Energy & Environmental Research Center (EERC)

BAKKEN RICH GAS EOR PROJECT

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U.S. Department of Energy

National Energy Technology Laboratory

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

August 13–16, 2018

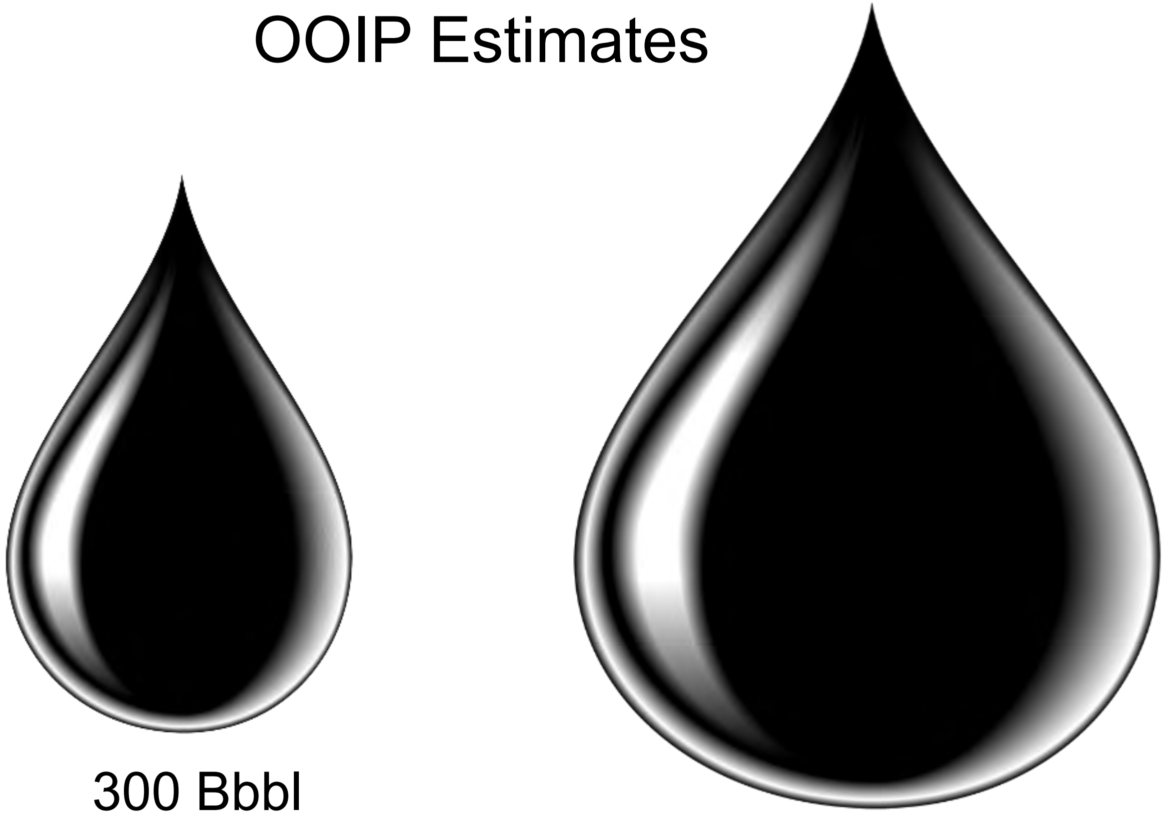
Critical Challenges. Practical Solutions.

PRESENTATION OUTLINE

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

BACKGROUND – BAKKEN EOR SIZE OF THE PRIZE

OOIP Estimates



300 Bbbl
(Flannery and Kraus, 2006)

900 Bbbl
(Continental Resources, 2011)

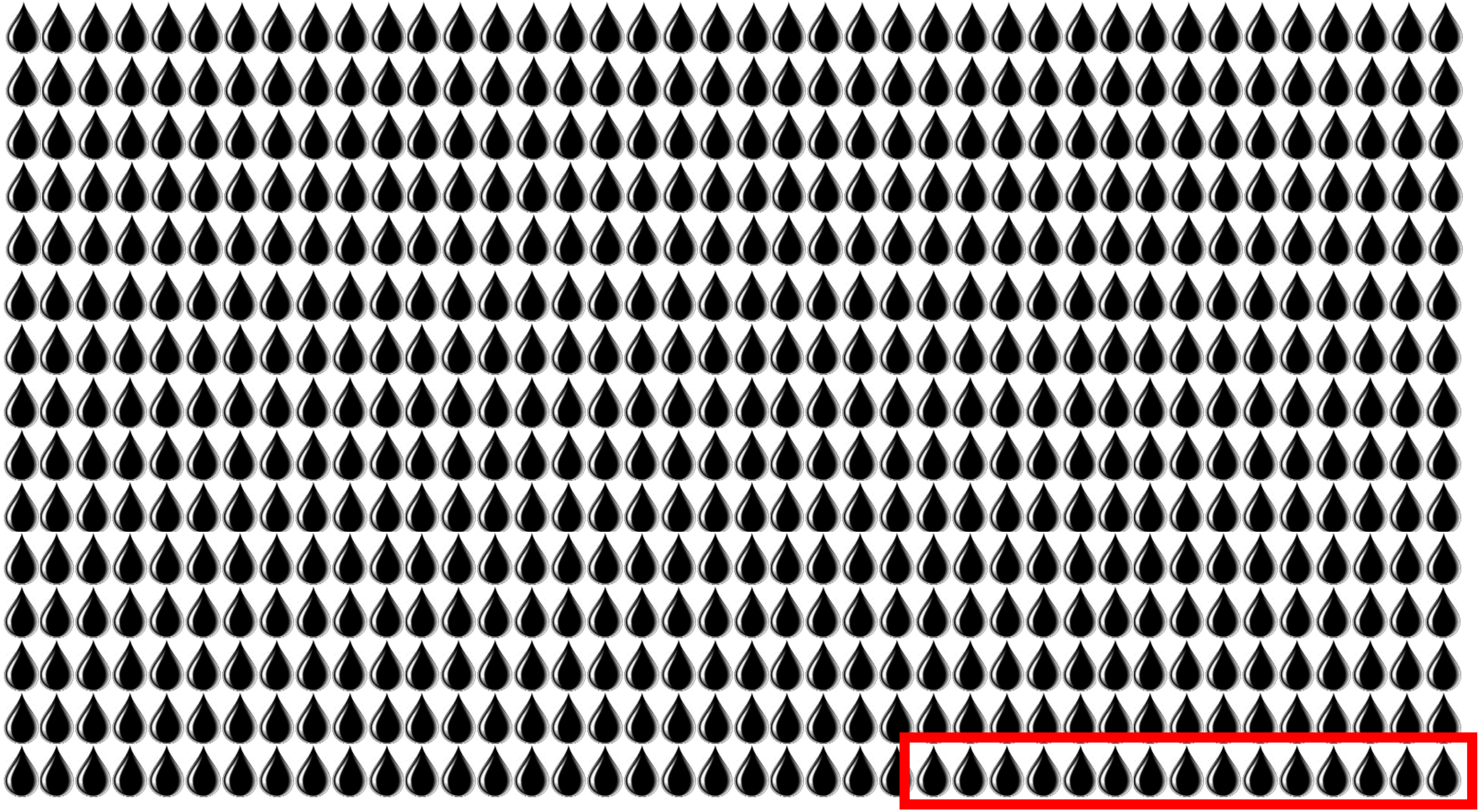
Technically Recoverable Reserve Estimates

7.4 Bbbl
(USGS, 2013)

24 Bbbl
(Continental Resource, 2011)

Business as usual gets about 15 billion barrels

LEAVES A LOT OF BAKKEN OIL TO CHASE!



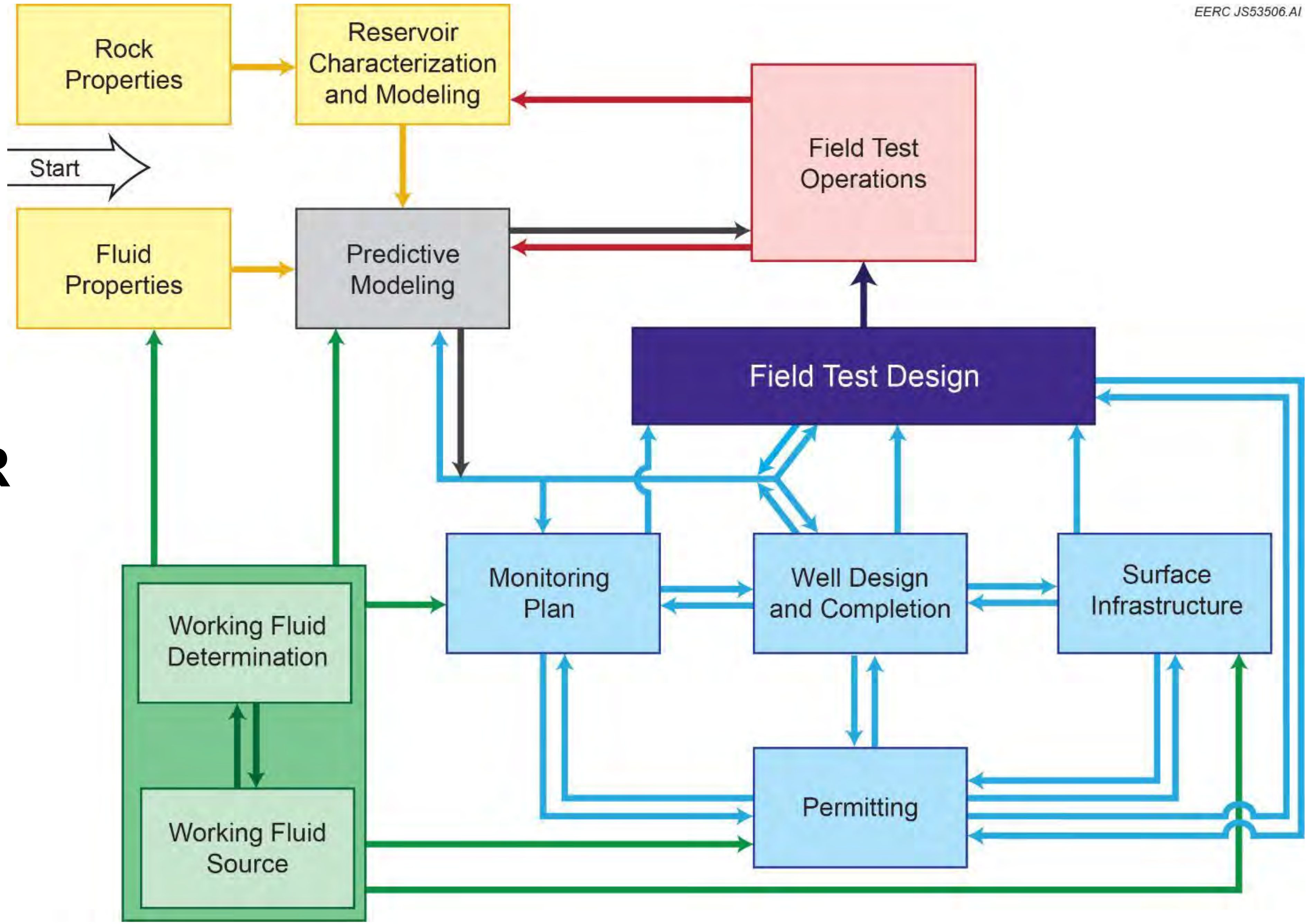
TECHNICAL STATUS

Lab experiments!

Modeling and simulations!

Injection tests!

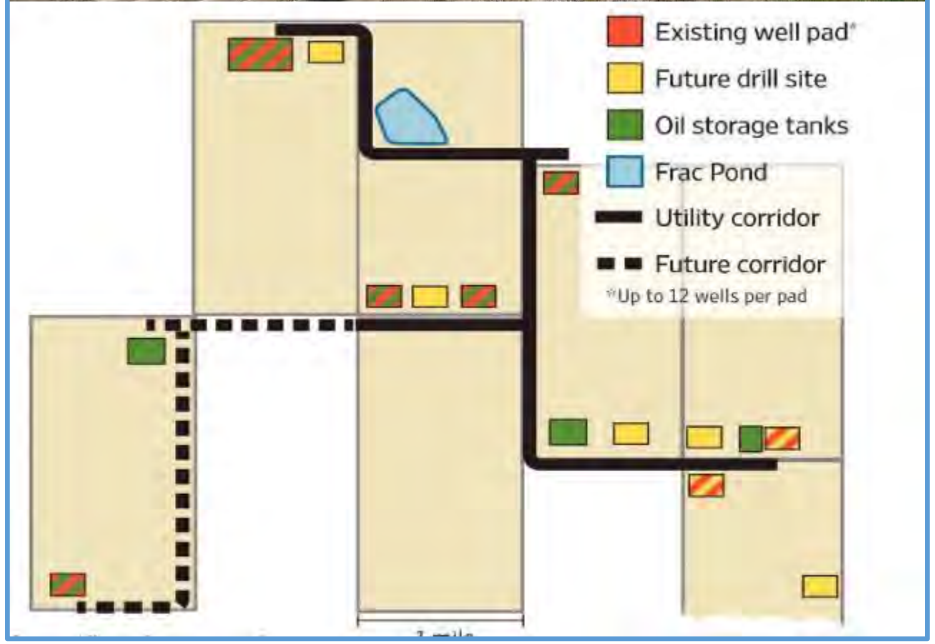
WHAT DOES IT TAKE TO DO AN EFFECTIVE EOR PILOT?



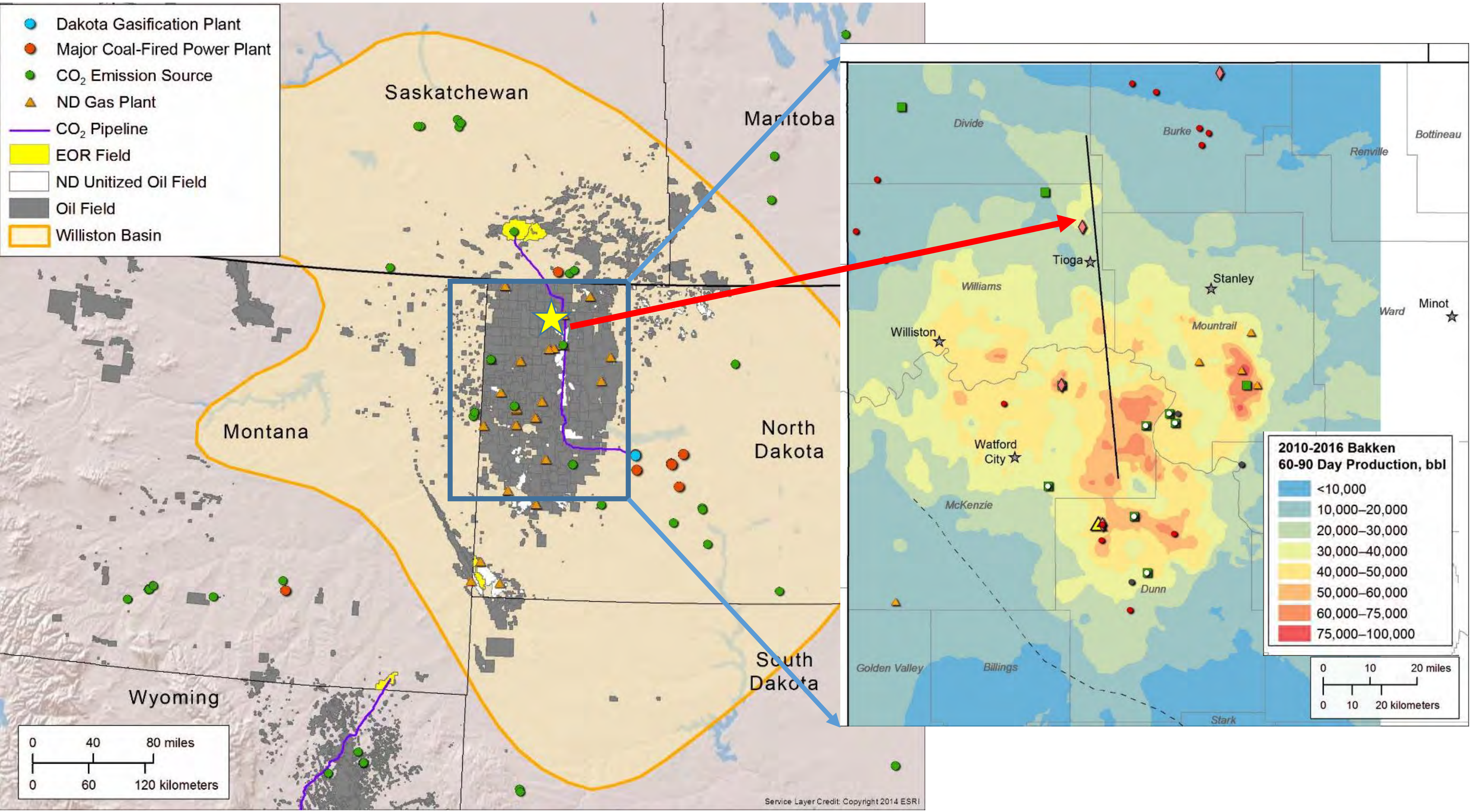
STOMPING HORSE OIL FACTORY

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

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



LIBERTY RESOURCES
NETL
North Dakota oil & gas research program



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

STOMPING HORSE RICH GAS COMPOSITIONS

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

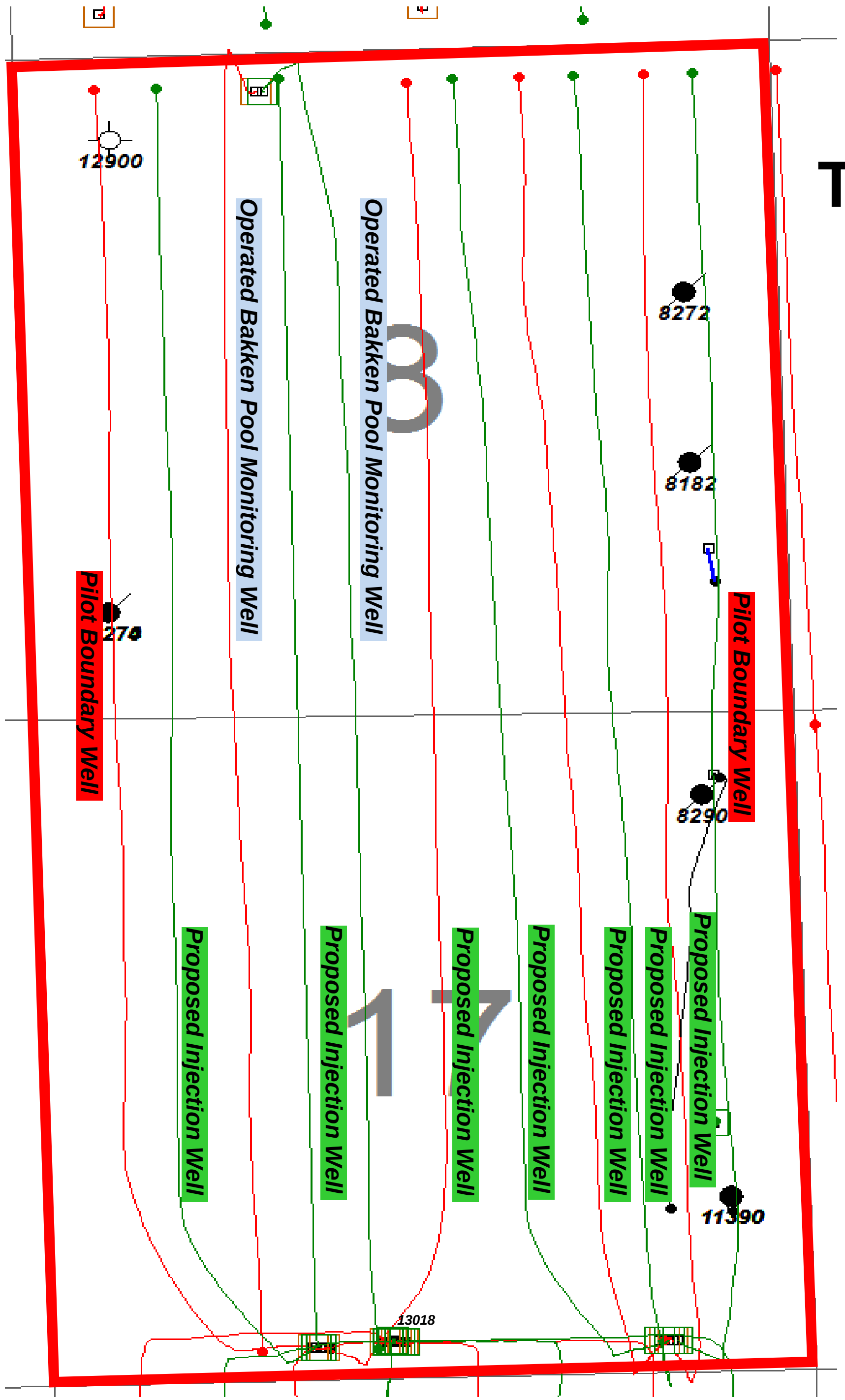
	WELLHEAD	PLANT INLET	DEETHANIZER	PLANT EXIT
METHANE	60%	62.7%	51%	71%
ETHANE	20%	21.4%	46%	22%
PROPANE	10%	11.4%	0.5%	2.0%
C4+	1.4%	1.2%	0.0%	1.6%
CO2	0.8%	0.9%	1.3%	1.0%
BTU	~1500	~1450	~1300	~1175

MULTIWELL PILOT LAYOUT

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

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

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



The Leon & Gohrick Pads

LIBERTY RESOURCES

Exhibit E-5
Case No. 26035

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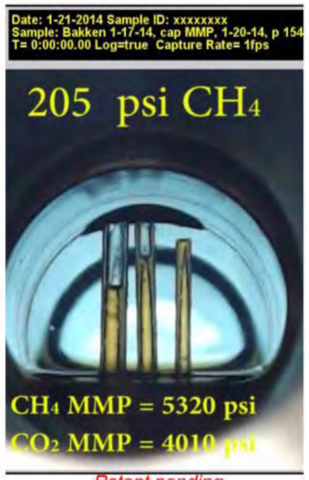
Critical Challenges. Practical Solutions.

GOALS AND OBJECTIVES OF THE RESEARCH PROJECT

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

RICH GAS–OIL FLUID BEHAVIOR AND ROCK EXTRACTION STUDIES

MMP Studies



Patent pending

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

– Methane, ethane, and propane.

Approximately 80 MMP determinations are anticipated.

Miscible Behavior Studies

Which hydrocarbons partition into this “miscible” upper phase?

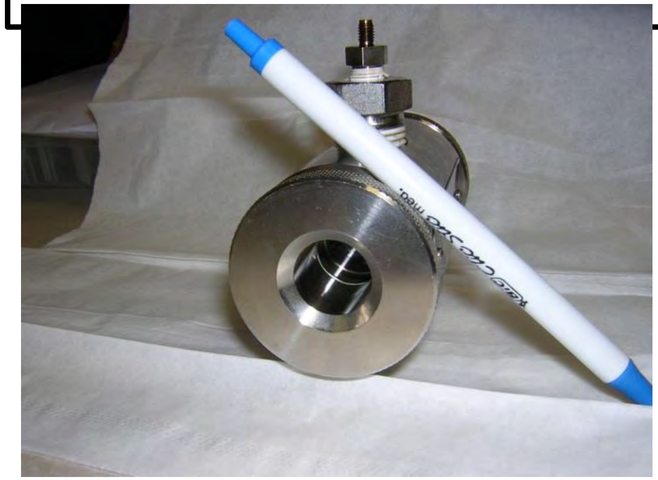
Which hydrocarbons are lost as pressure drops?

Rock Extraction Studies

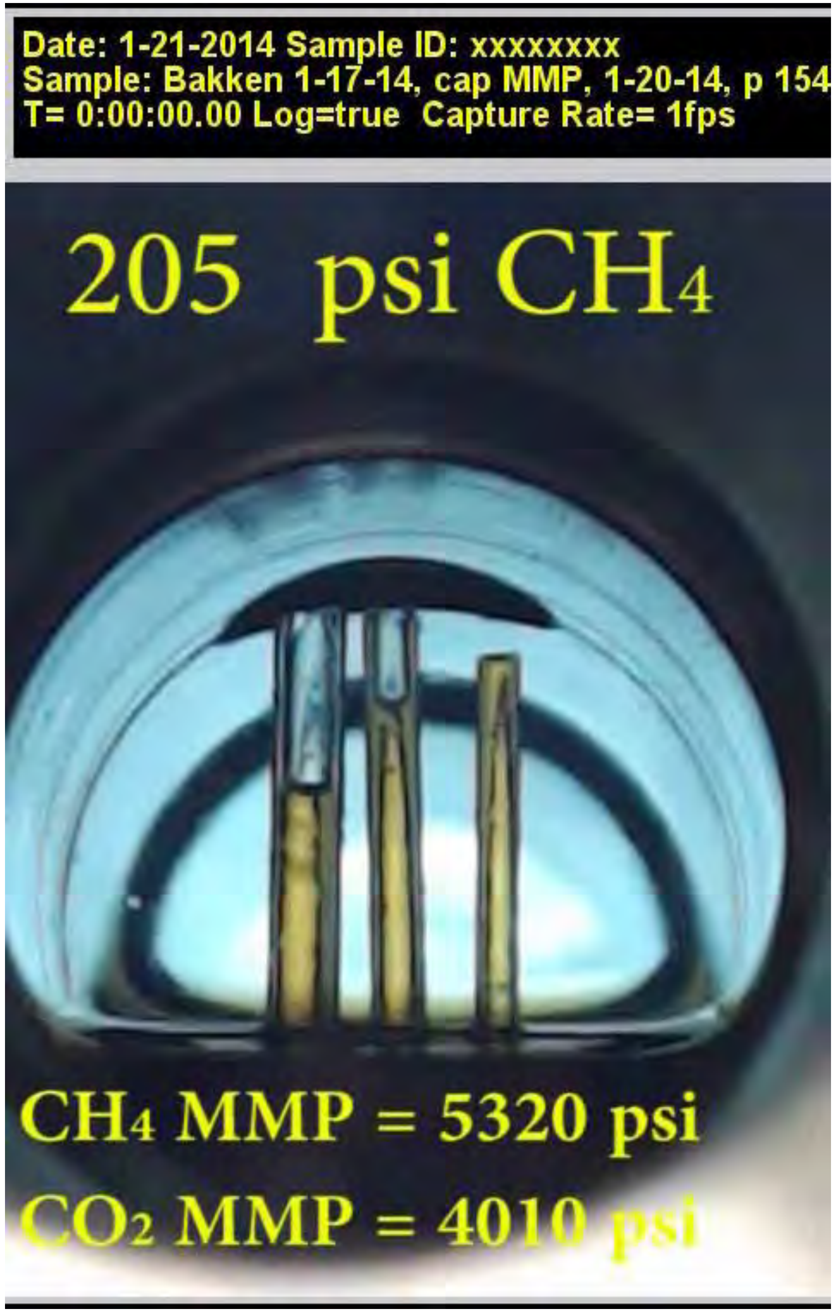
Determine ability of rich gas components to mobilize oil from the Bakken matrix.

– Methane, ethane, and propane at reservoir conditions.

MMP by vanishing interfacial tension/capillary rise.



1.12, 0.84, 0.68 mm i.d.



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

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

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

energy&fuels

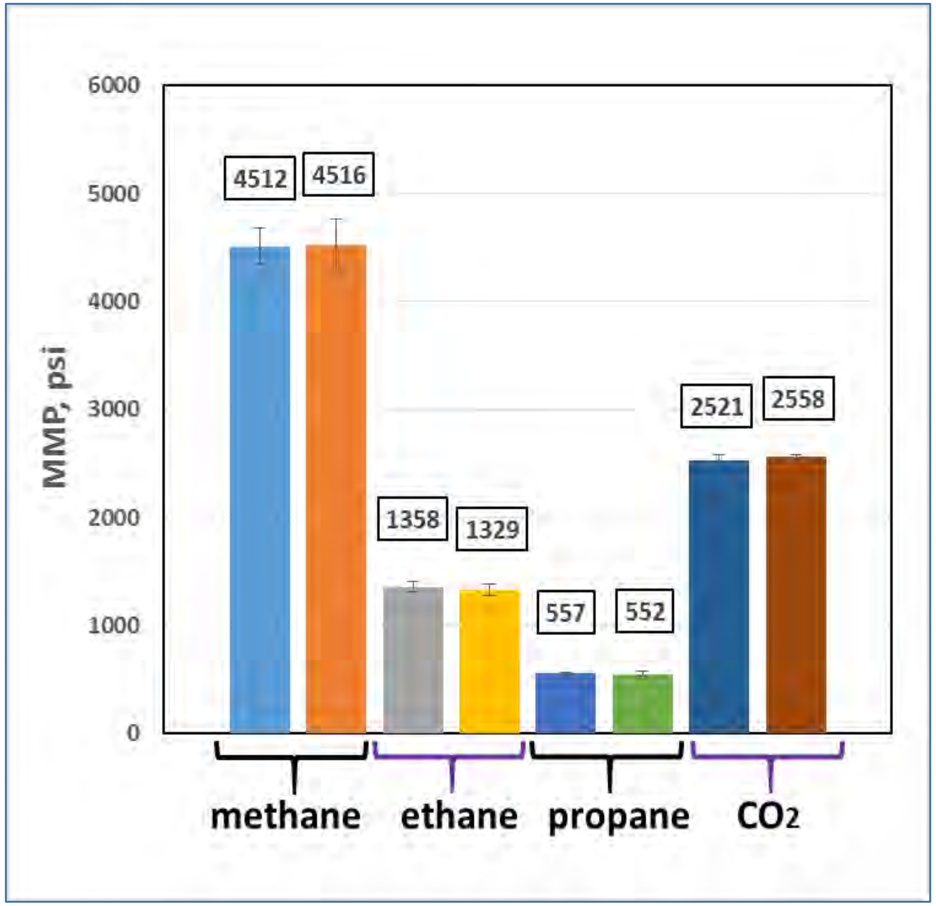
Reprinted from
Volume 30, Number 8, Pages 6365-6372

U.S. Patent 9,851,339

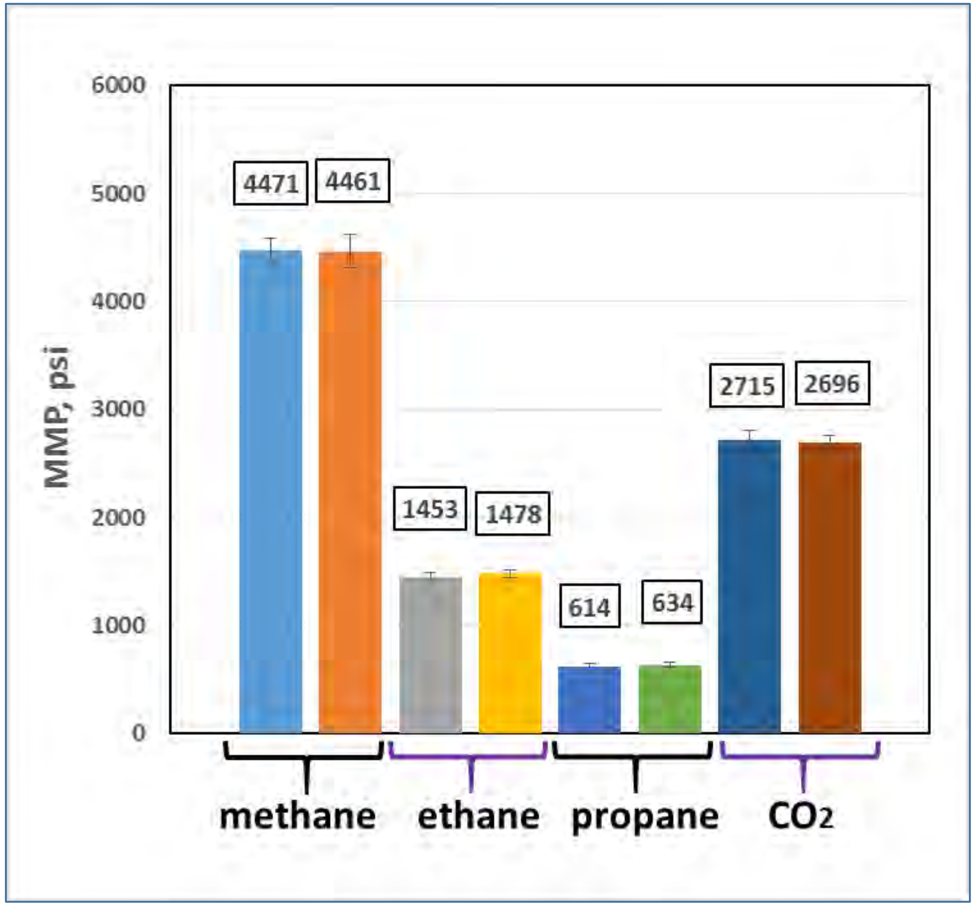
MMP with Methane, Ethane, Propane, and CO_2*

The richer the gas, the lower the MMP!!

Bakken Crude Oil (230 F, 110



Three Forks Crude (264 F,



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

ROCK EXTRACTION STUDIES

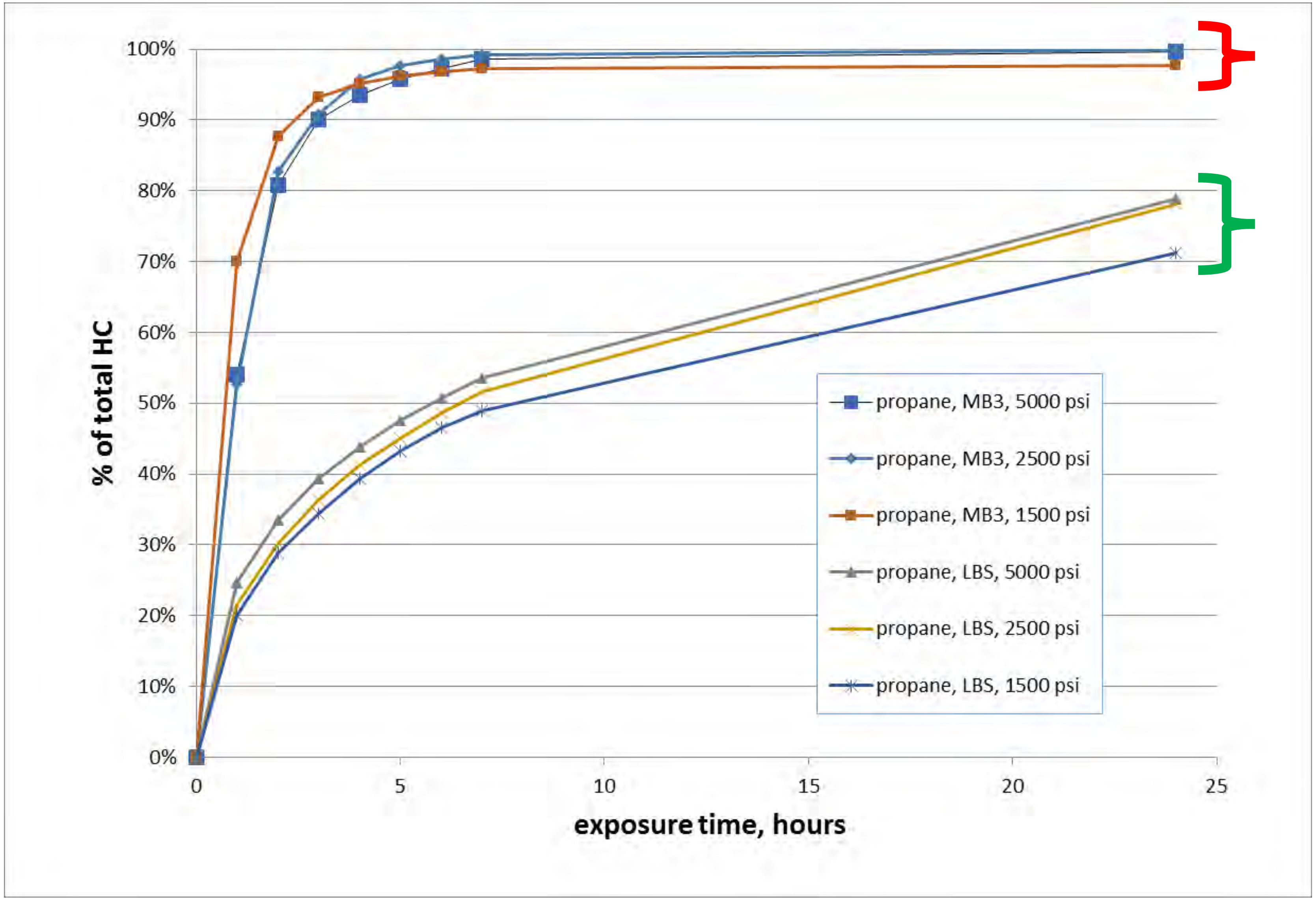
Determine ability of methane, ethane, and propane at different pressures to recover hydrocarbons from Middle Bakken and Bakken Shale rock samples

Laboratory Exposures Include:

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

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

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



Middle Bakken nonshale results

Lower Bakken shale results

MISCIBLE BEHAVIOR STUDIES

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

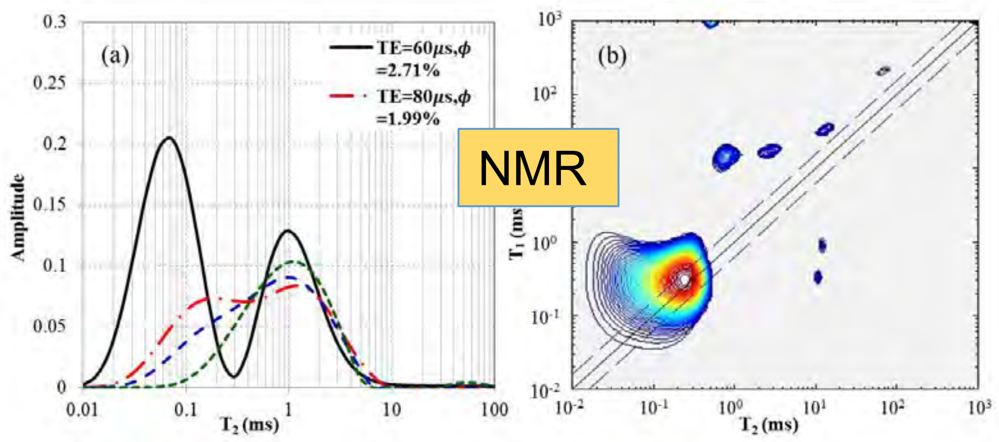
So if the oil and the injected fluids are not truly miscible, what oil components are in the "miscible" phase?

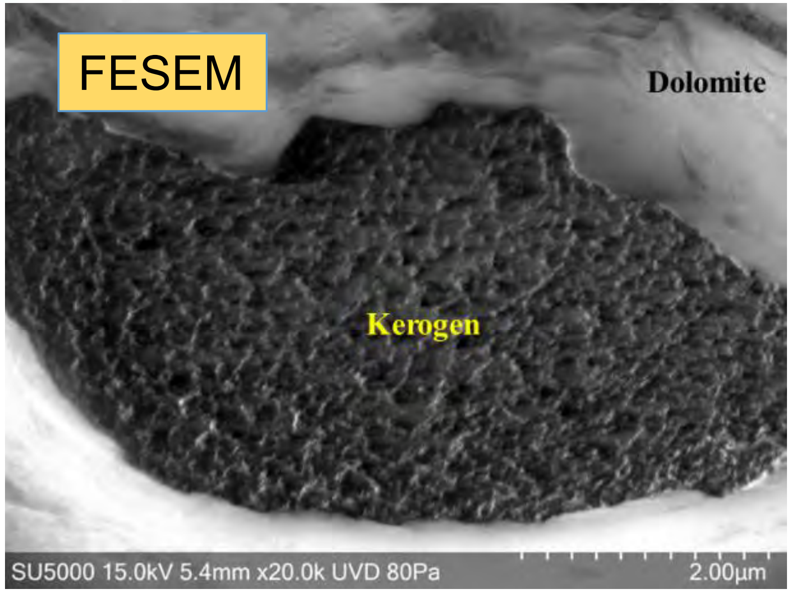
Initial experiments have been conducted, and results are being interpreted and assessed.

RICH GAS IN SHALE PERMEABILITY AND SORPTION STUDIES

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

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





RICH GAS CHARACTERIZATION FOR EOR OPERATIONS

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

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

FLUIDS MONITORING

- Baseline gas composition has been established by the EERC for all 24 wells within the study area.

- Background crude and water samples have been collected and analyzed.

  - Evaluating API gravity, molecular weight distribution, and general water chemistry.

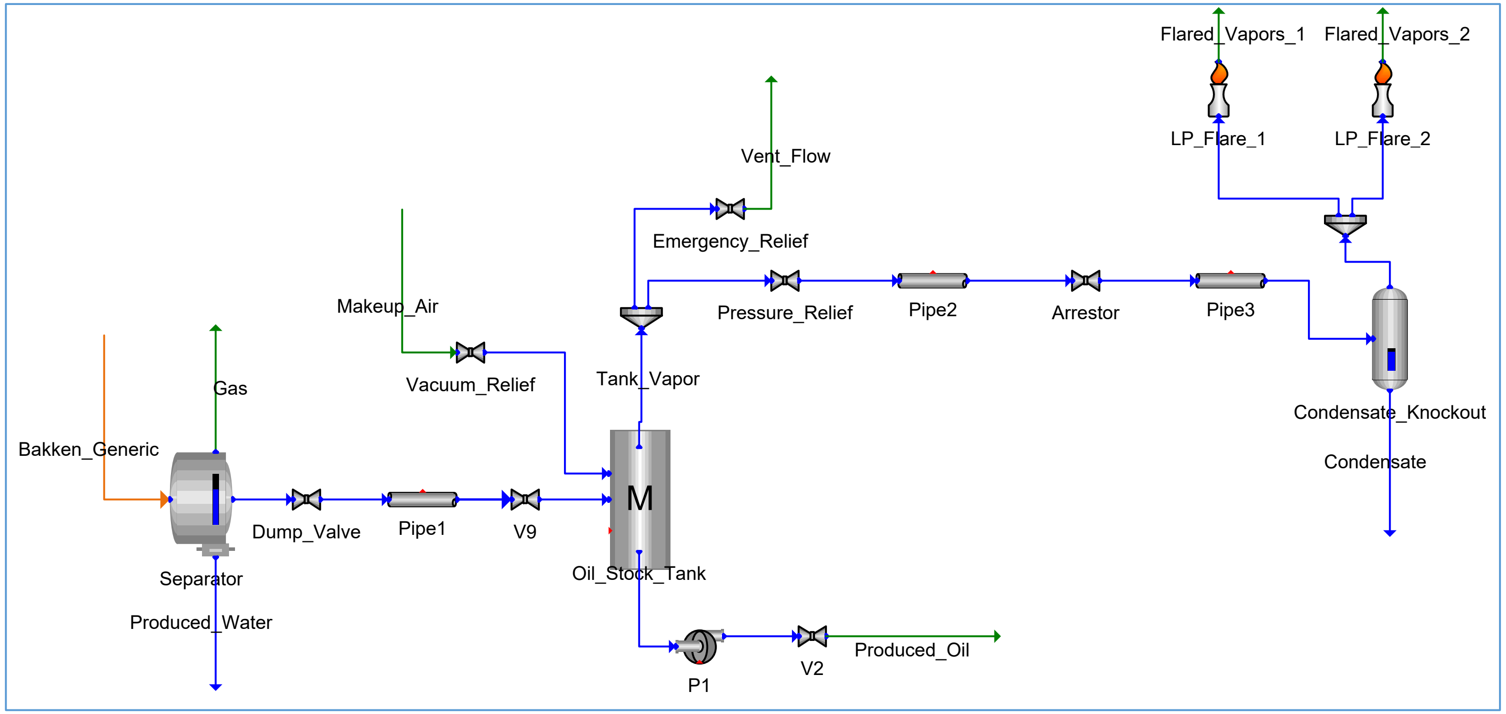
SURFACE FACILITY MODELING

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

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

SURFACE FACILITY MODELING – STATUS

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



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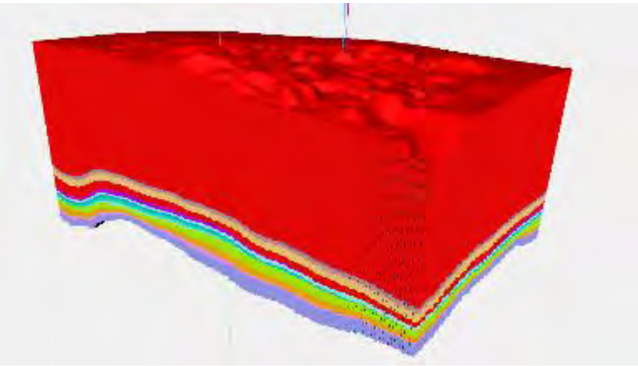
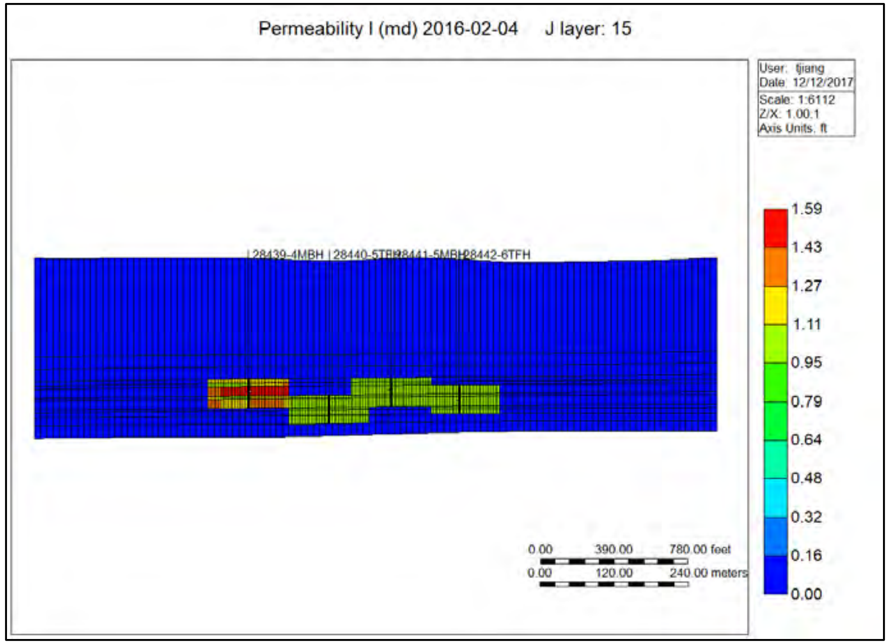
ITERATIVE MODELING OF SUBSURFACE EOR COMPONENTS

Bakken Reservoir Modeling and Simulations

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

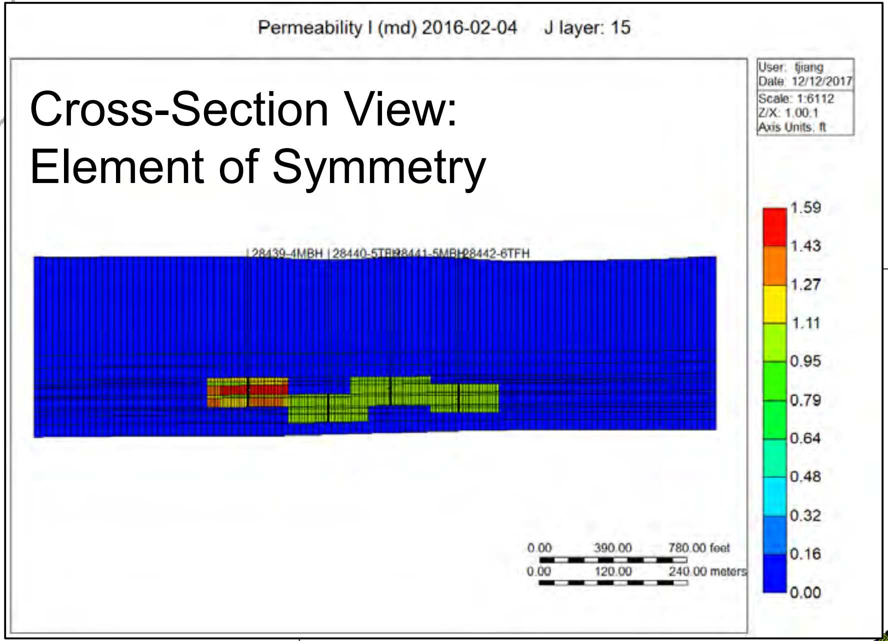


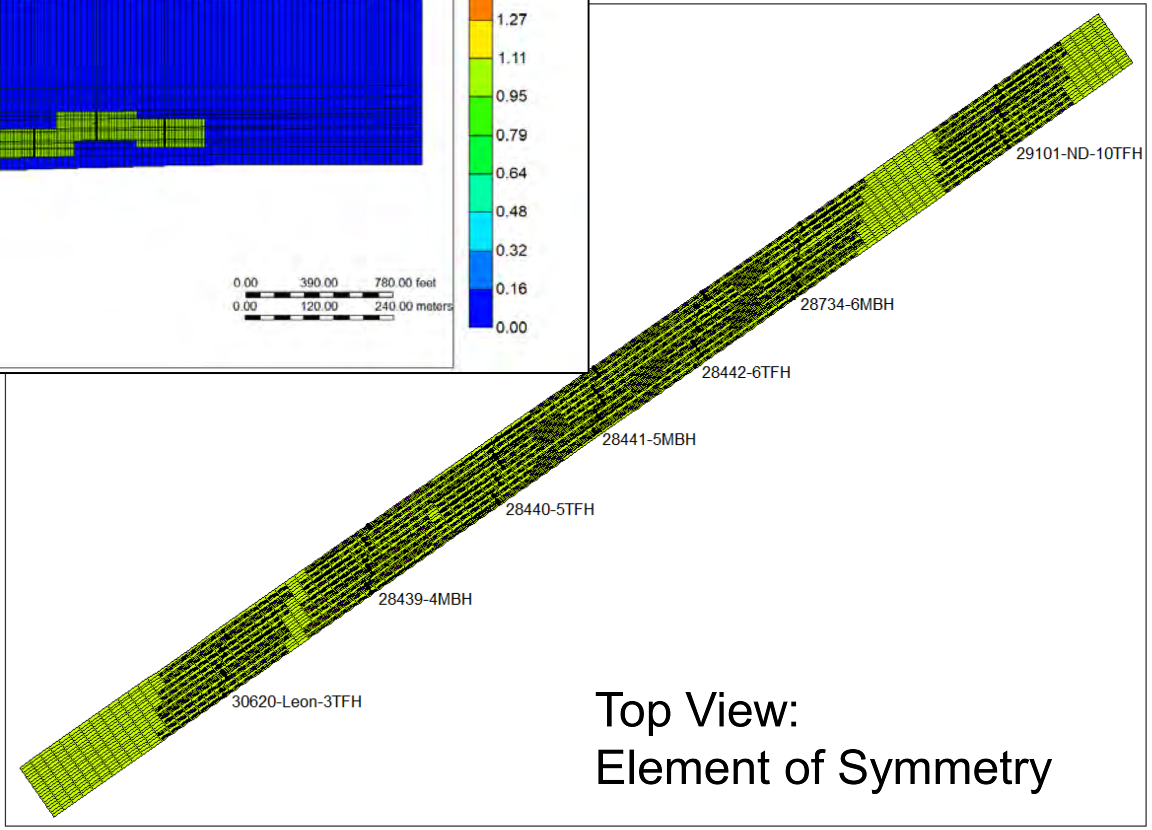


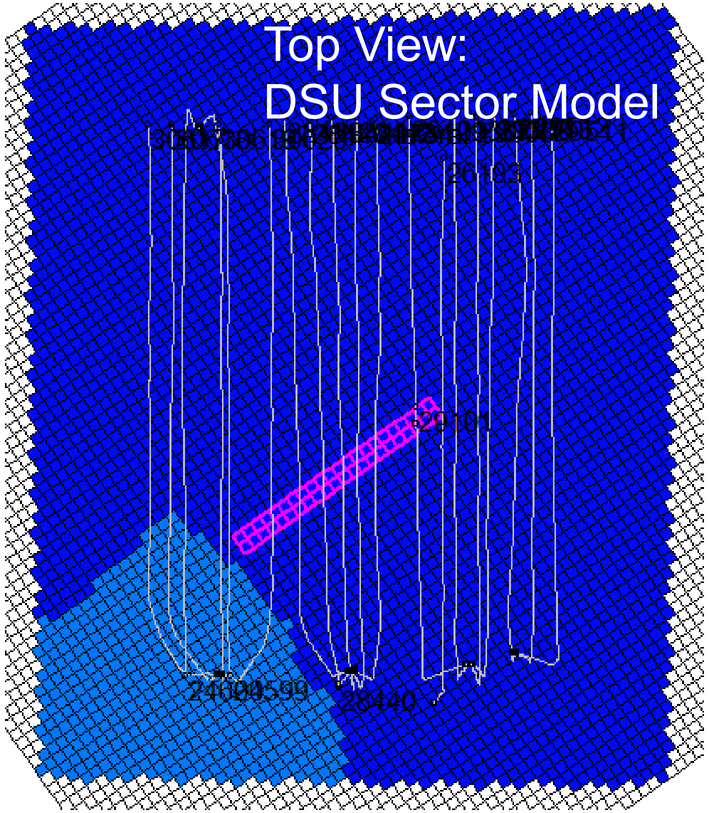
SINGLE-STAGE MODEL

Model Assumptions:

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







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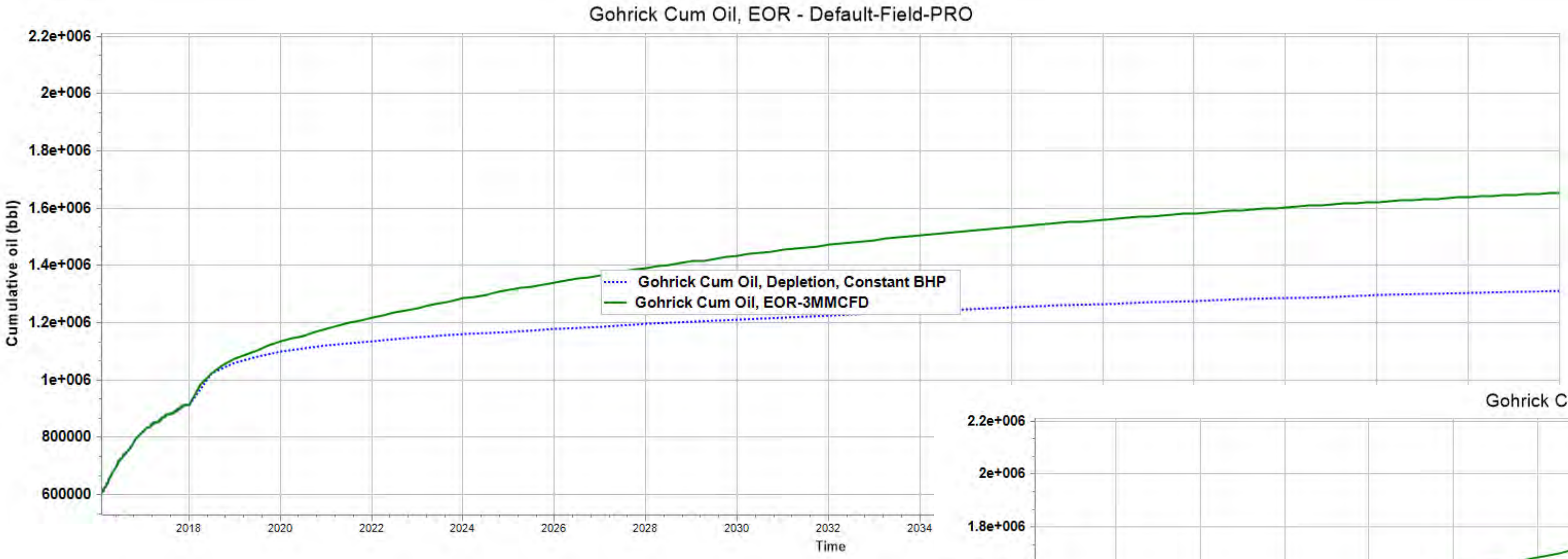
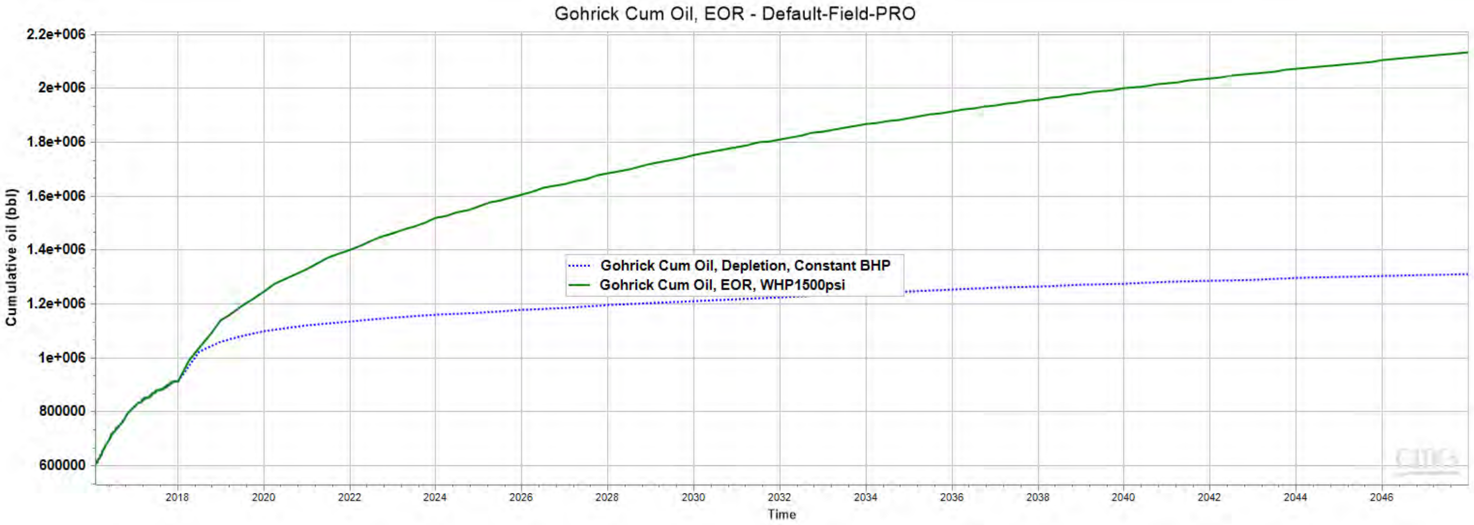
Critical Challenges. **Practical Solutions.**

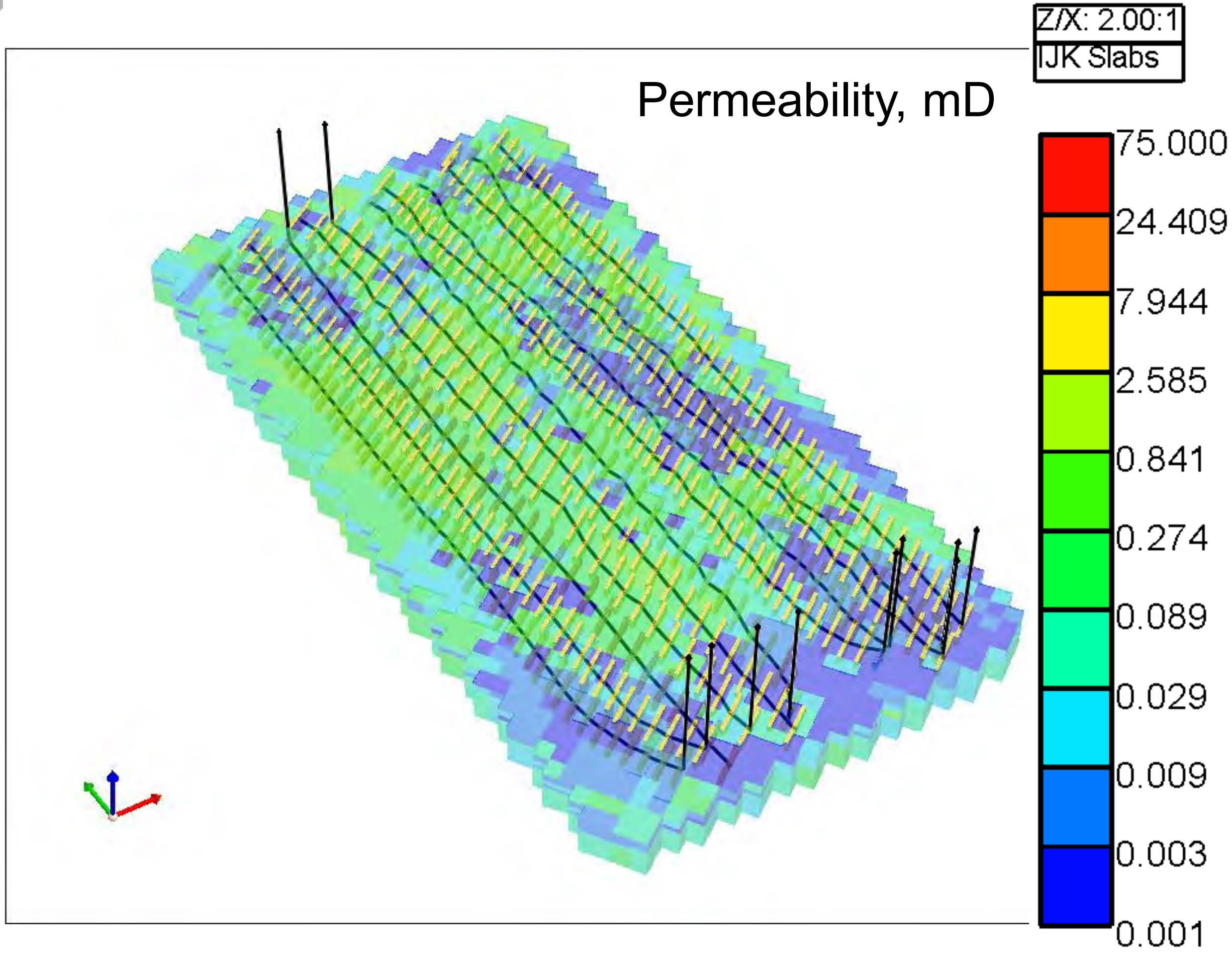
EXAMPLE SIMULATION RESULTS

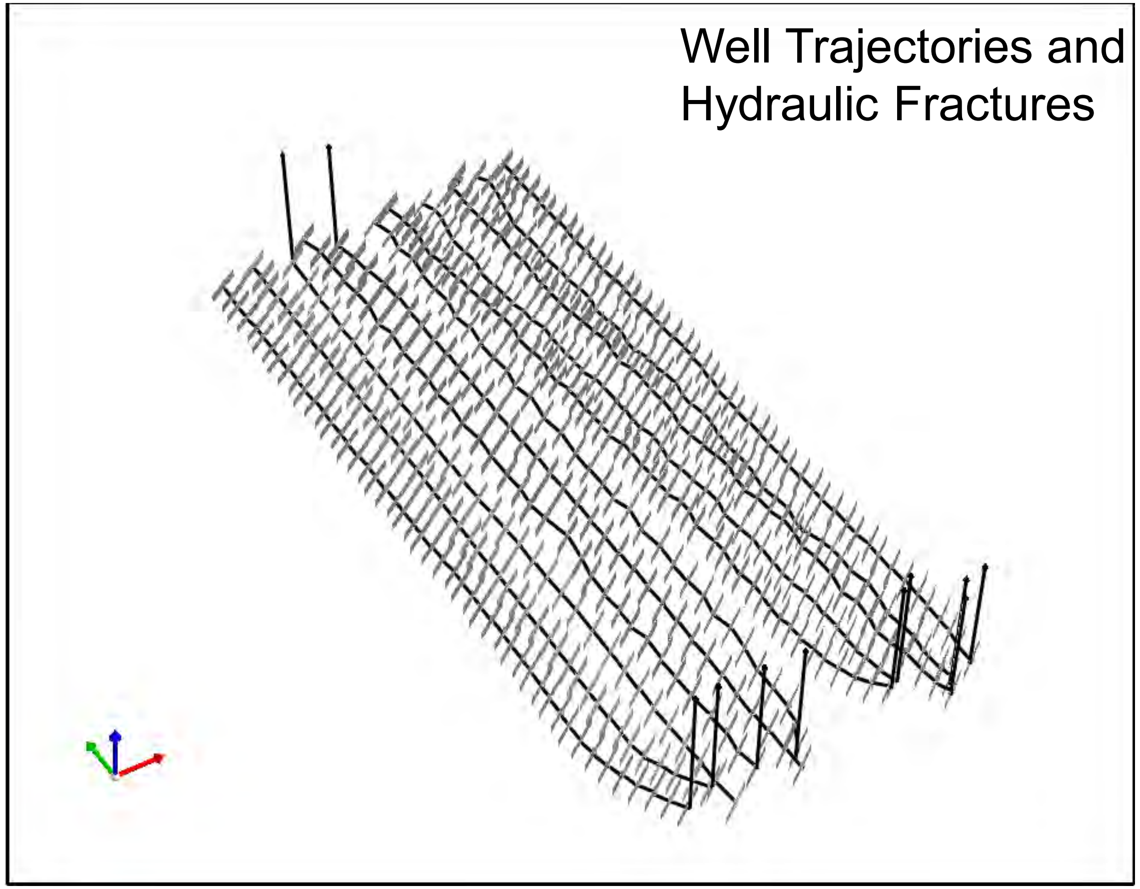
- **Predicted incremental recovery for five wells ranges from 26% to 63%.**





ONGOING EFFORT TO UPSCALE TO A DSU MODEL





PILOT PERFORMANCE ASSESSMENT

Determine effectiveness of CMWHP

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

PILOT PERFORMANCE ASSESSMENT

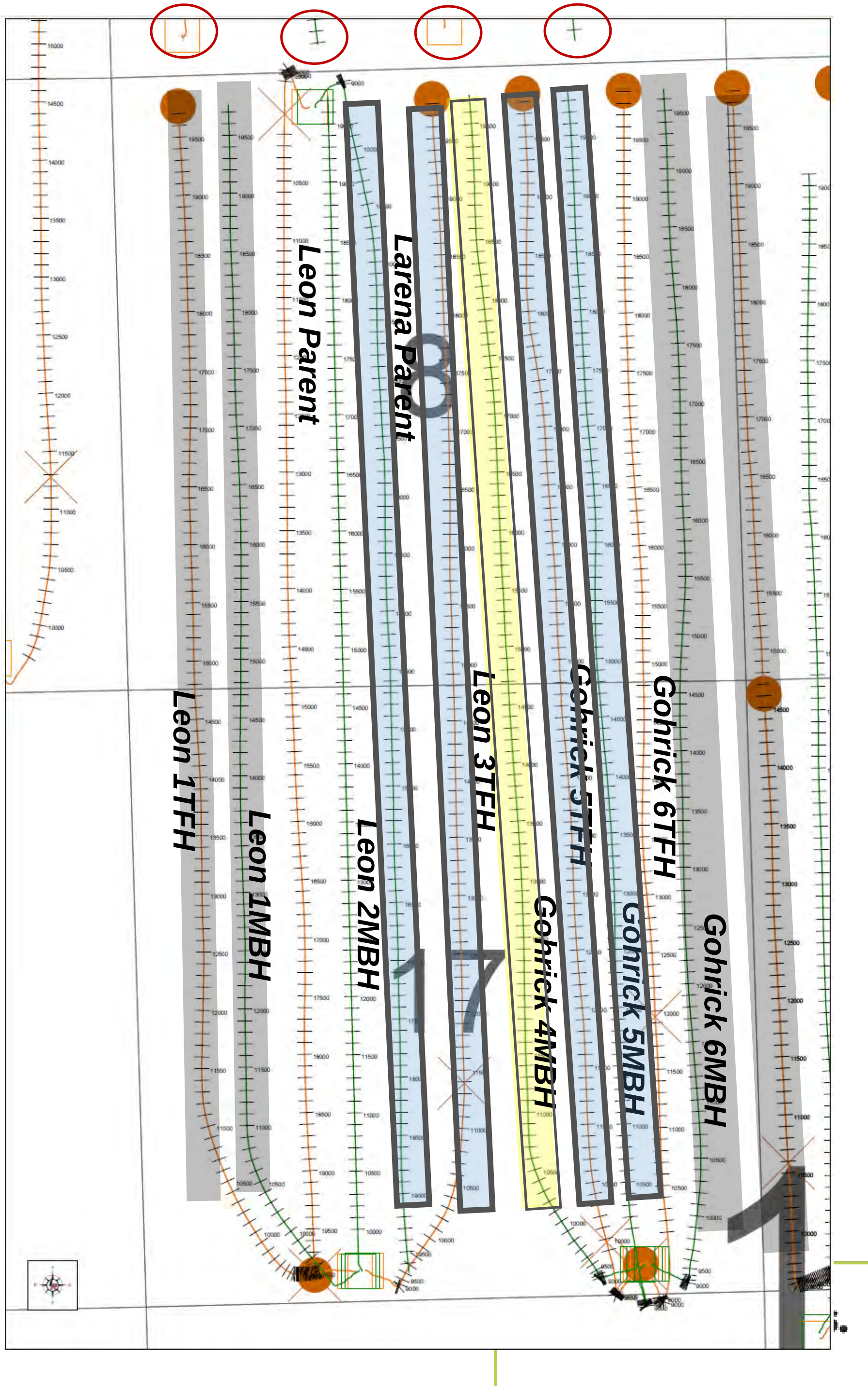
Initial Injection

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

SURVEILLANCE INCLUDES PRODUCTION, BOTTOMHOLE PRESSURE, AND GAS COMPOSITION MONITORING

Surveillance Plan

- ✓Oil, gas, and water rates will be monitored continuously from Liberty operated wells.
- ✓The four wellbores immediately offset the injector well will have daily samples for GC.
- ✓The four wellbores immediately offset the injector (pattern allowing) will be equipped with bottomhole pressure gauges.
- ✓The offset operator to the north has been contacted and has agreed to provide operational information.



Boundary Well
Injection Well
Monitor Well BHP Gauge
Monitor Well Gas Chromatograph
Offset Operator Notification

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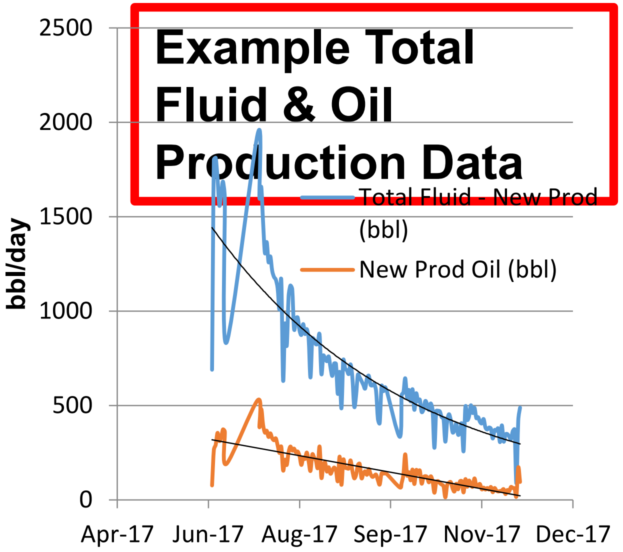
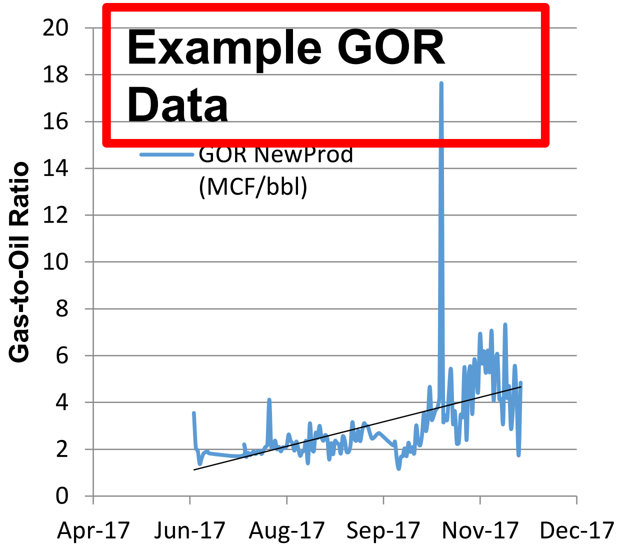
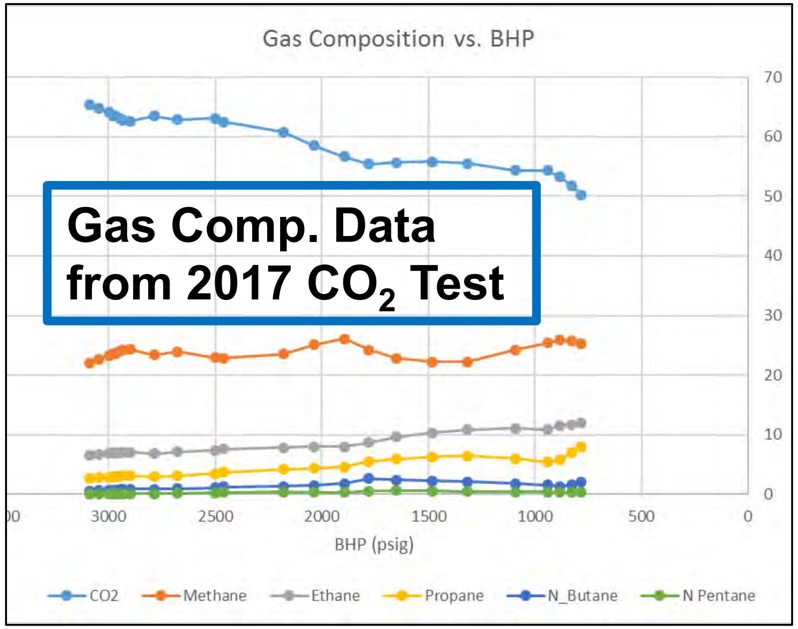
HOW DO WE ASSESS PILOT PERFORMANCE?

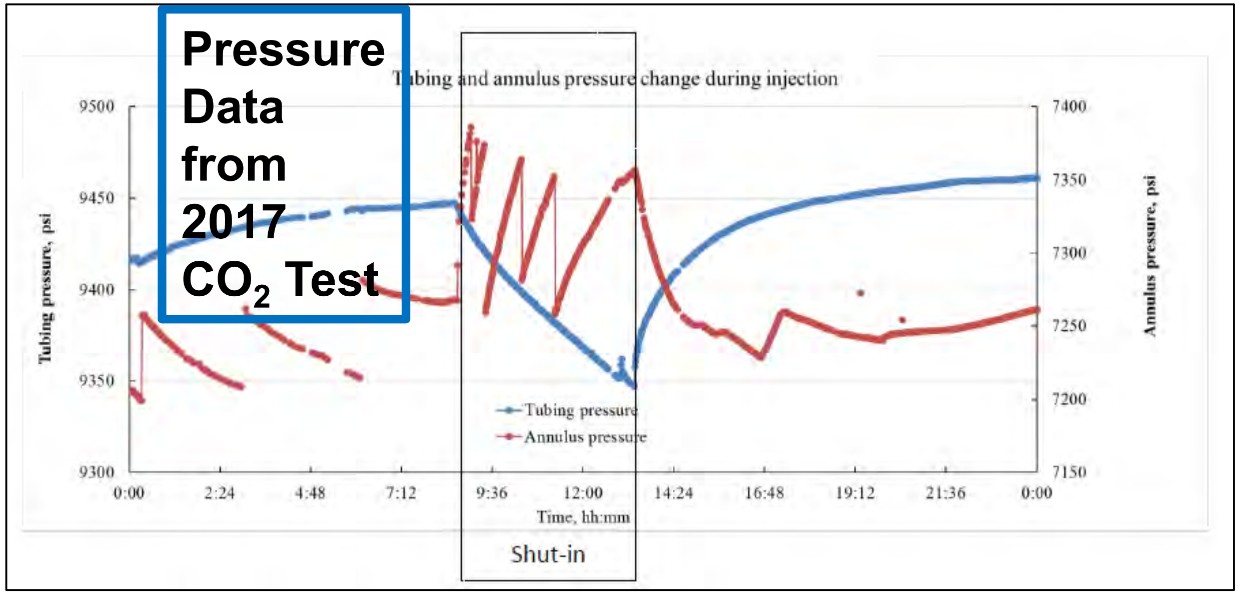
Short Term:

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







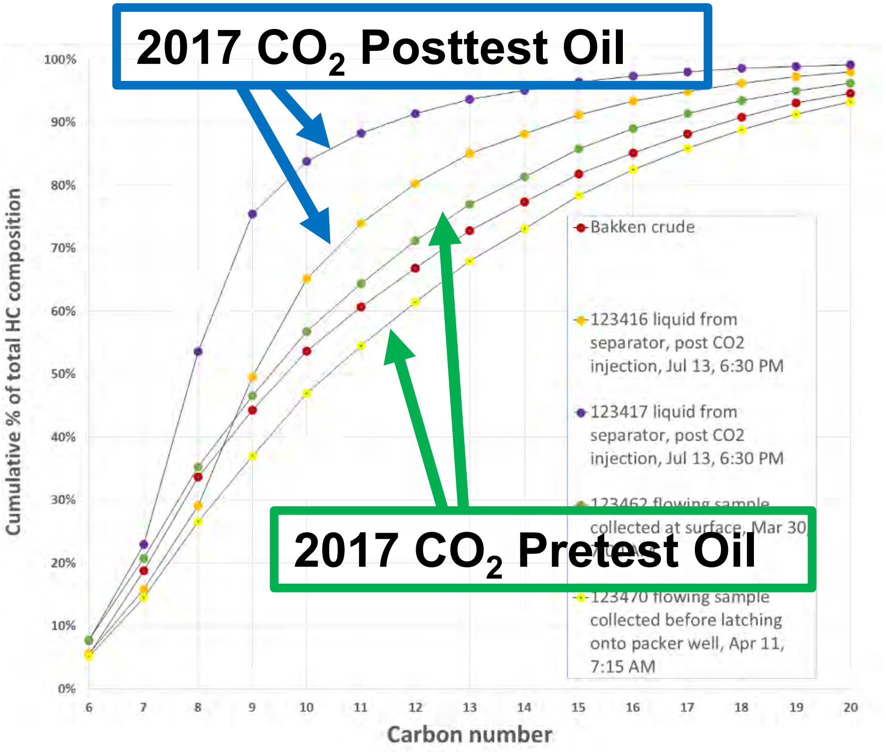


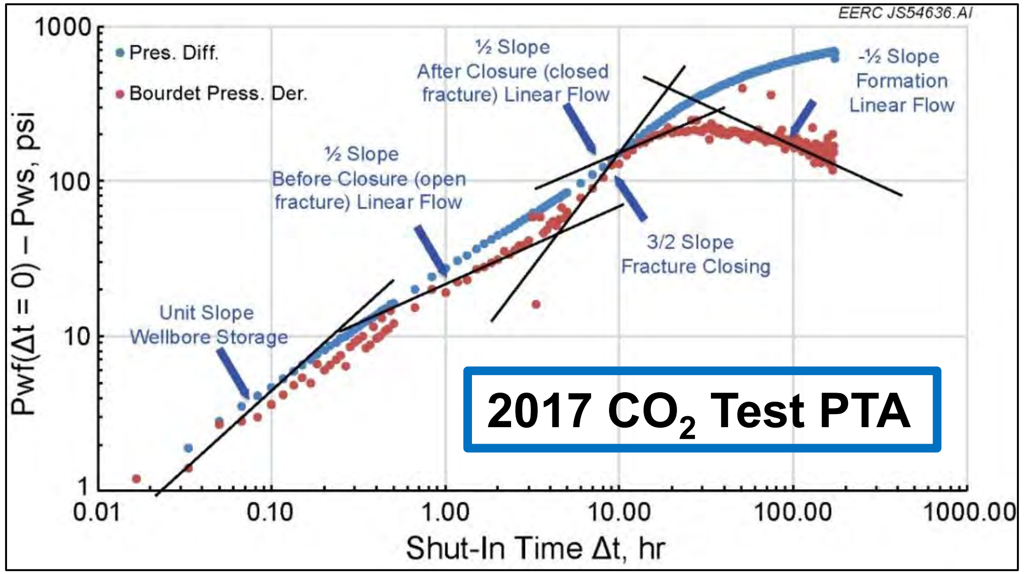
Example Data taken from Williams County Bakken Wells.

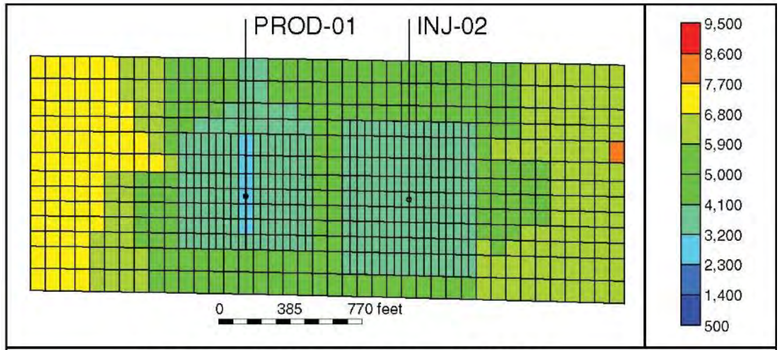
HOW DO WE ASSESS PILOT PERFORMANCE?

Long Term:

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





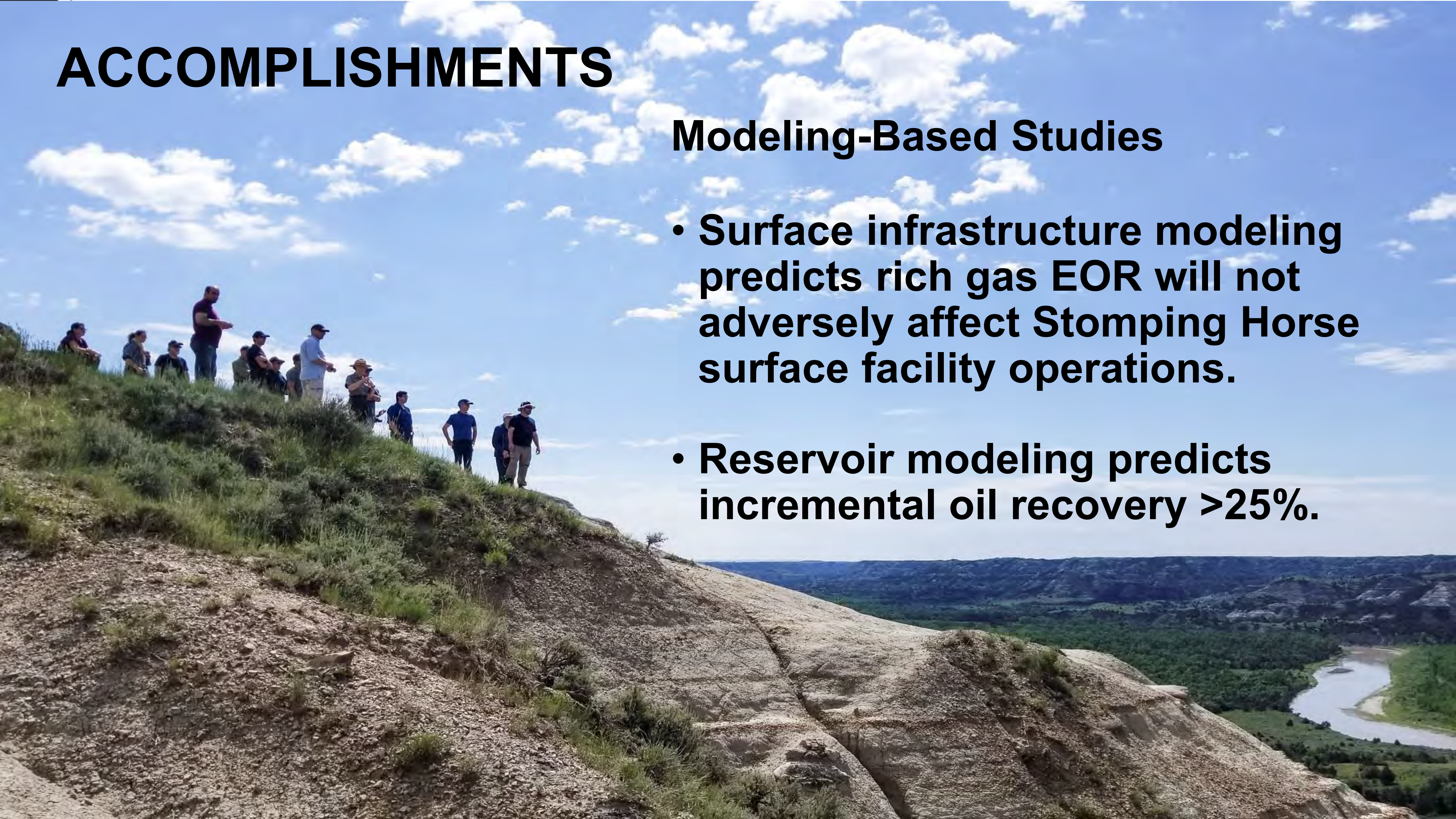


(a) Pressure (BHP > MMP)

ACCOMPLISHMENTS

Lab-Based Studies

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



ACCOMPLISHMENTS

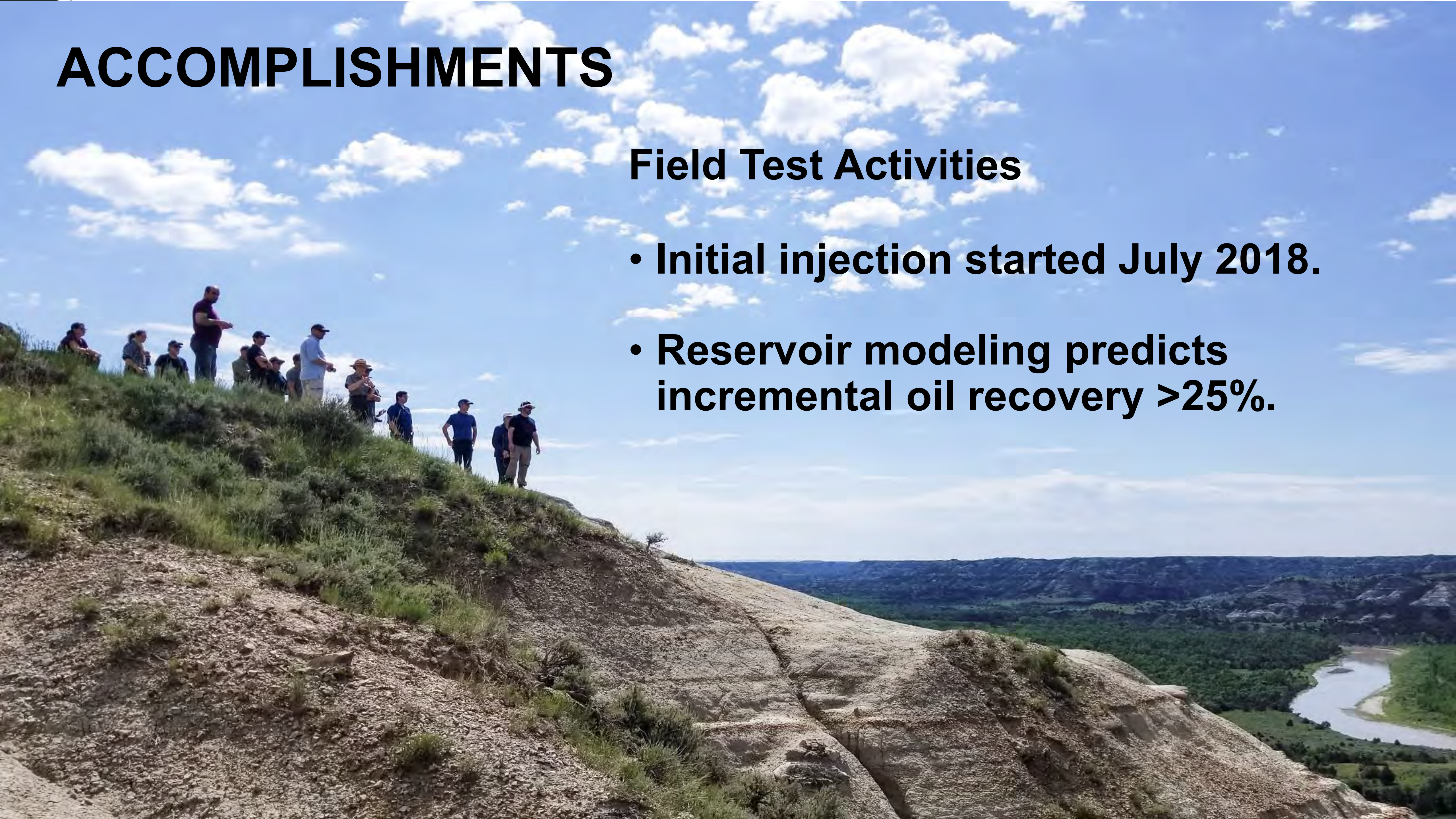
Modeling-Based Studies

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

ACCOMPLISHMENTS

Field Test Activities

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



LESSONS LEARNED

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

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

LESSONS LEARNED

- Technical disappointments
  - Challenges in procuring desired compression equipment led to delays in injection.
- Changes that should be made next time
  - Too early to tell…

SYNERGY OPPORTUNITIES

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

CONTACT INFORMATION

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THANK YOU!

APPENDIX

BENEFIT TO THE PROGRAM

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

PROJECT OVERVIEW – GOALS AND OBJECTIVES

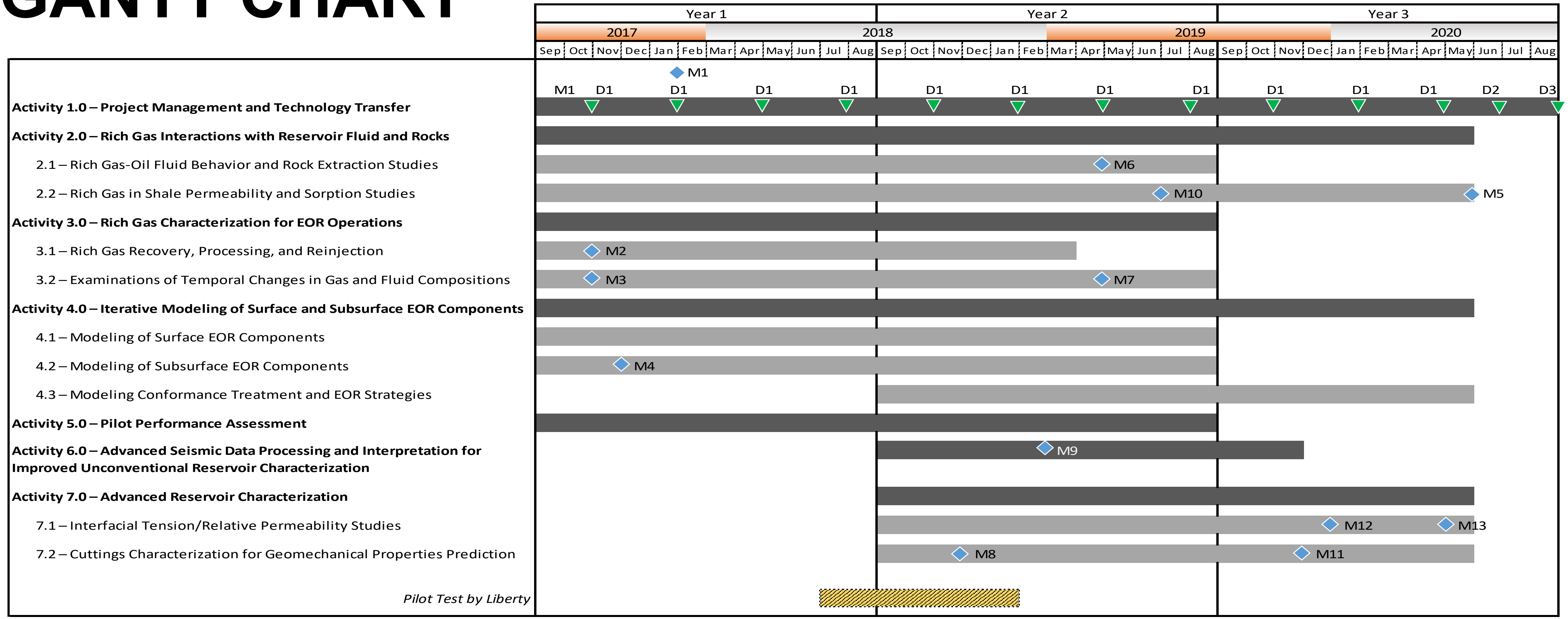
- Goals:
- To develop knowledge that will determine the feasibility of re-injecting captured rich gas into a Bakken petroleum system reservoir to enhance oil recovery. Specific research objectives related to this goal are as follows:
    - These goals relate to the Program goals in that:
        - Tight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

ORGANIZATION CHART

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

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

GANTT CHART



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

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