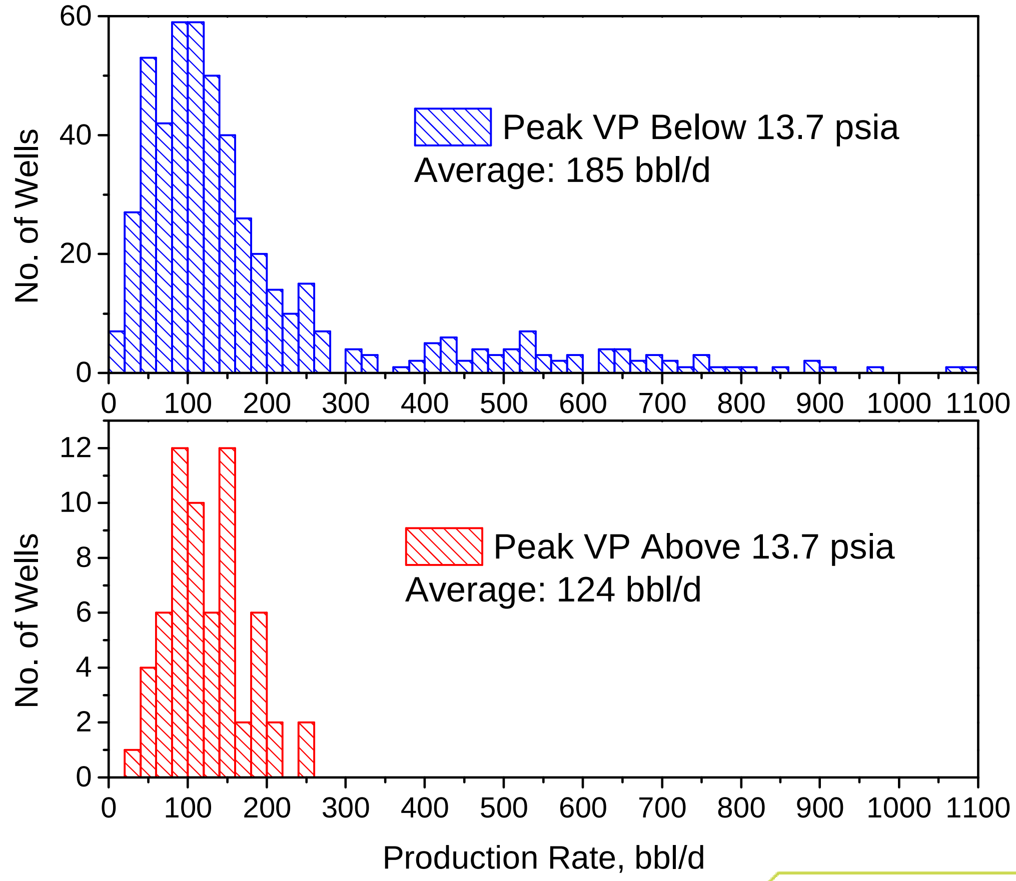
- GOR was another loose correlation factor for VP.
- GOR associated strongly with location (i.e. field). Possibly places a geographic constraint on problematic wells.





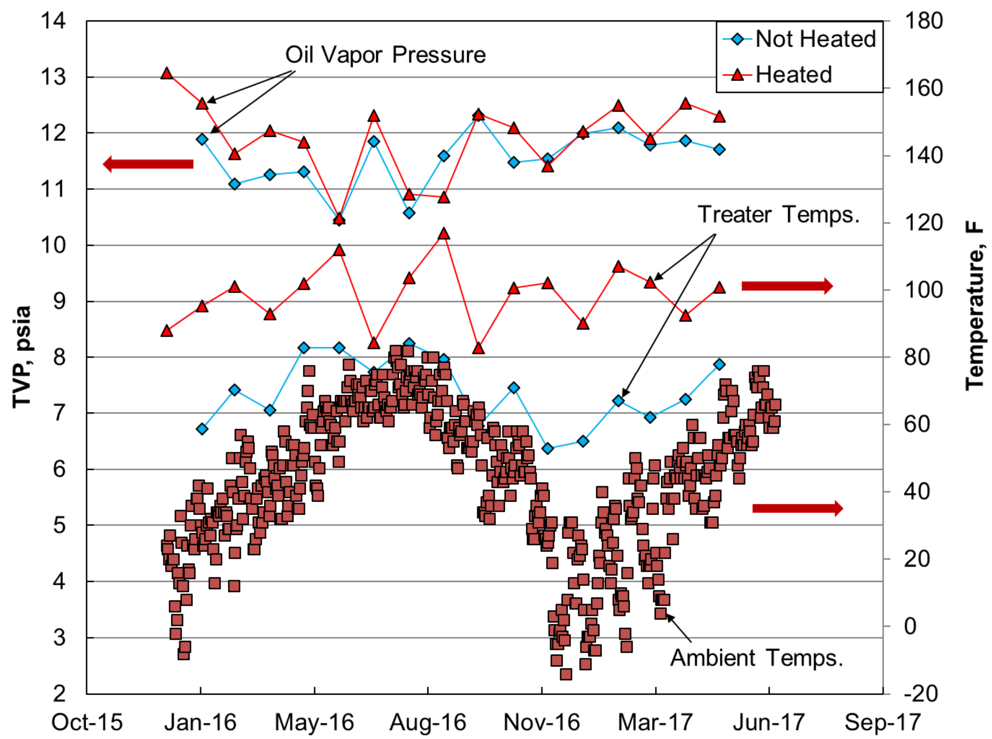
Production Rate

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



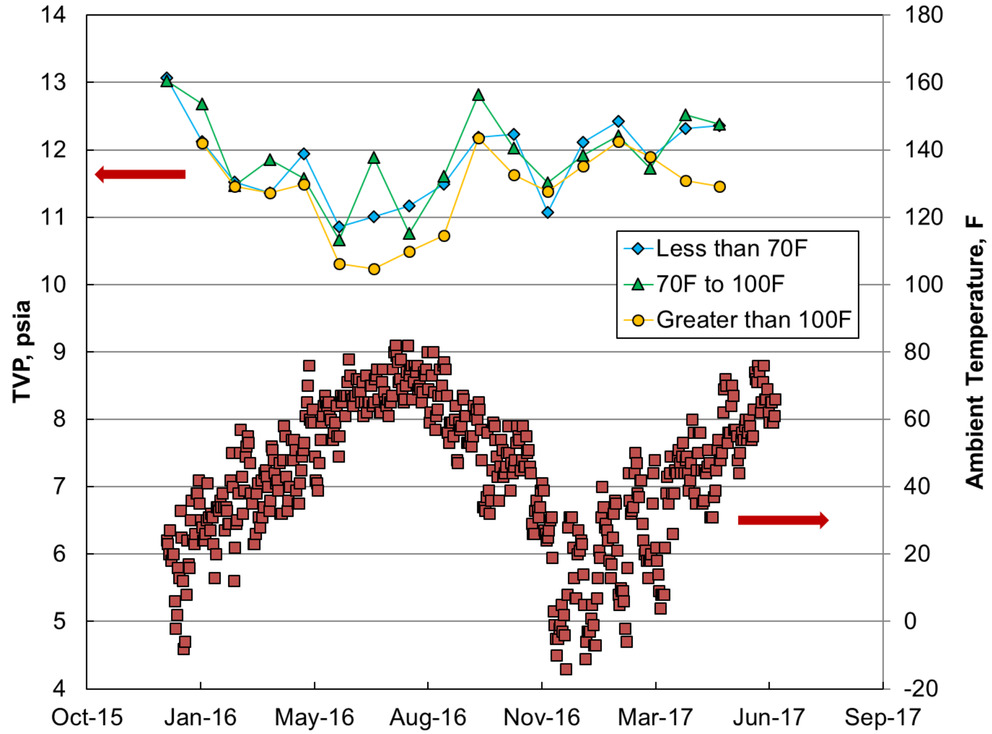
Heated vs. Unheated Treaters

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



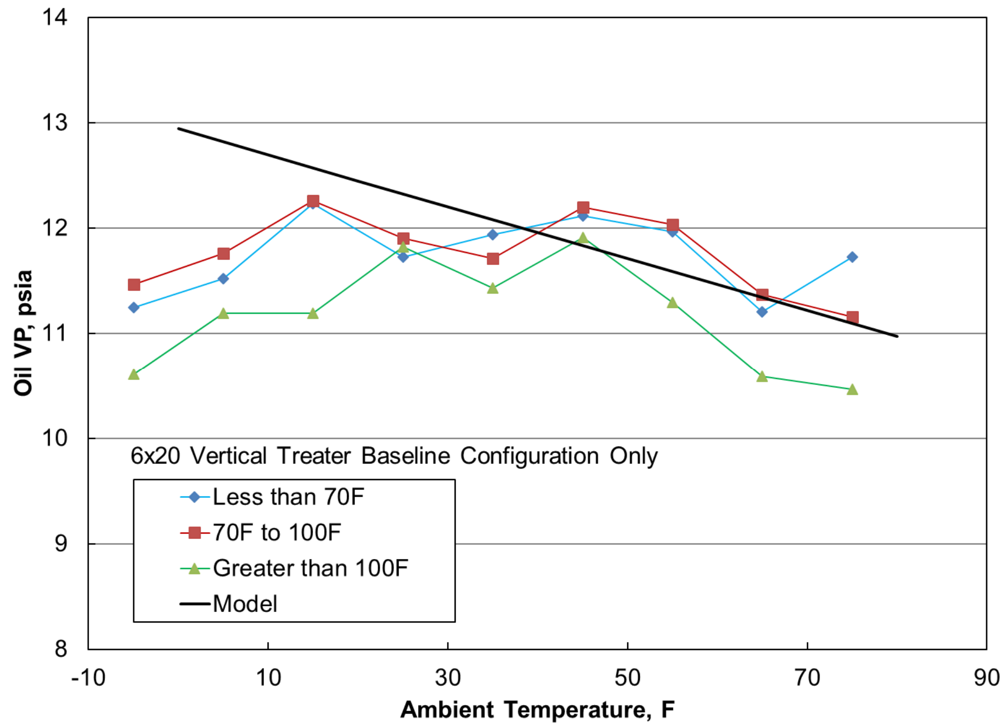
Breakdown by Treater Temperature

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



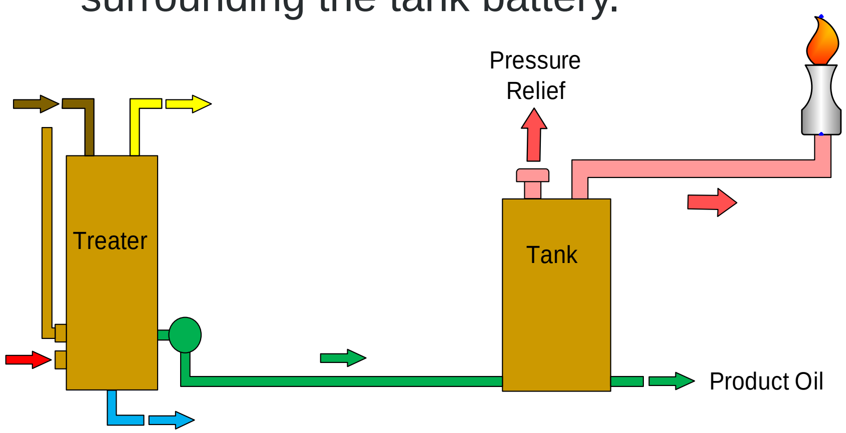
Treater Temperature Model Comparison

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



Conclusions

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



Possible explanations for the missing details:

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

Next Steps

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

Identified cold weather upgrades from May volatility meeting:

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

APPENDIX C

LIBERTY RESOURCES EXHIBIT PRESENTED TO NDIC

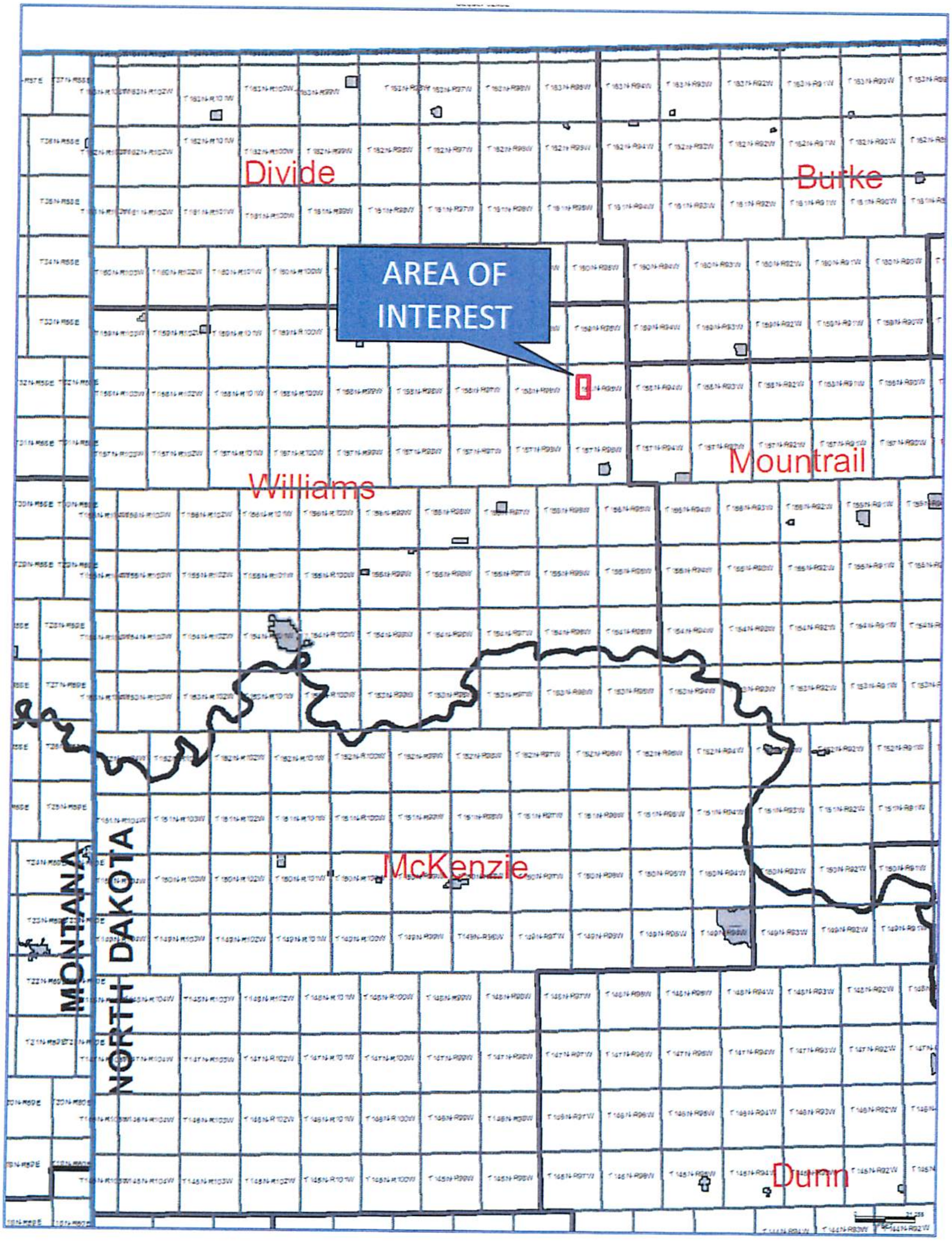
CASE No. 26035

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

Before the North Dakota Industrial Commission
September 21, 2017

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

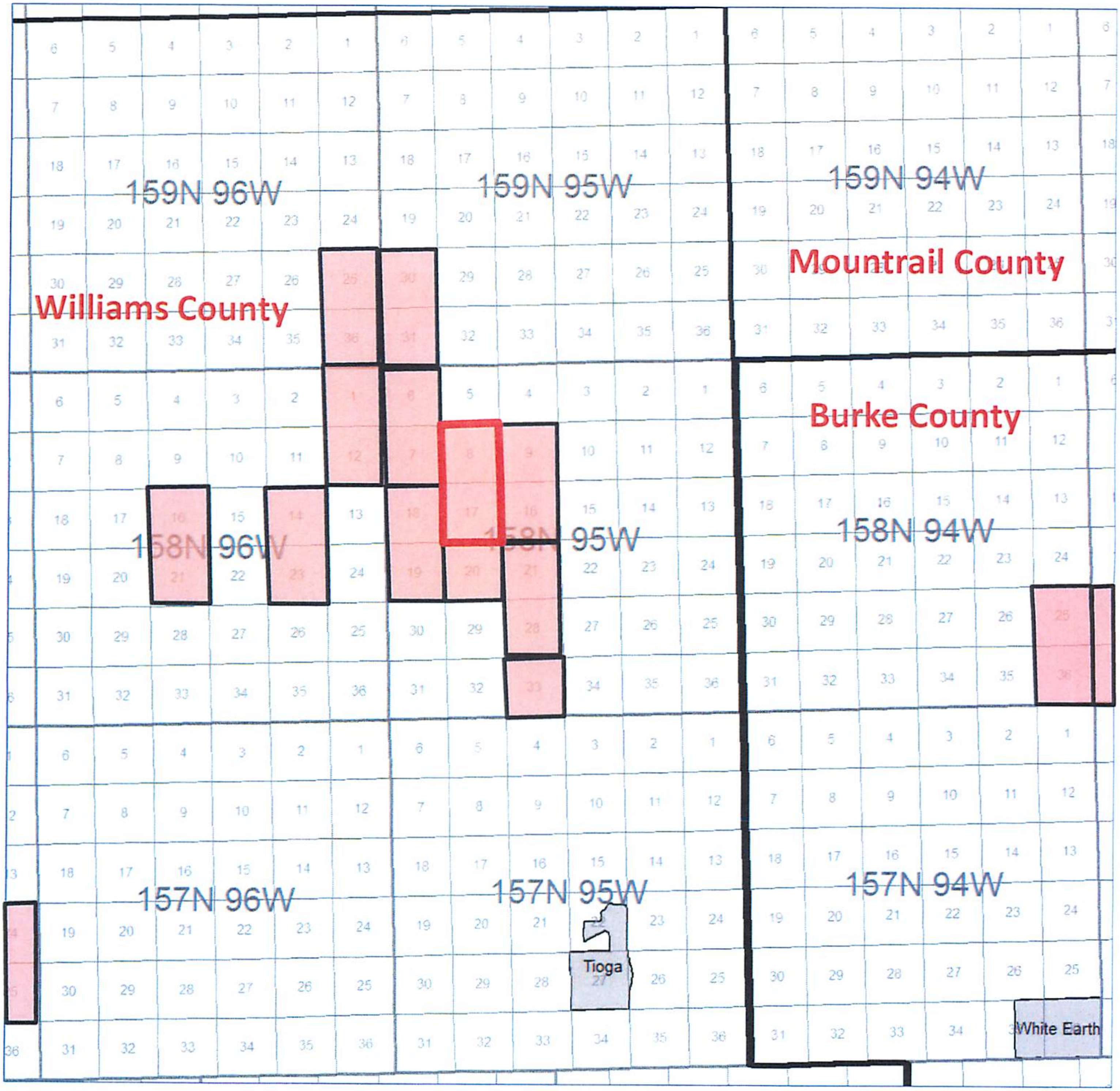
Regional Map



LIBERTY RESOURCES

Exhibit L-1
Case No. 26035

Location Map



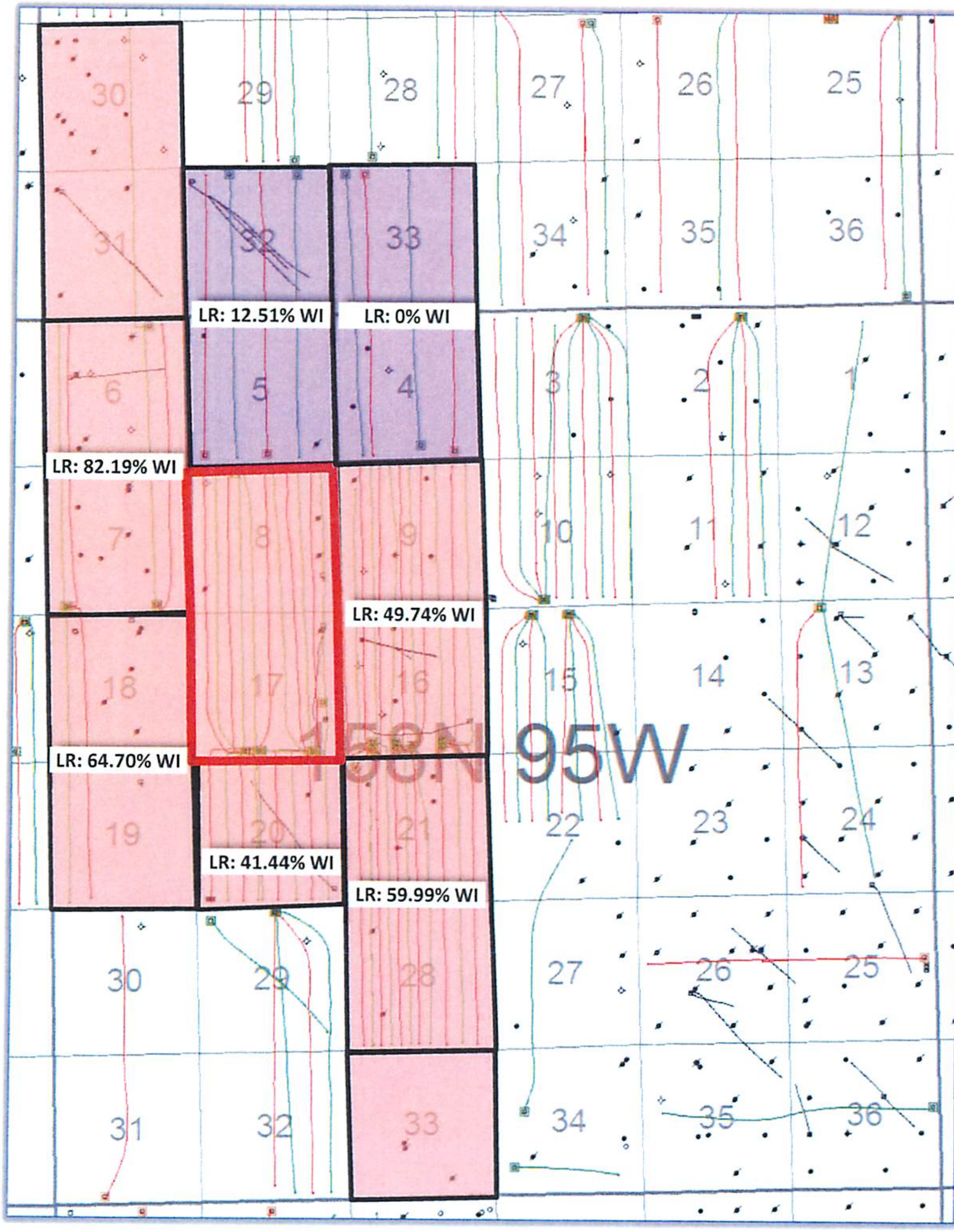
- 1280-acre Spacing Unit of Interest

- Existing Liberty Spacing Unit

LIBERTY RESOURCES

Exhibit L-2
Case No. 26035

Location Map – Offset Ownership

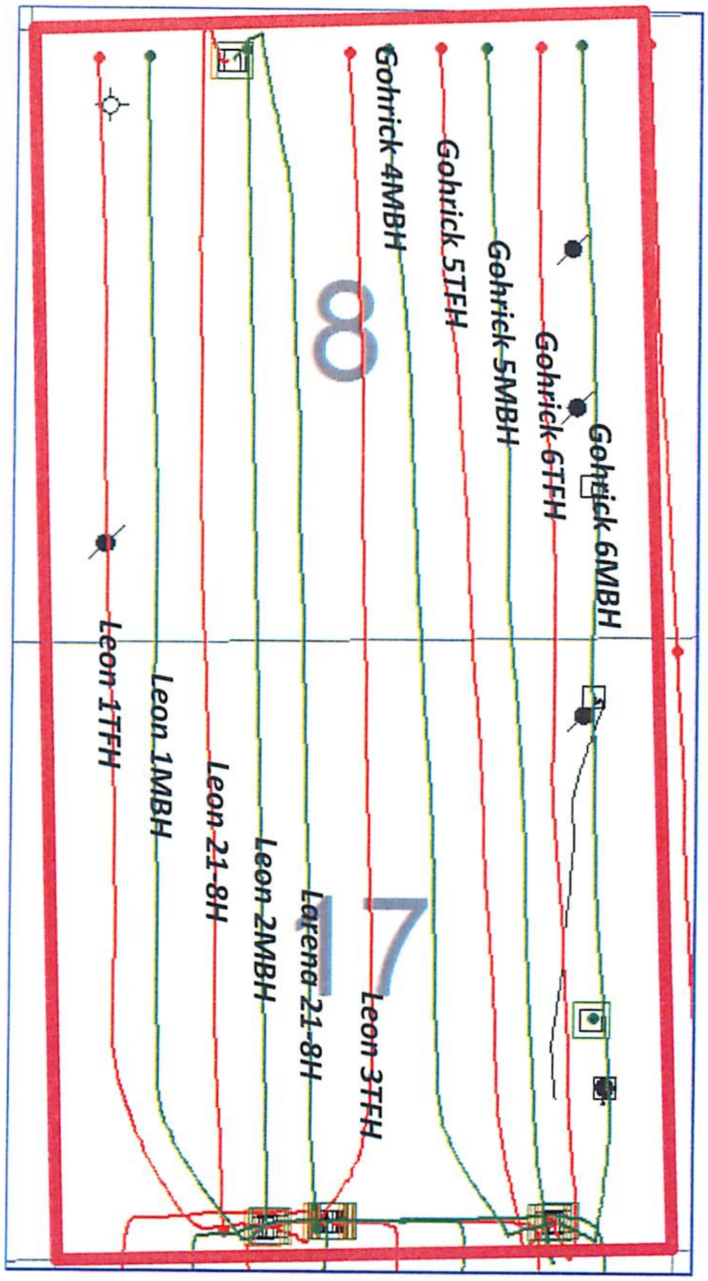


- 1280-acre Spacing Unit of Interest
- Existing Liberty Spacing Unit
- Murex Operated Spacing Unit
- Existing Middle Bakken Horizontal
- Existing Three Forks Horizontal

LIBERTY RESOURCES

Exhibit L-3
Case No. 26035

Current 1280 Acre Spacing Unit
Township 158 North, Range 95 West, Sections 8 & 17
Williams County, North Dakota
Containing 1280 Acres



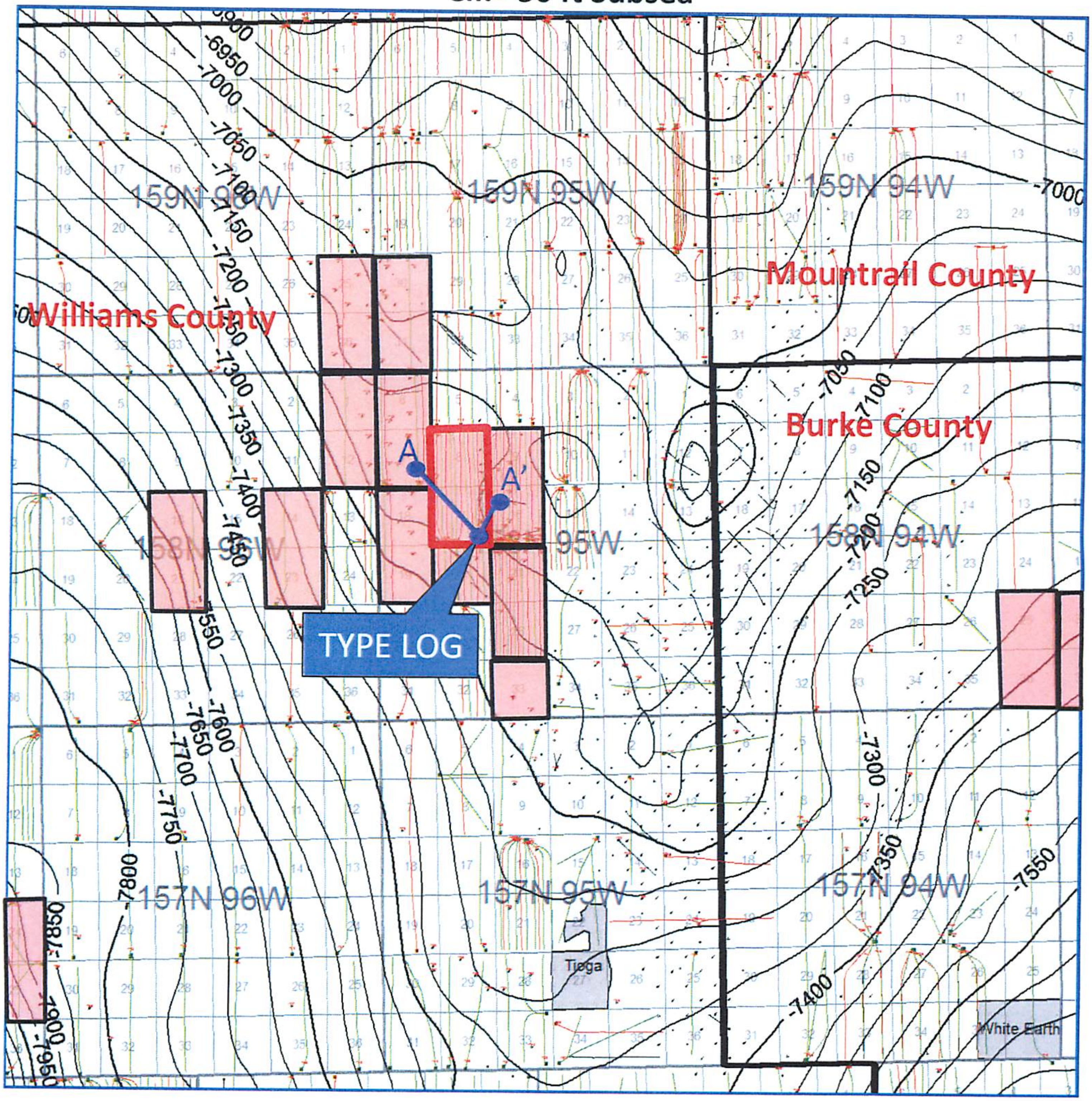
- Existing Middle Bakken Horizontal
- Existing Three Forks Horizontal
- 1280-acre Spacing Unit

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

LIBERTY RESOURCES

Exhibit L-4
Case No. 26035

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



- Existing Liberty Resources Spacing Unit

- Existing Middle Bakken Horizontal

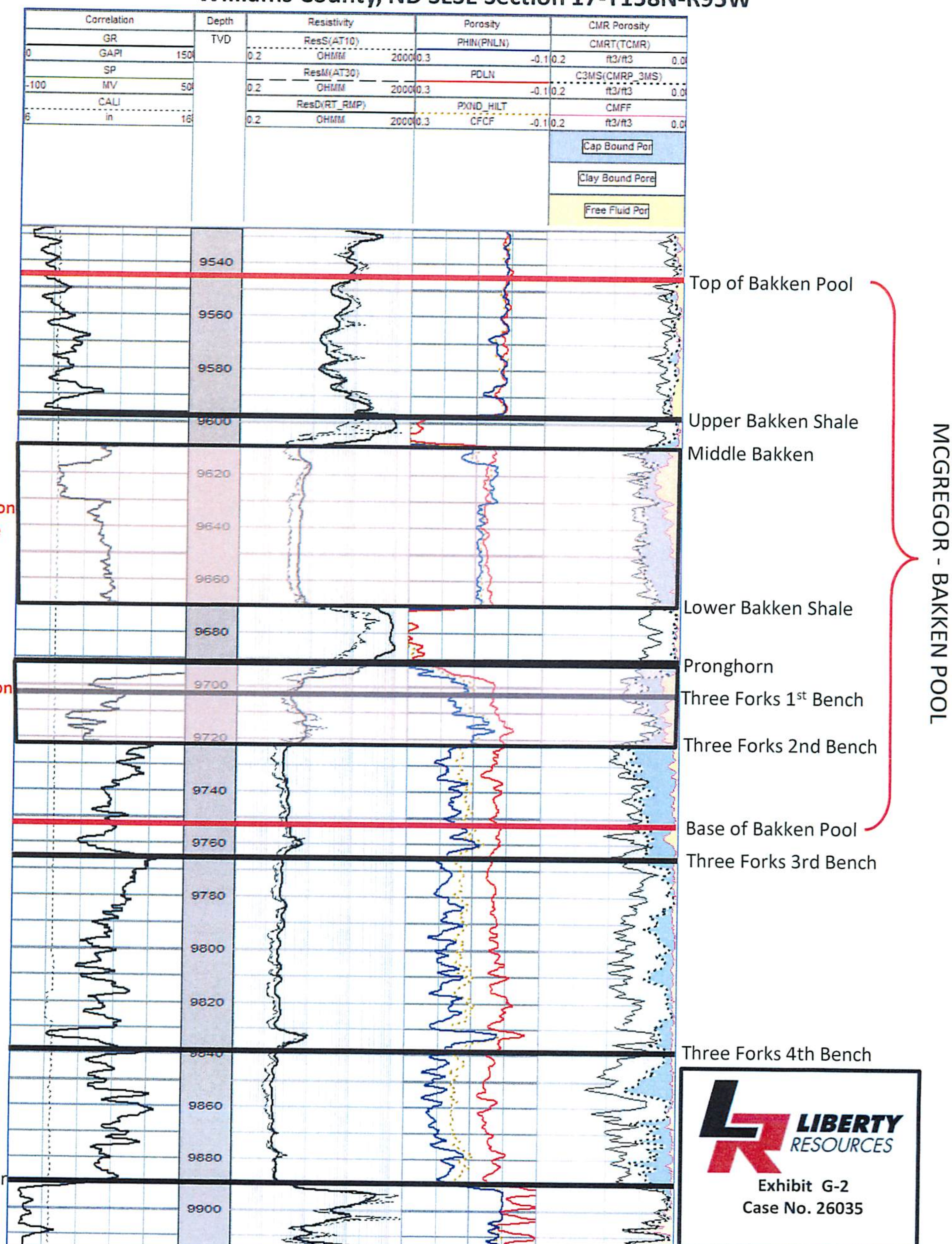
- Existing Three Forks Horizontal

- 1280-acre Spacing Unit of Interest

LIBERTY RESOURCES

Exhibit G-1
Case No. 26035

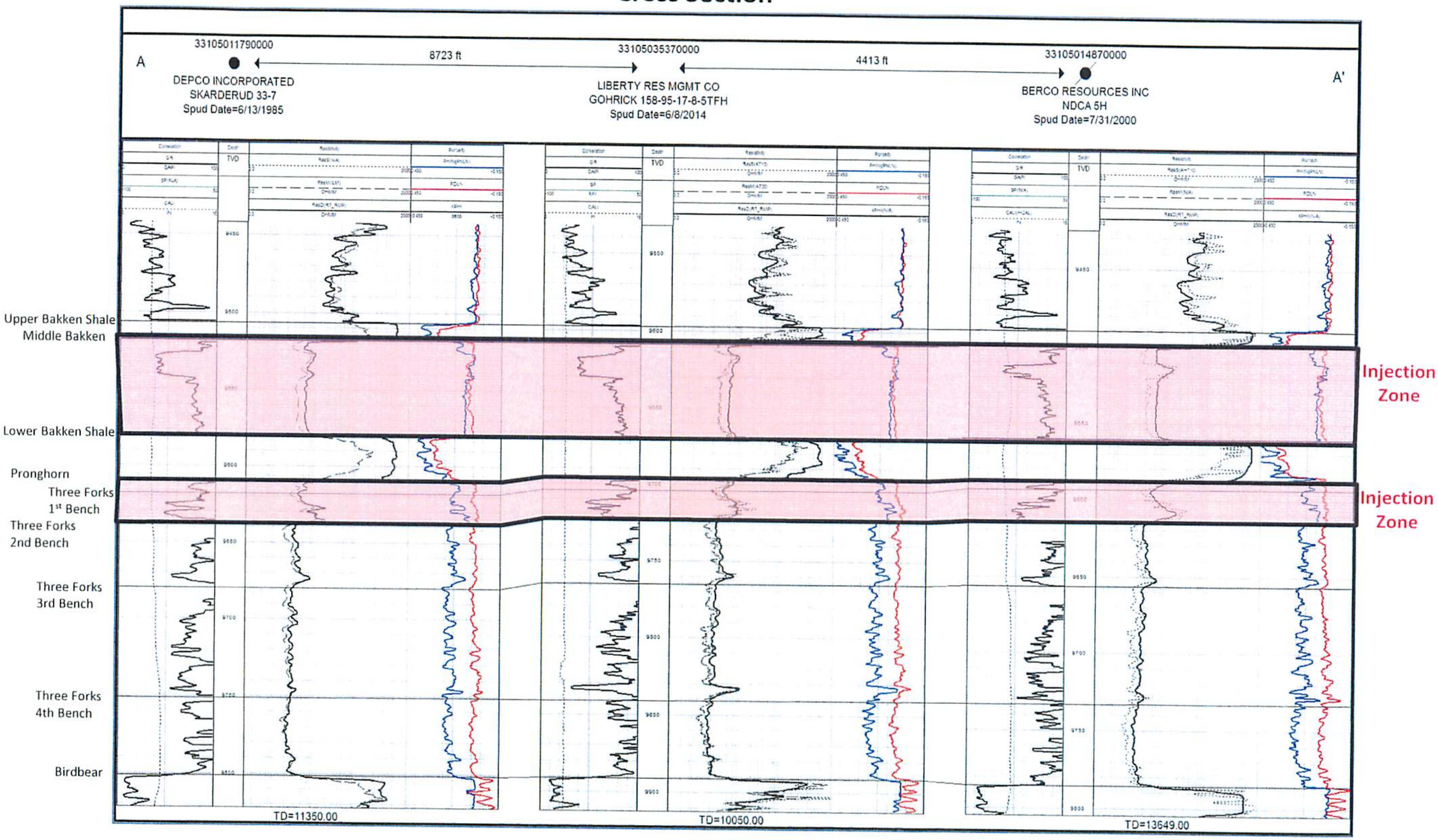
Type Log
Liberty Resources, LLC –Gohrick 158-95-17-8-5TFH
Williams County, ND SESE Section 17-T158N-R95W



LIBERTY RESOURCES

Exhibit G-2
Case No. 26035

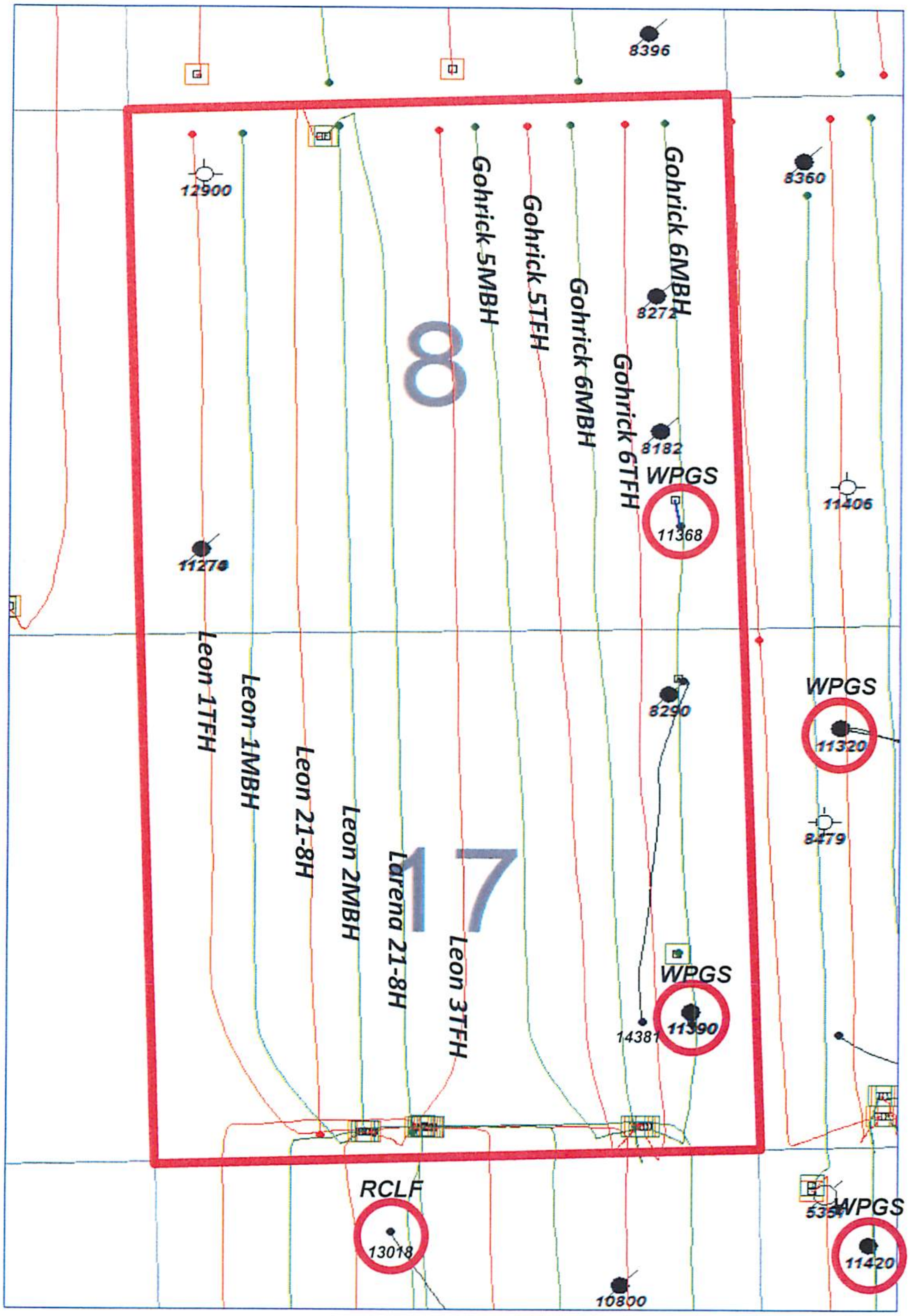
Cross Section



LIBERTY RESOURCES

Exhibit G-3
Case No. 26035

Non-Bakken Pool Offsets



- 1280-acre Spacing Unit of Interest

PROD FM

TD

- Active Producer

- Existing Middle Bakken Horizontal

- Existing Three Forks Horizontal

LIBERTY RESOURCES

Exhibit E-1
Case No. 26035

Pilot Goals

Pilot Goals

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

Source of Injection Gas

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

Anticipated Injection Rates

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

Maximum Allowable Surface Injection Pressure

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

Proposed Injection Period

- 2 year period inclusive of all wells in the pilot

Proposed Injection Volume

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

Surveillance Plan

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

LIBERTY RESOURCES

Exhibit E-2
Case No. 26035

Pilot Estimated Cost Summary

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

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

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

Gas Chromatograph – $9,100/month

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

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

LIBERTY RESOURCES

Exhibit E-2
Case No. 26035

Stomping Horse Bakken Rich Gas EOR Project

Stomping Horse Bakken Rich Gas EOR Project –

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

Summary Overview

Prepared by

Energy & Environmental Research Center
Grand Forks, North Dakota

Prepared for

Liberty Resources Management Company

September 11, 2017

LIBERTY RESOURCES

Exhibit E-3A
Case No. 26035

Stomping Horse Bakken Rich Gas EOR Project

Introduction

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

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

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

Goals

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

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

LIBERTY RESOURCES
Exhibit E-3B
Case No. 26035

Stomping Horse Bakken Rich Gas EOR Project

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

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

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

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

Hypothesis

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

Experimental Design

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

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

LIBERTY RESOURCES
Exhibit E-3C
Case No. 26035

Stomping Horse Bakken Rich Gas EOR Project

- Small scale injectivity tests using water have been conducted on representative wells in the area to determine injection pressures and rates and estimate gas injection performance in the subject wells. This information is being incorporated into the project design.
- A final design for the primary CMWHP test will be developed, including maps and diagrams to illustrate key design elements of the test, and detailed operational procedures for the baseline reservoir characterization, rich gas injection, and monitoring elements of the field test.
- The delivery, compression, and injection of rich gas will be conducted at selected wells in the Leon-Gohrick drill spacing unit. It is anticipated that approximately 2,500 mmcf of rich gas will be injected over the course of the primary CMWHP test. The primary test will include injection of rich gas into four wells in the Middle Bakken and three wells in the Three Forks.
- Fluid samples and detailed reservoir pressure and temperature data will be collected and analyzed during and after the primary CMWHP test. Those data will be used to rapidly generate insight regarding injection conformance and to determine the effects of rich gas on reservoir dynamics and oil mobility.
- The EERC methods used in previous laboratory-based evaluations of rich gas/oil interaction and hydrocarbon extraction will be applied to samples from the field test location. Those data will be used to provide insight on the mechanisms controlling the movement of fluids in the matrix which, when combined with injection/production schemes that improve conformance, will ultimately support the development of longer-term, commercial scale rich gas EOR operations.
- EERC personnel will assist with selected field-based monitoring aspects of the test. EERC efforts in the field will be focused on obtaining information and data from the injection operation that may yield insight regarding the conformance of injected rich gas in the reservoir.

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

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

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

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

LIBERTY RESOURCES

Exhibit E-3D
Case No. 26035

Stomping Horse Bakken Rich Gas EOR Project

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

References:

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

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

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

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

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

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

LIBERTY RESOURCES

Exhibit E-3E
Case No. 26035

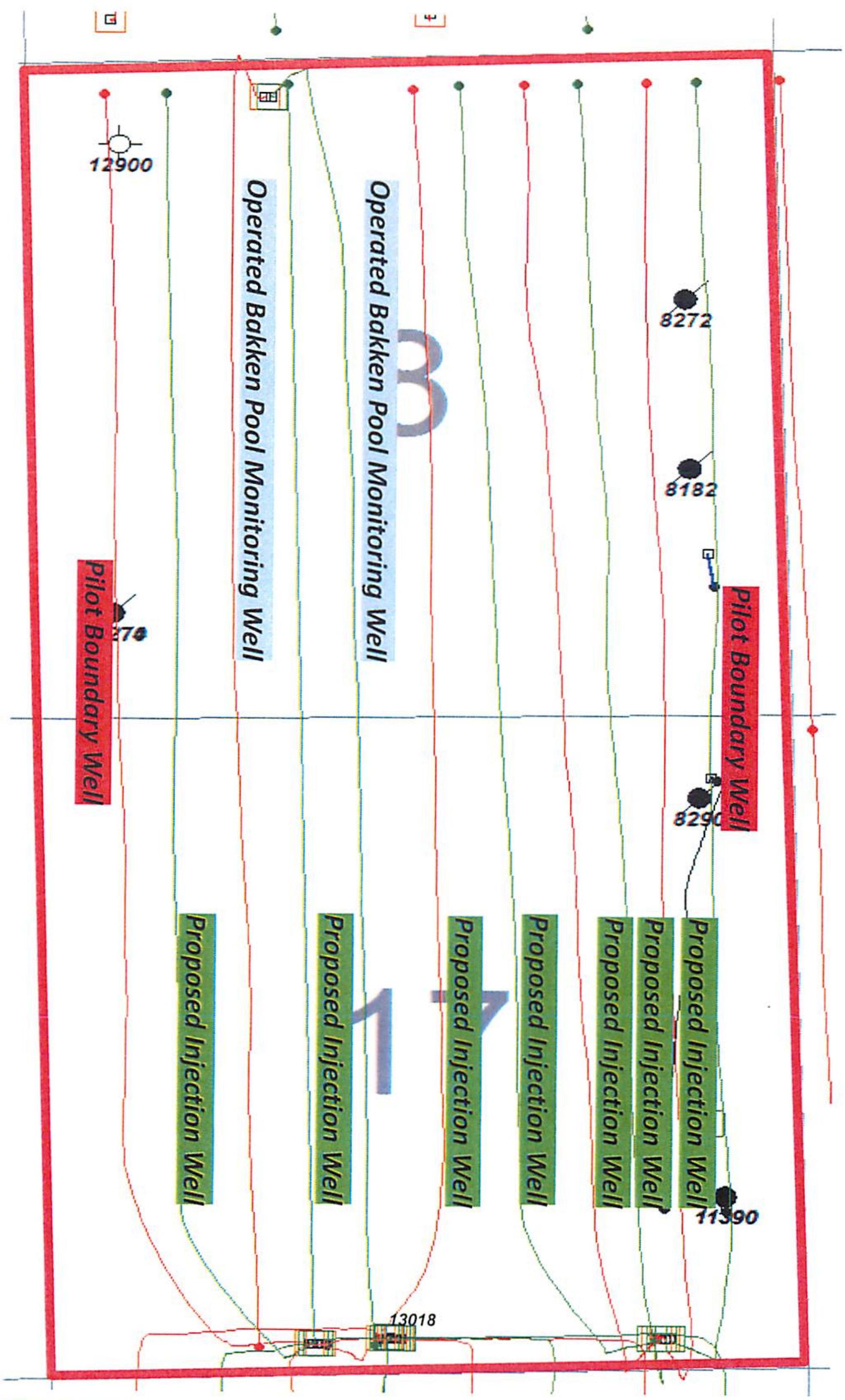
Reservoir Data

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

LIBERTY RESOURCES

Exhibit E-4
Case No. 26035

Pilot Layout & Well Nomenclature



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

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

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

LIBERTY RESOURCES

Exhibit E-5
Case No. 26035

Bakken Pool Wells

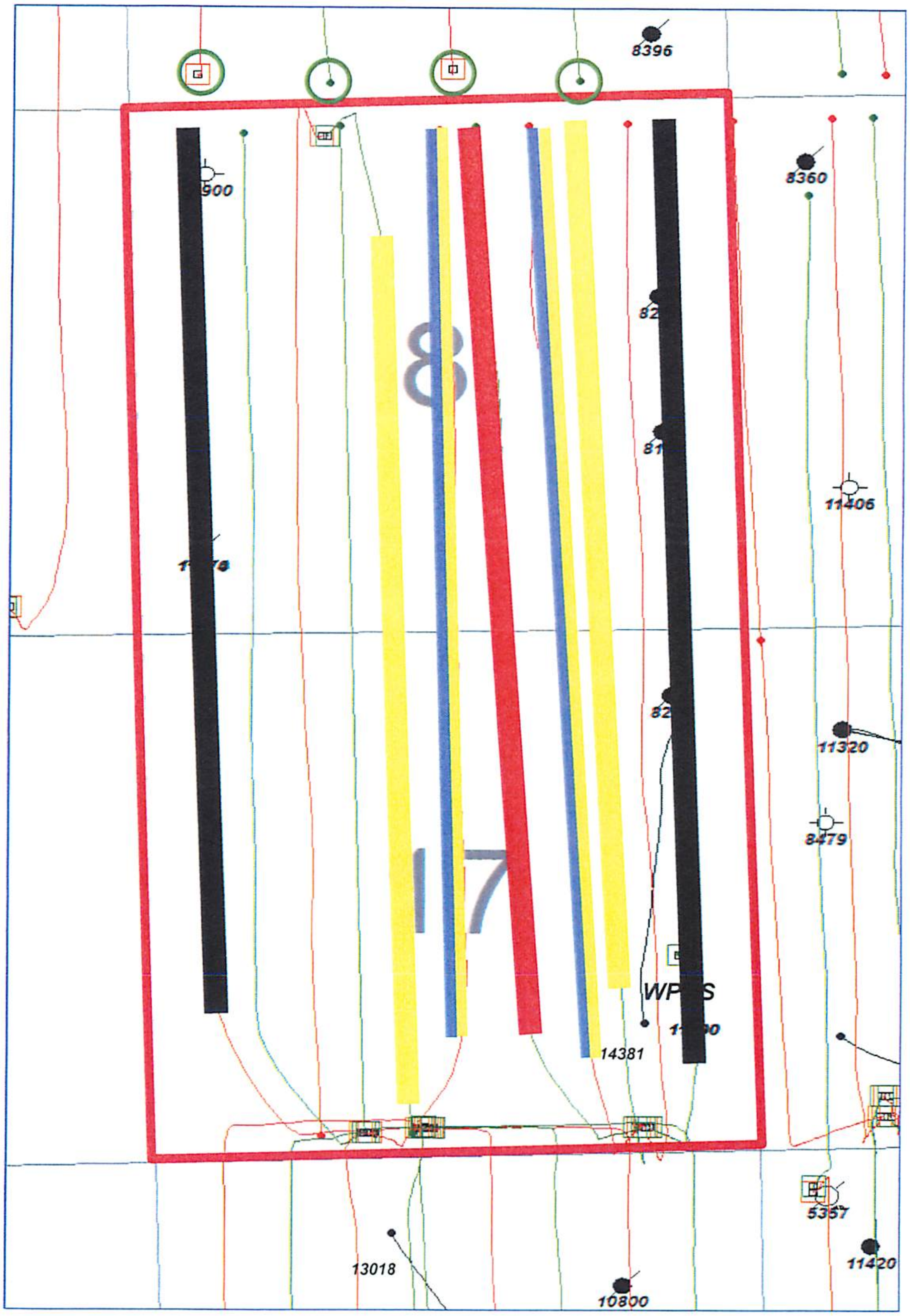
Township 158 North, Range 95 West, Sections 8 & 17

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

LIBERTY RESOURCES

Exhibit E-6
Case No. 26035

Example Surveillance Plan

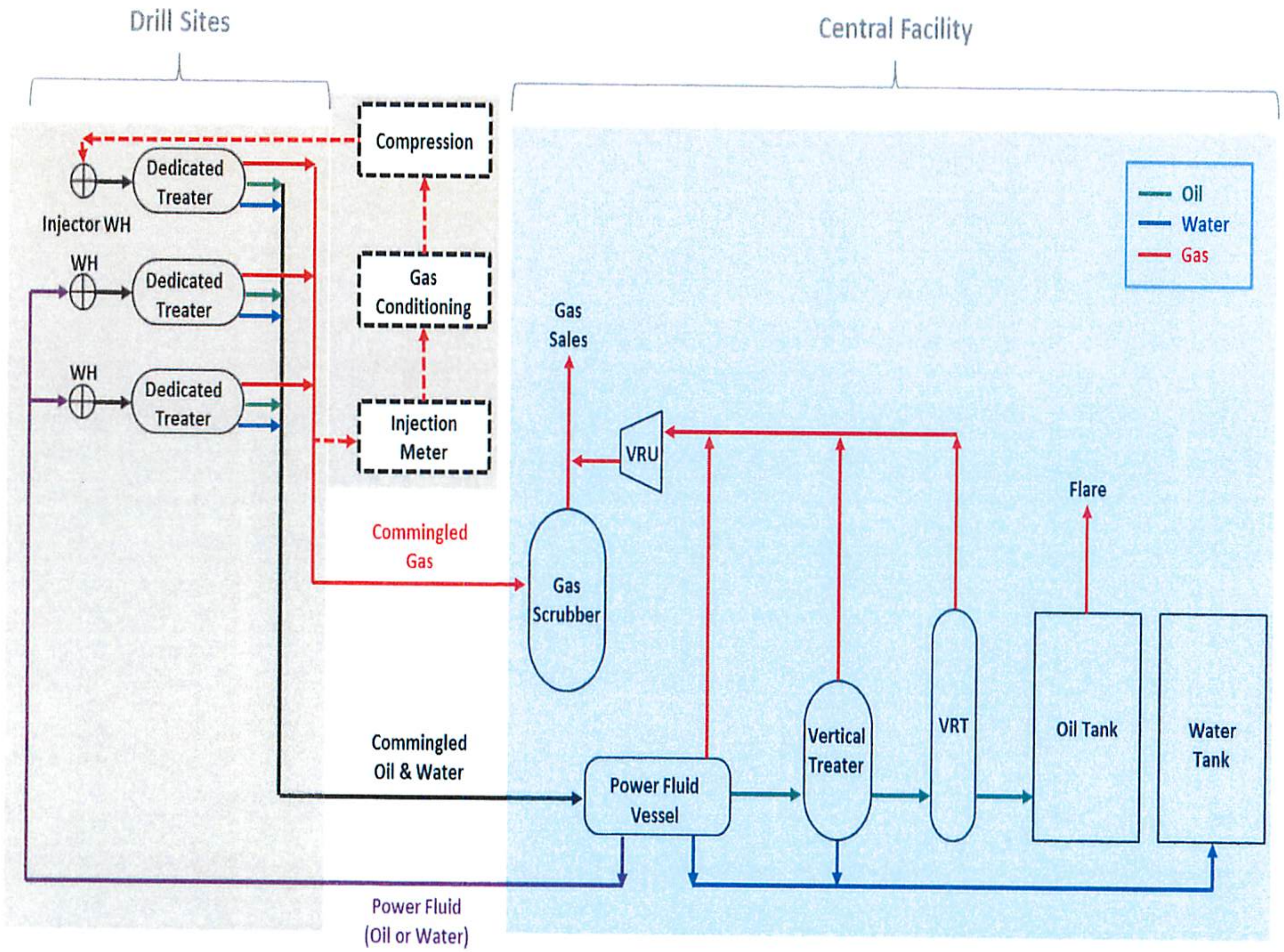


- Injector Wellbore Outline
- Monitor Well Chromatograph
- Monitor Well BHP Gauge
- Boundary Well
- Offset Operator Notification

LIBERTY RESOURCES

Exhibit E-7
Case No. 26035

Process Flow Illustration



LIBERTY RESOURCES

Exhibit E-8
Case No. 26035

Gas Composition for Proposed Injection

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

Component Results

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

Results Summary

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

LIBERTY RESOURCES

Exhibit E-9
Case No. 26035

Gas Supply Wells

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

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

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

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

LIBERTY RESOURCES

Exhibit E-10

Case No. 26035

Rich Gas EOR Pilot Summary

Goals

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

Design Summary

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

LIBERTY RESOURCES

Exhibit E-11
Case No. 26035