EERC | UND UNIVERSITY OF NORTH DAKOTA

Critical Challenges. Practical Solutions.

Energy & Environmental Research Center (EERC)

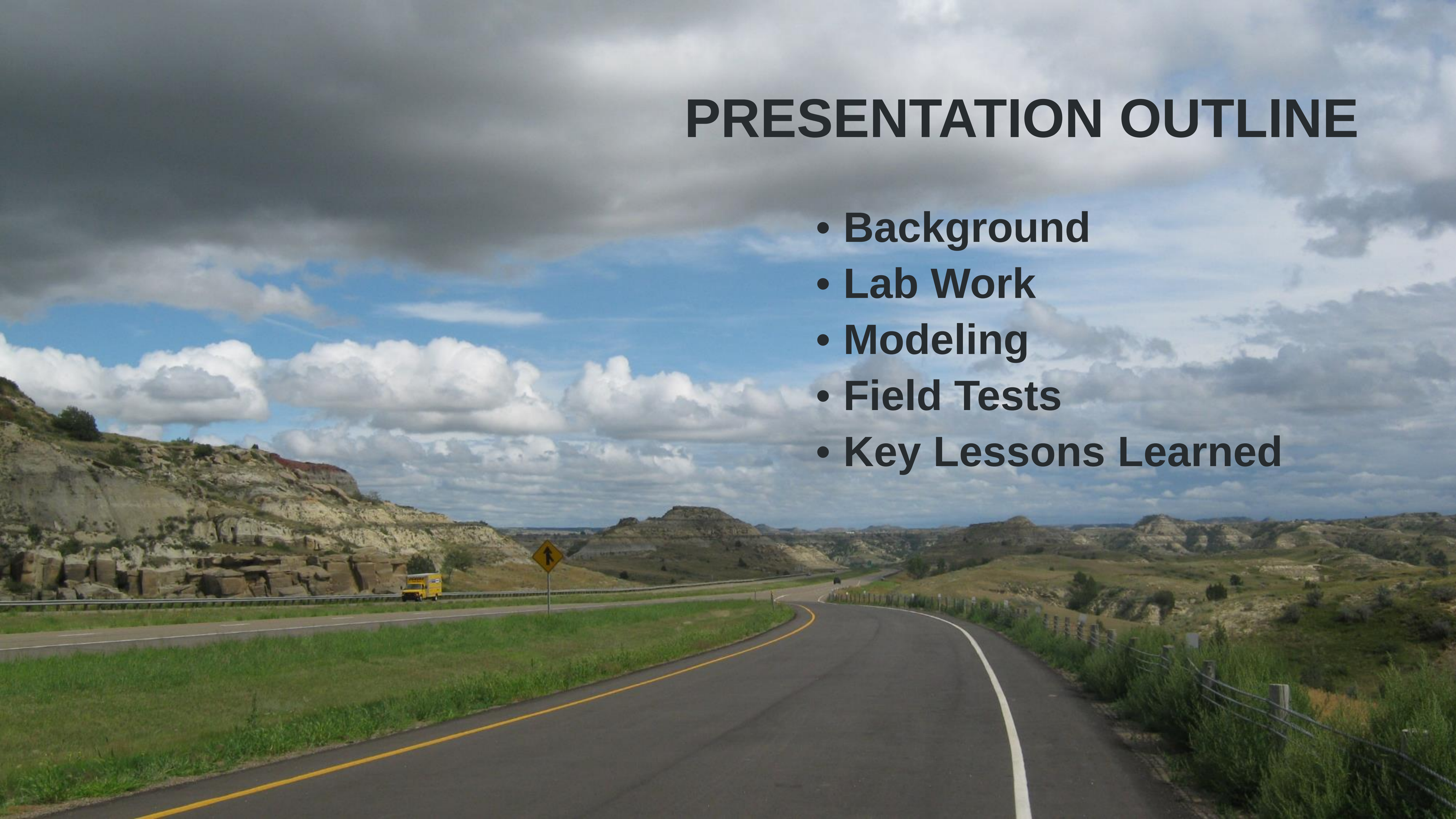
BAKKEN RICH GAS EOR PROJECT

U.S. Department of Energy National Energy Technology Laboratory
Addressing the Nation's Energy Needs Through Technology Innovation – 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting
August 26–30, 2019

Jim Sorensen
Interim Director for Subsurface R&D

PRESENTATION OUTLINE

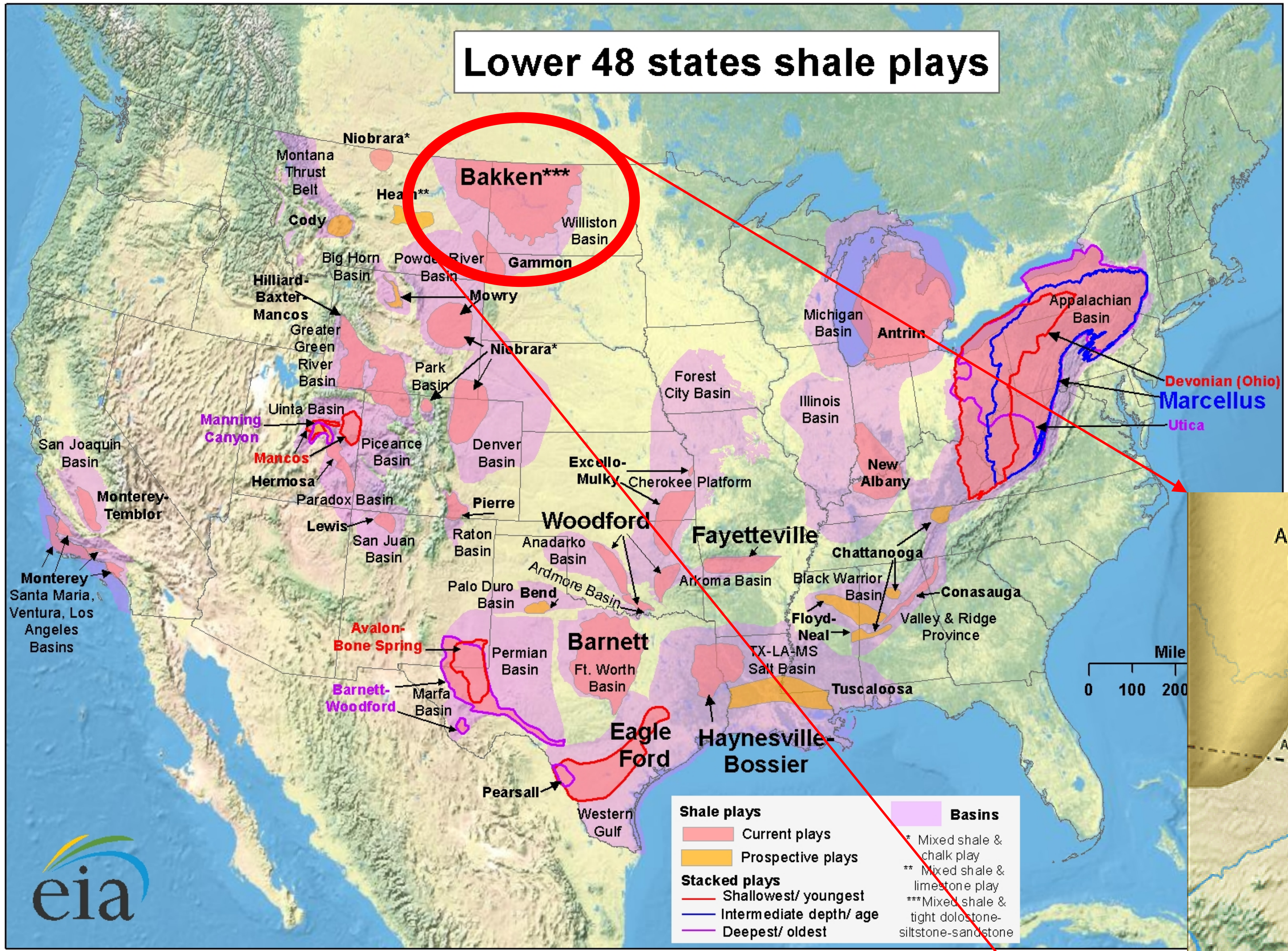
- Background
- Lab Work
- Modeling
- Field Tests
- Key Lessons Learned



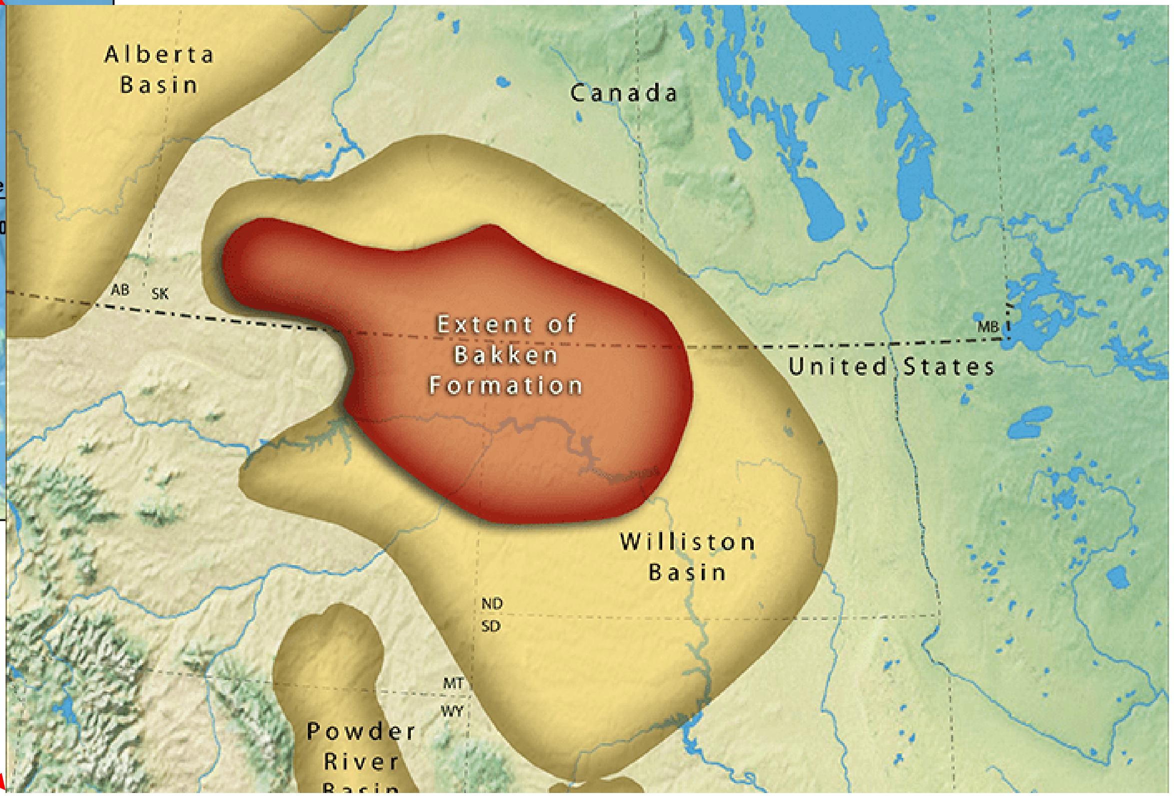
The Bakken Play

Oil production currently

- **1.4MM bbl/day**
- from **>15,000 horizontal wells**.

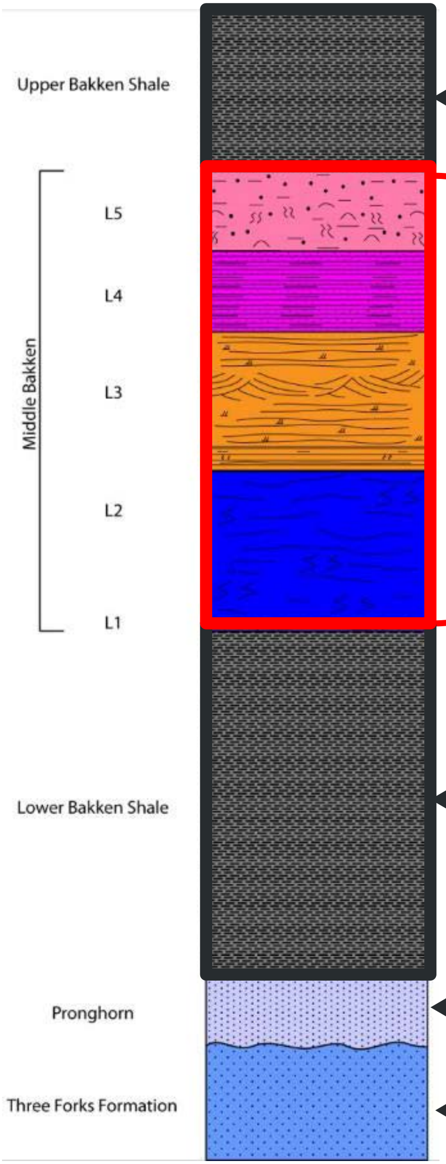


Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011



Deposited during Late Devonian to Early Mississippian.

LITHOLOGY OF THE BAKKEN SYSTEM



Drilling Targets

Upper Bakken Shale: Brown to black, organic-rich.
- **Bakken source rock**

Middle Bakken: Variable lithology (up to 9 lithofacies), ranging from silty sands to siltstones and tight carbonates
- **Bakken tight reservoir rock (horizontal drilling target)**

Lower Bakken Shale: Brown to black, organic-rich
- **Bakken source rock**

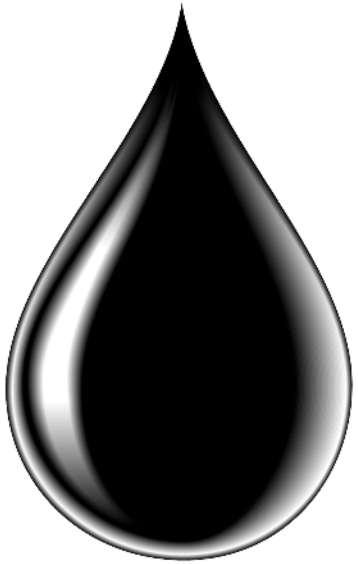
Drilling Targets

Pronghorn Member: Mixed sandstone, siltstone, dolomite, and shale.

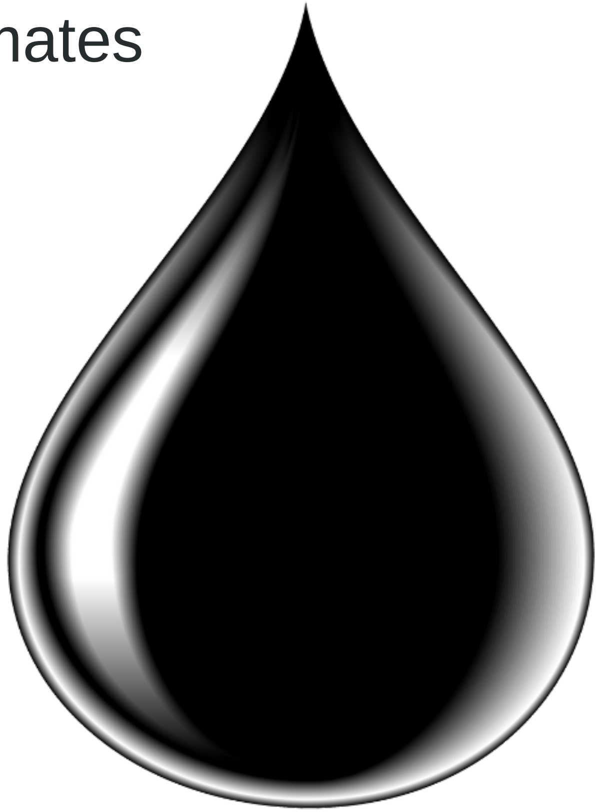
Three Forks Formation: Interbedded dolostone/limestone, siltstone/mudstone, shale, evaporites.

BACKGROUND – BAKKEN EOR SIZE OF THE PRIZE

OOIP Estimates



300 Bbbl
(Flannery and Kraus, 2006)



900 Bbbl
(Continental Resources, 2011)

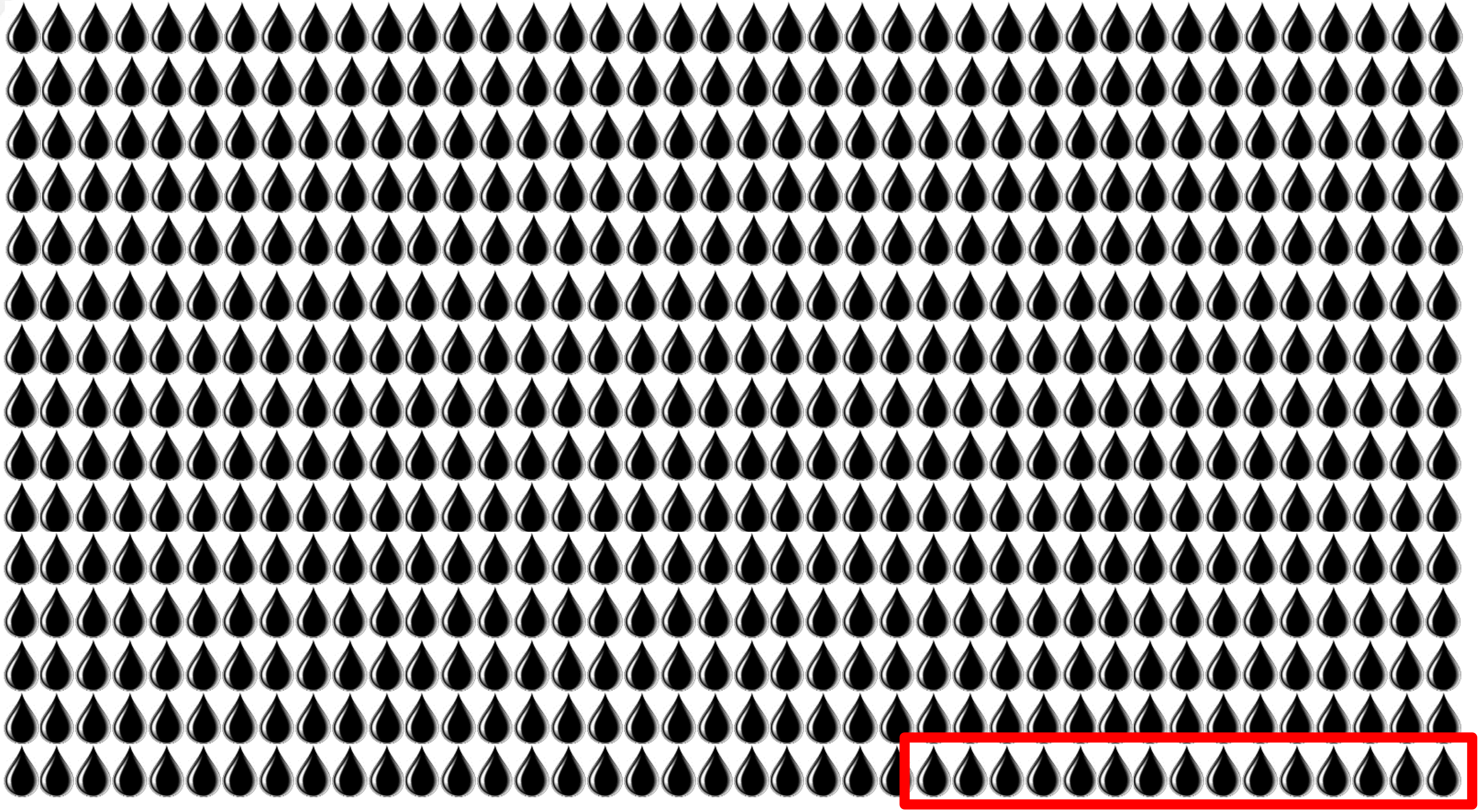
Technically Recoverable Reserve Estimates

7.4 Bbbl
(USGS, 2013)

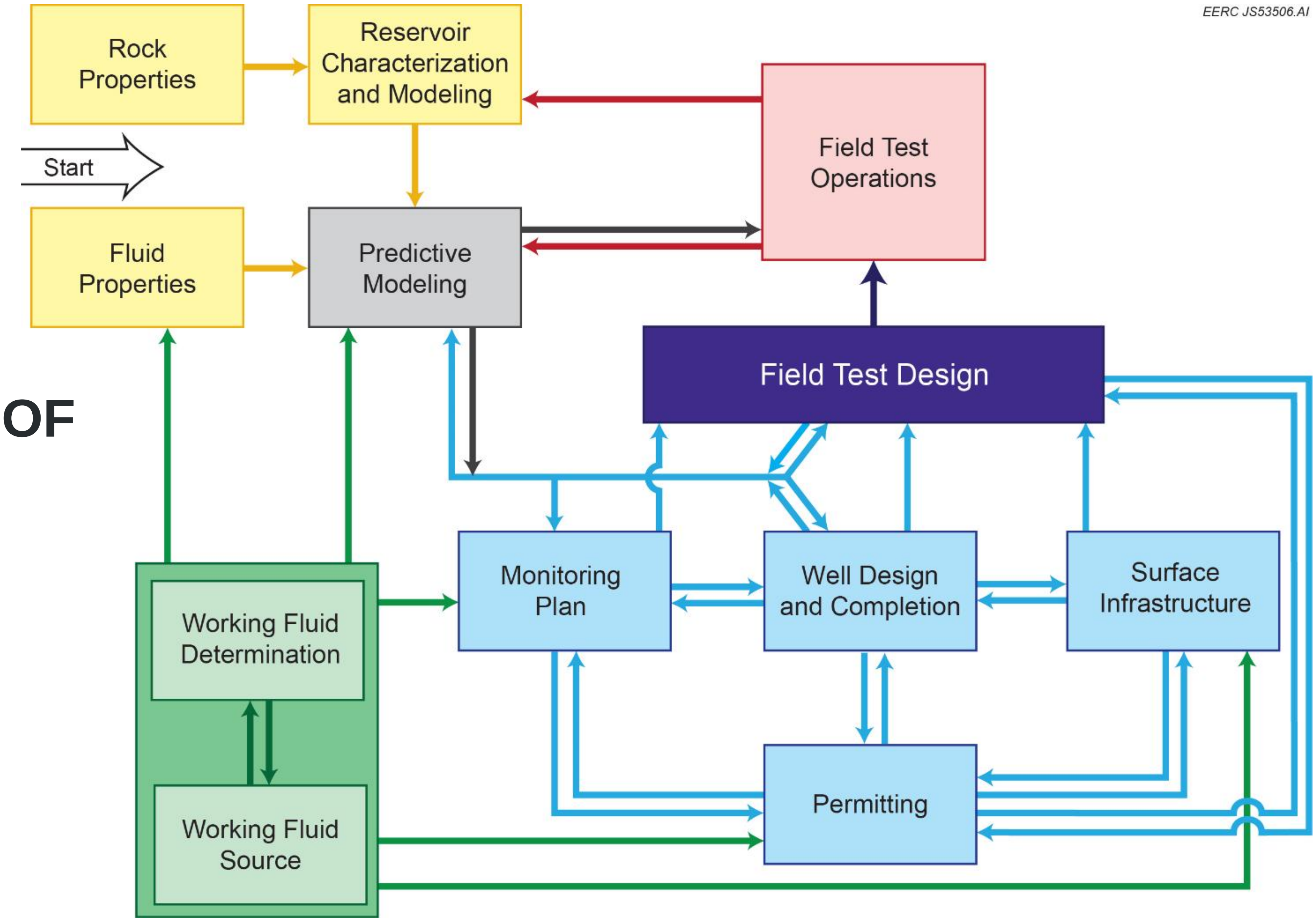
24 Bbbl
(Continental Resource, 2011)

Business as usual gets about 15 billion barrels

LEAVES A LOT OF OIL… HOW DO WE GET MORE?



COMPONENTS OF AN EOR PILOT



STOMPING HORSE OIL FACTORY NORTH DAKOTA

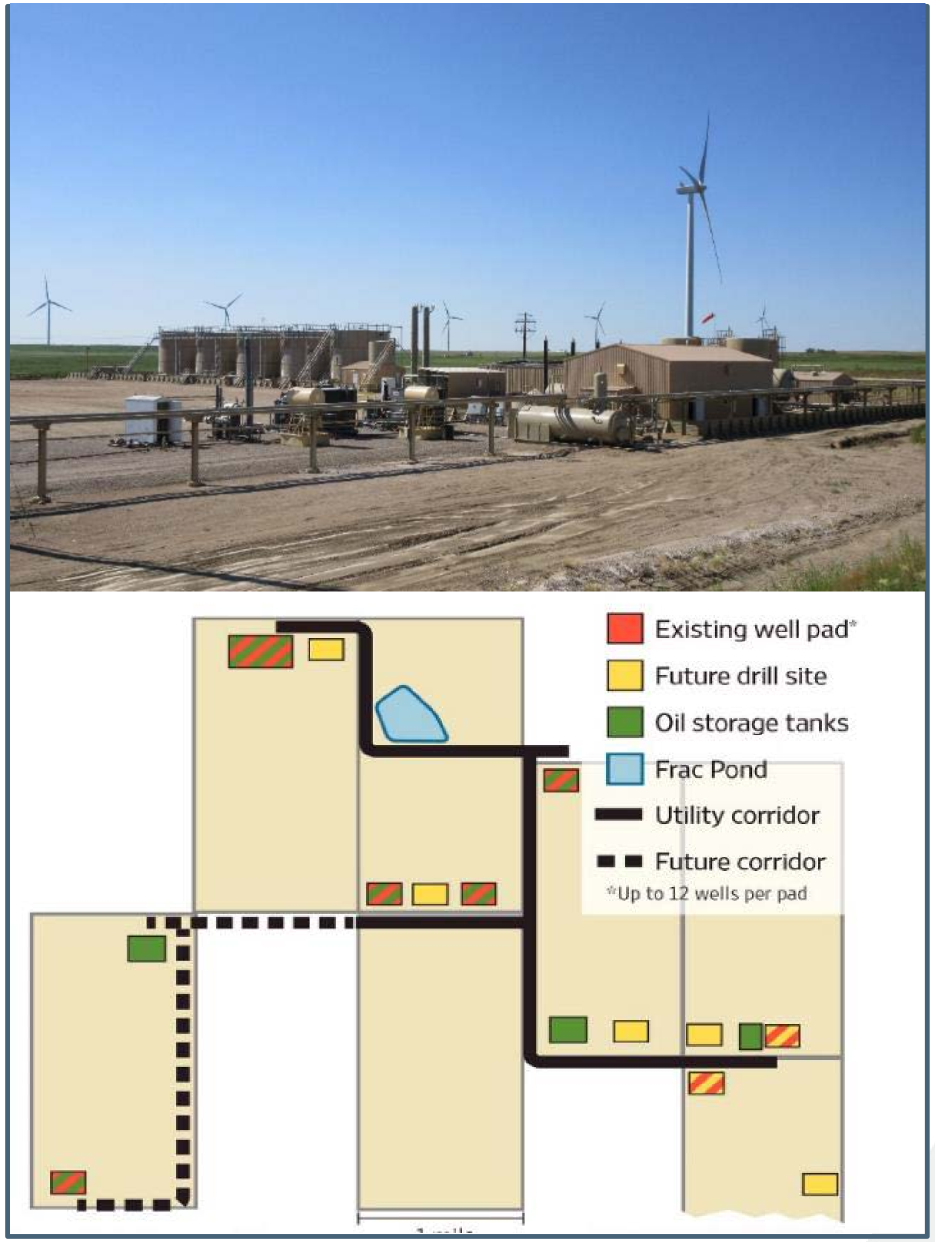
- A methodical, structured approach to oilfield development
- Maximizing field and DSU productivity, ***including the use of rich gas for EOR***

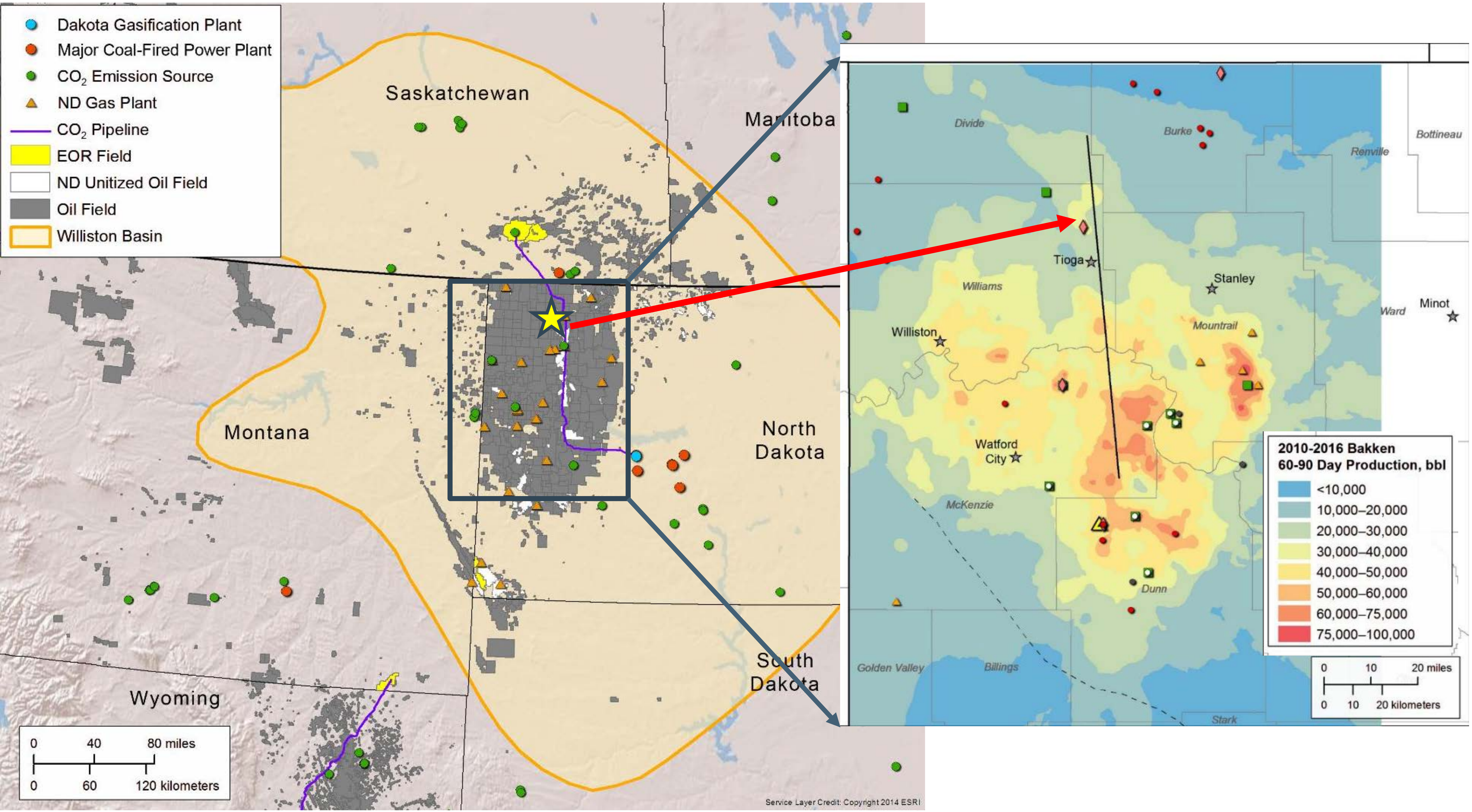
- Liberty approached the EERC in December 2016 to explore partnering on an EOR test at Stomping Horse.
- In 2017 DOE NETL and the North Dakota Oil & Gas Research Program provided funding.

LIBERTY RESOURCES

NETL

North Dakota oil & gas research program





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
Minot
Ward
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

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.**
- **Determine the sorptive capacity of Bakken shales for rich gas components and the effects of sorption in the shales on gas utilization rates.**

STOMPING HORSE RICH GAS COMPOSITIONS

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

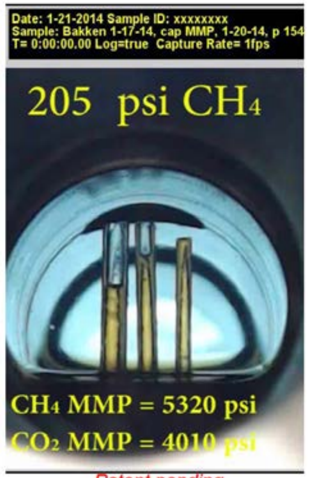
	WELLHEAD	PLANT INLET	DEETHANIZER	PLANT EXIT
METHANE	60%	62.7%	51%	71%
ETHANE	20%	21.4%	46%	22%
PROPANE	10%	11.4%	0.5%	2.0%
C4+	1.4%	1.2%	0.0%	1.6%
CO2	0.8%	0.9%	1.3%	1.0%
BTU	~1500	~1450	~1300	~1175

Lab Test
Gas Mix =

Methane 68%
Ethane 22%
Propane 10%

RICH GAS–OIL FLUID BEHAVIOR AND ROCK EXTRACTION STUDIES

MMP Studies



Patent pending

Minimum miscibility pressure (MMP) of crude oil with rich gas components and different rich gas mixtures.

- Methane, ethane, and propane.

~ Eighty MMP determinations done.

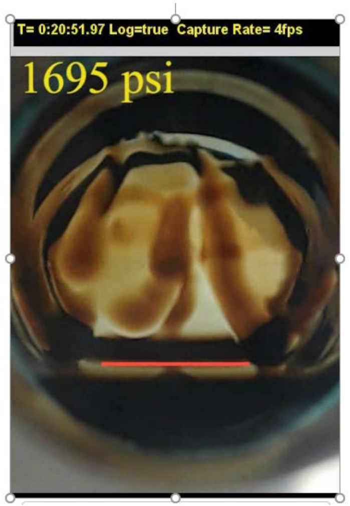
(Capillary-rise, vanishing interfacial tension measurements of MMP, EERC patent US 9851339)

Rock Extraction Studies

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

- Methane, ethane, and propane at reservoir conditions.
- *(2018 URTeC 2671596)*

Miscible Behavior Studies

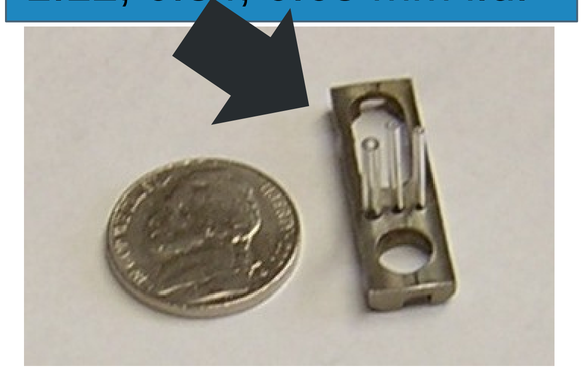


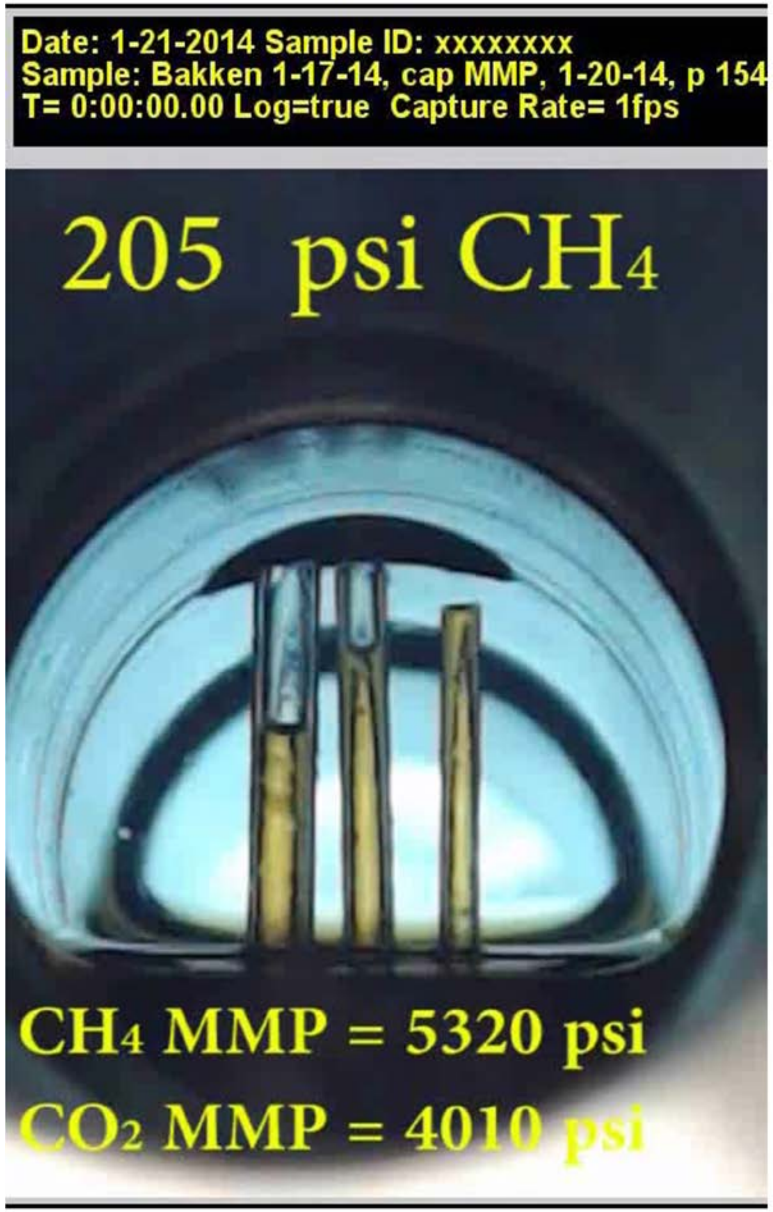
Which hydrocarbons partition into this "miscible" upper phase?

Which hydrocarbons are lost as pressure drops?

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

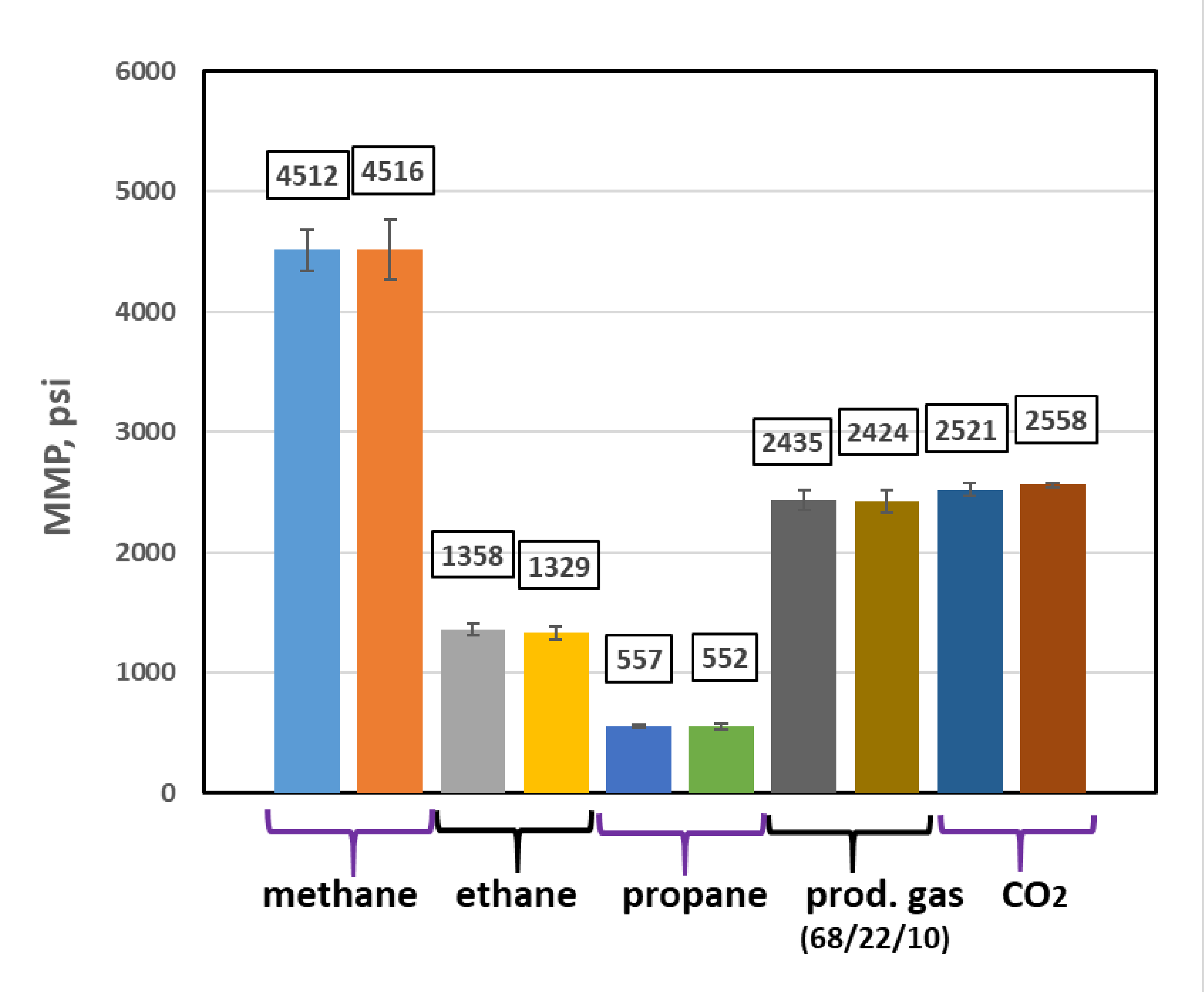
energy&fuels

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

U.S. Patent 9,851,339

BAKKEN CRUDE OIL MMP WITH METHANE, ETHANE, PROPANE, PRODUCED GAS MIXTURE, AND CO_2

All MMPs determined in duplicate at 110°C, 230°F. (Error bars represent SDs from the three capillaries in each experiment.)



The richer the gas, the lower the MMP!!

Stomping Horse wellhead produced gas mixture and CO_2 have similar MMP.

* CO_2 MMPs were determined as part of a previous project under separate funding from the DOE and are presented only for comparison purposes.

ROCK EXTRACTION STUDIES

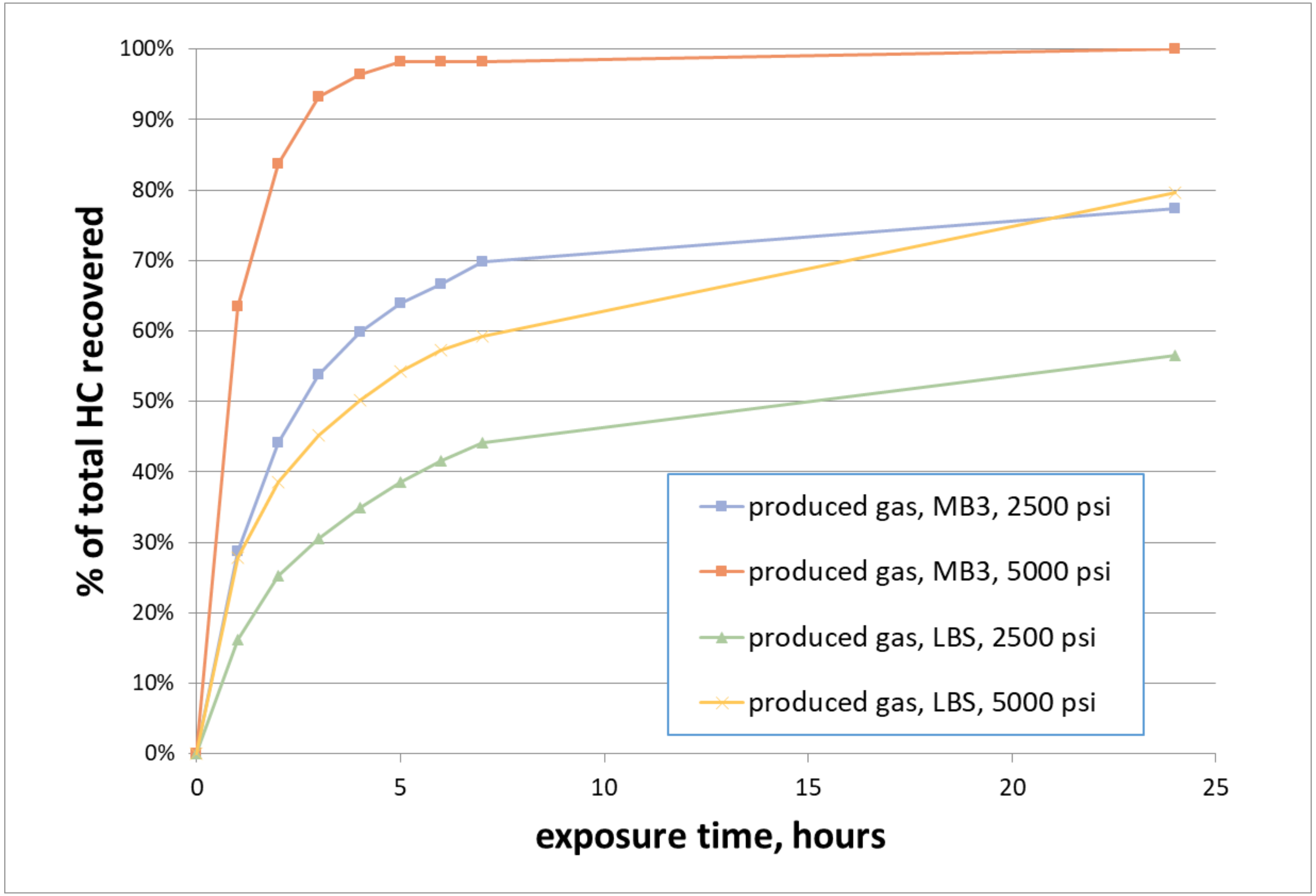
Determine ability of methane, ethane, and propane at different pressures to recover hydrocarbons from Middle Bakken and Bakken Shale rock samples

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, 230ºF (110ºC).

Total hydrocarbon recovery from Middle Bakken and Lower Bakken Shale with produced gas is best with higher pressures.

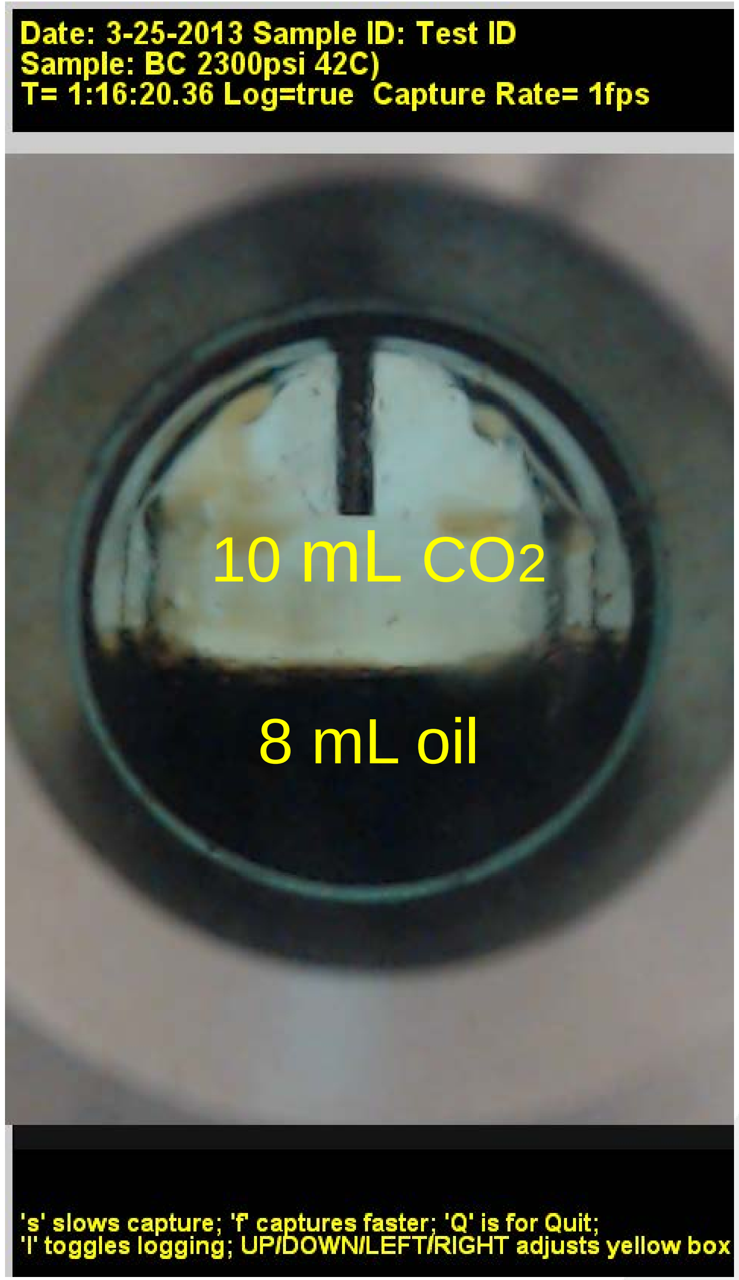


Detailed description of method and results can be found in URTeC 2671596.

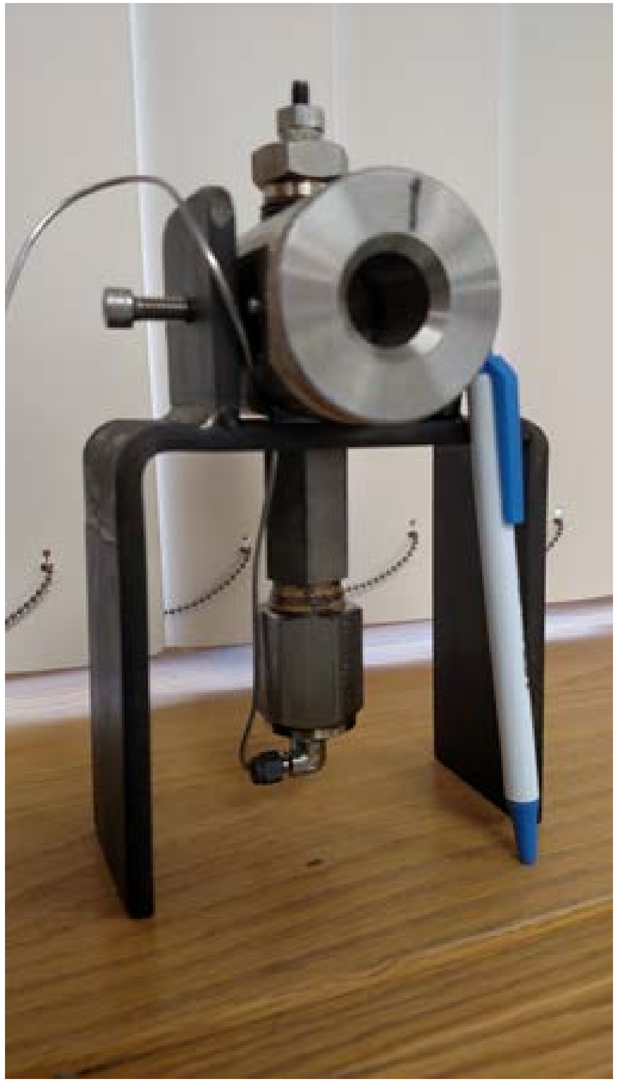
MISCIBLE BEHAVIOR STUDIES

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?



WHICH CRUDE OIL HYDROCARBONS ARE DISSOLVED INTO THE GAS-DOMINATED UPPER "MISCIBLE" PHASE?

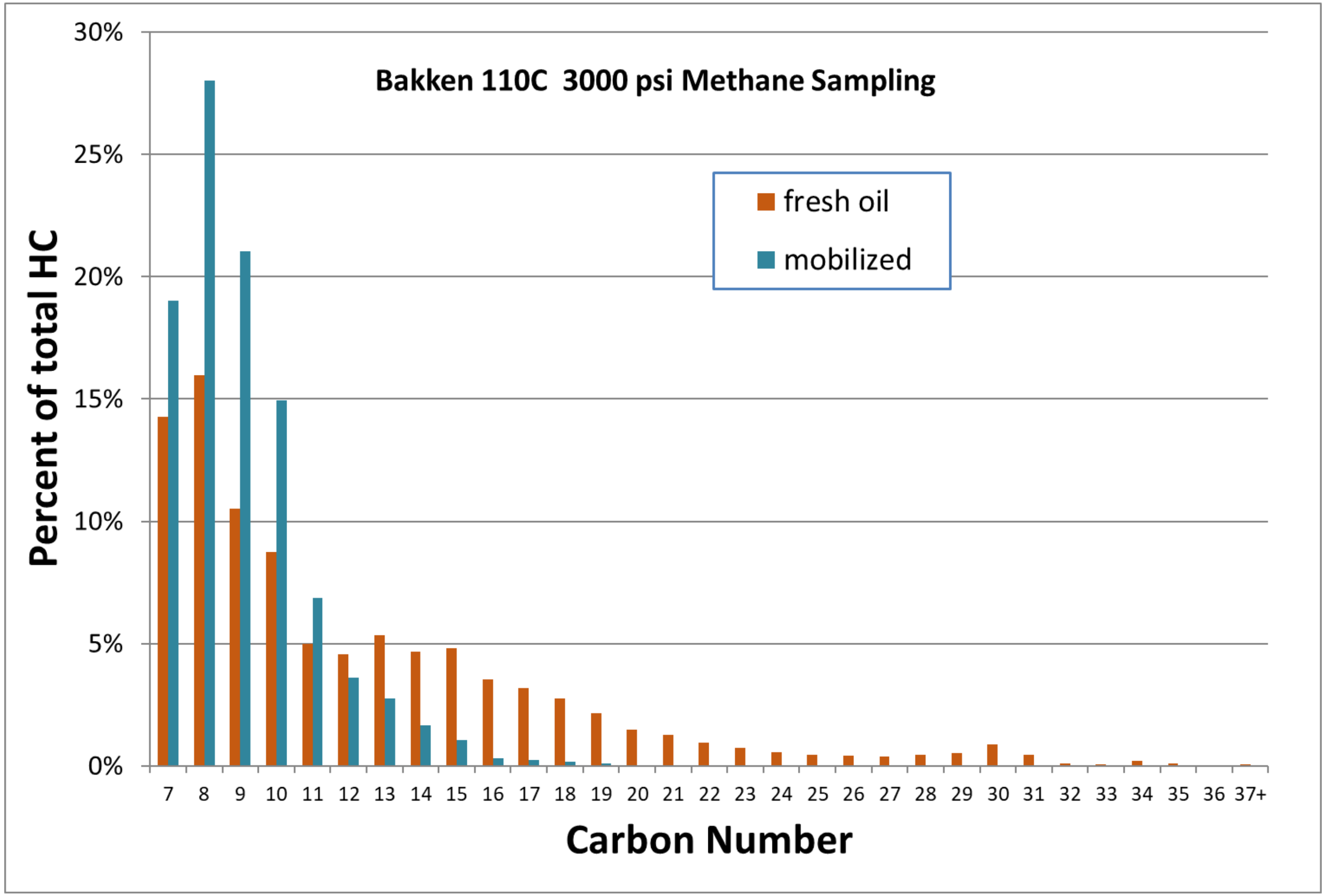


1. The gas is percolated through an oil column and equilibrated at reservoir temperature and pressure.

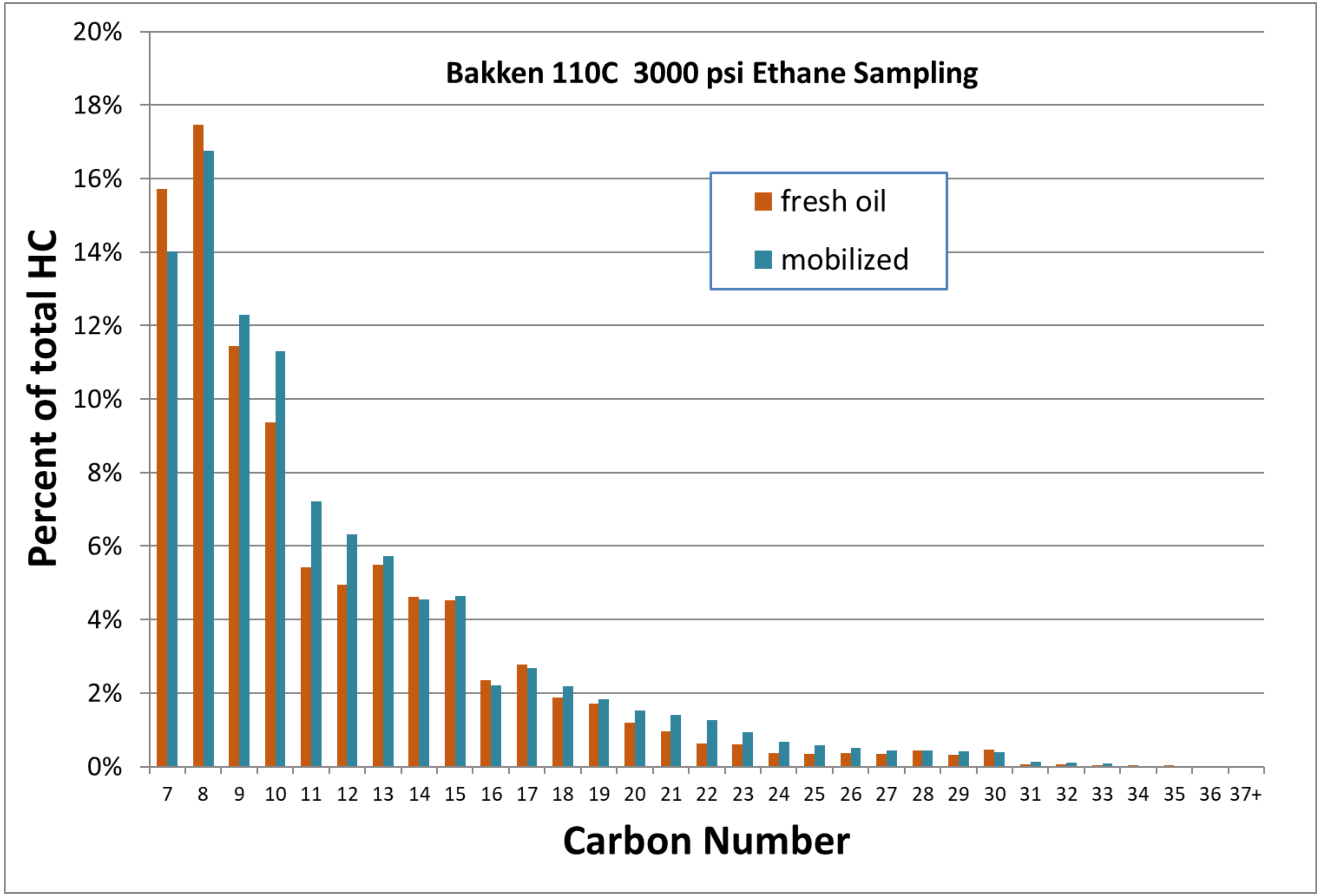
2. The upper "miscible" phase is sampled while maintaining reservoir T and P.

3. Dissolved hydrocarbons are collected analyzed by GC/FID.

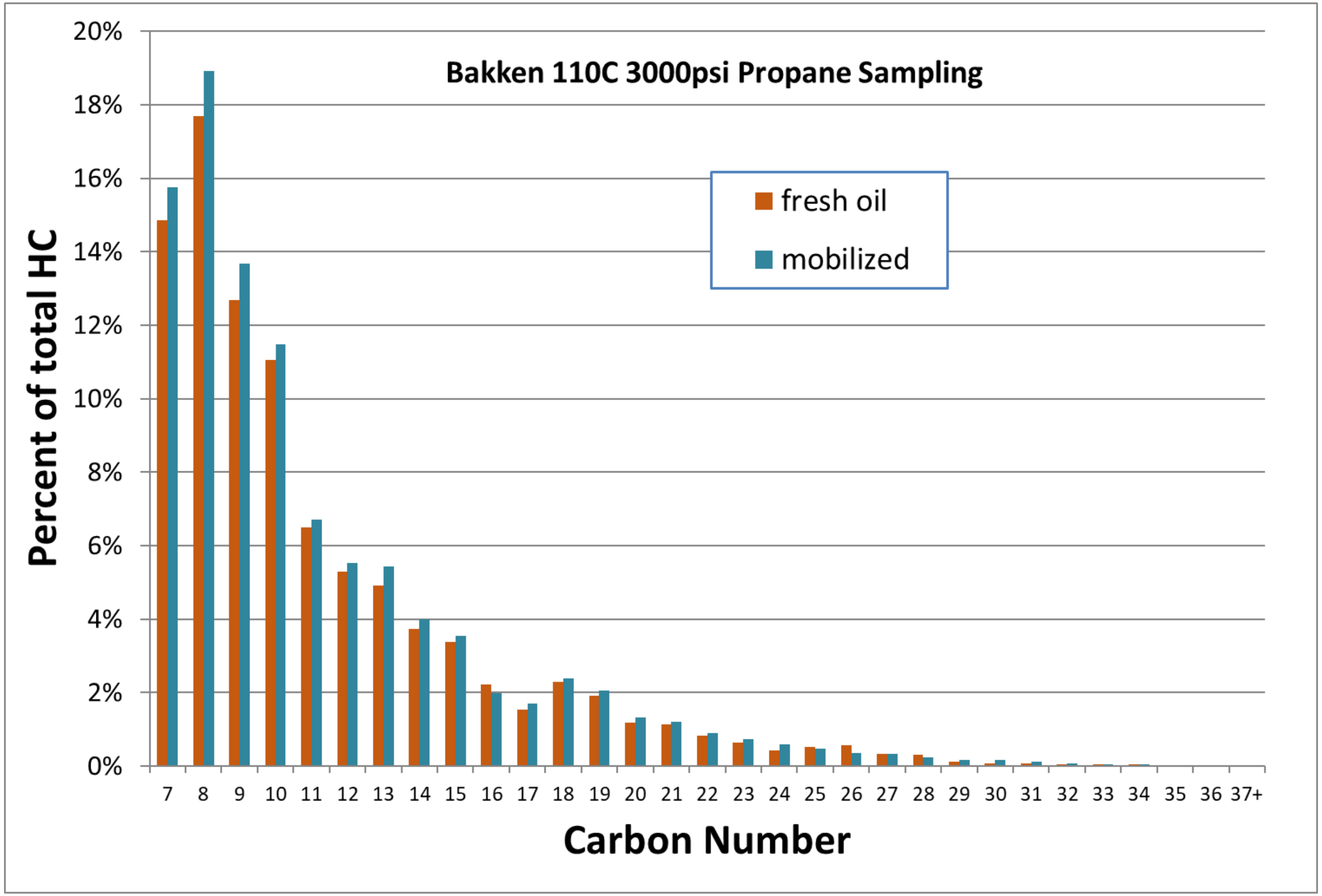
HYDROCARBON MOLECULAR SIZE MOBILIZED BY METHANE



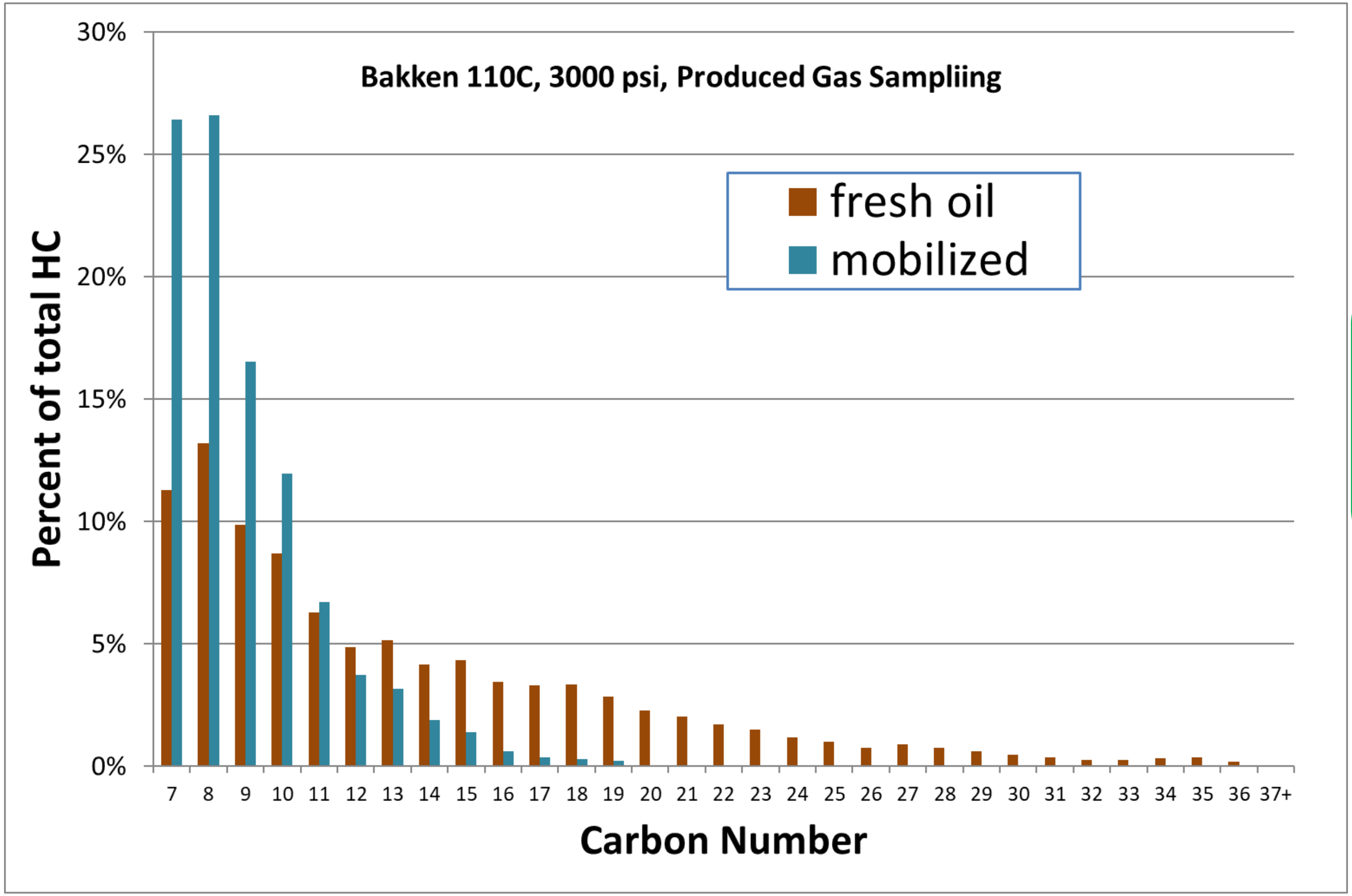
HYDROCARBON MOLECULAR SIZE MOBILIZED BY ETHANE



HYDROCARBON MOLECULAR SIZE MOBILIZED BY PROPANE



HYDROCARBON MOLECULAR SIZE MOBILIZED BY PRODUCED GAS



Produced Gas Mix
Methane 68%
Ethane 22%
Propane 10%

How effective are methane, ethane, propane, and C1/C2/C3 produced gas at mobilizing higher-MW hydrocarbons into the "miscible" phase?

At 3000 psi, ethane and propane efficiently mobilize the heavier hydrocarbons (determined up to C36) effectively, but ethane is less efficient at lower pressures.

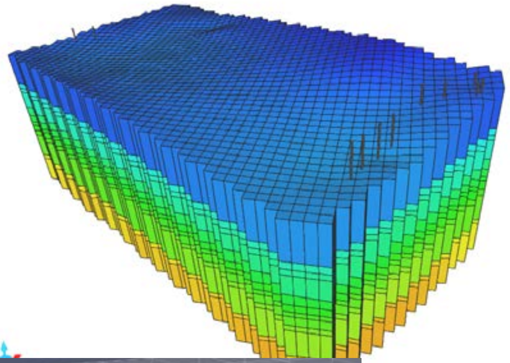
Methane ONLY mobilizes low-MW hydrocarbons (smaller than ca. C12) at any pressure, leaving most mid- and higher-MW hydrocarbons in the reservoir.

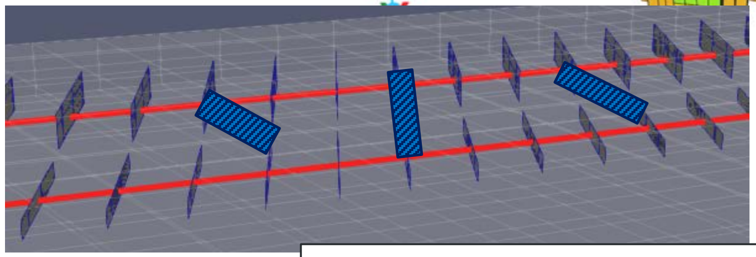
Produced gas is better than methane at 3000 psi.

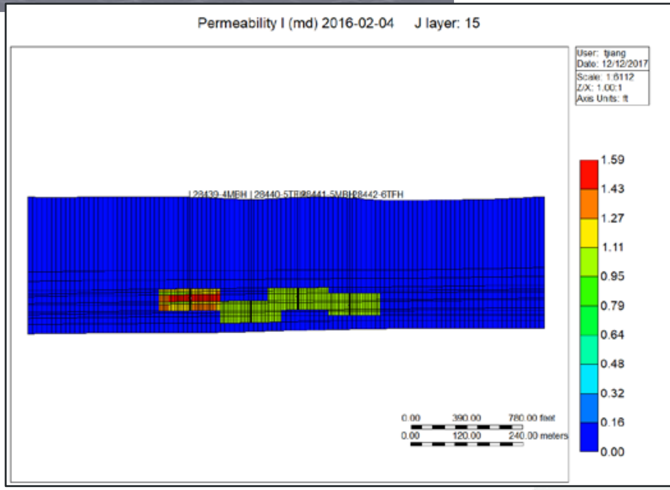
STATIC AND DYNAMIC MODELING OF EOR SCHEMES AT STOMPING HORSE

Bakken Reservoir Modeling and Simulations

- The EERC worked closely with the Liberty Resources (LR) geoscience team to build static geocellular models 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).
  - **Mechanistic model showed that gas injection could improve oil recovery up to 26%.**
  - **Surface infrastructure modeling predicts rich gas EOR will not adversely affect Stomping Horse surface facility operations.**

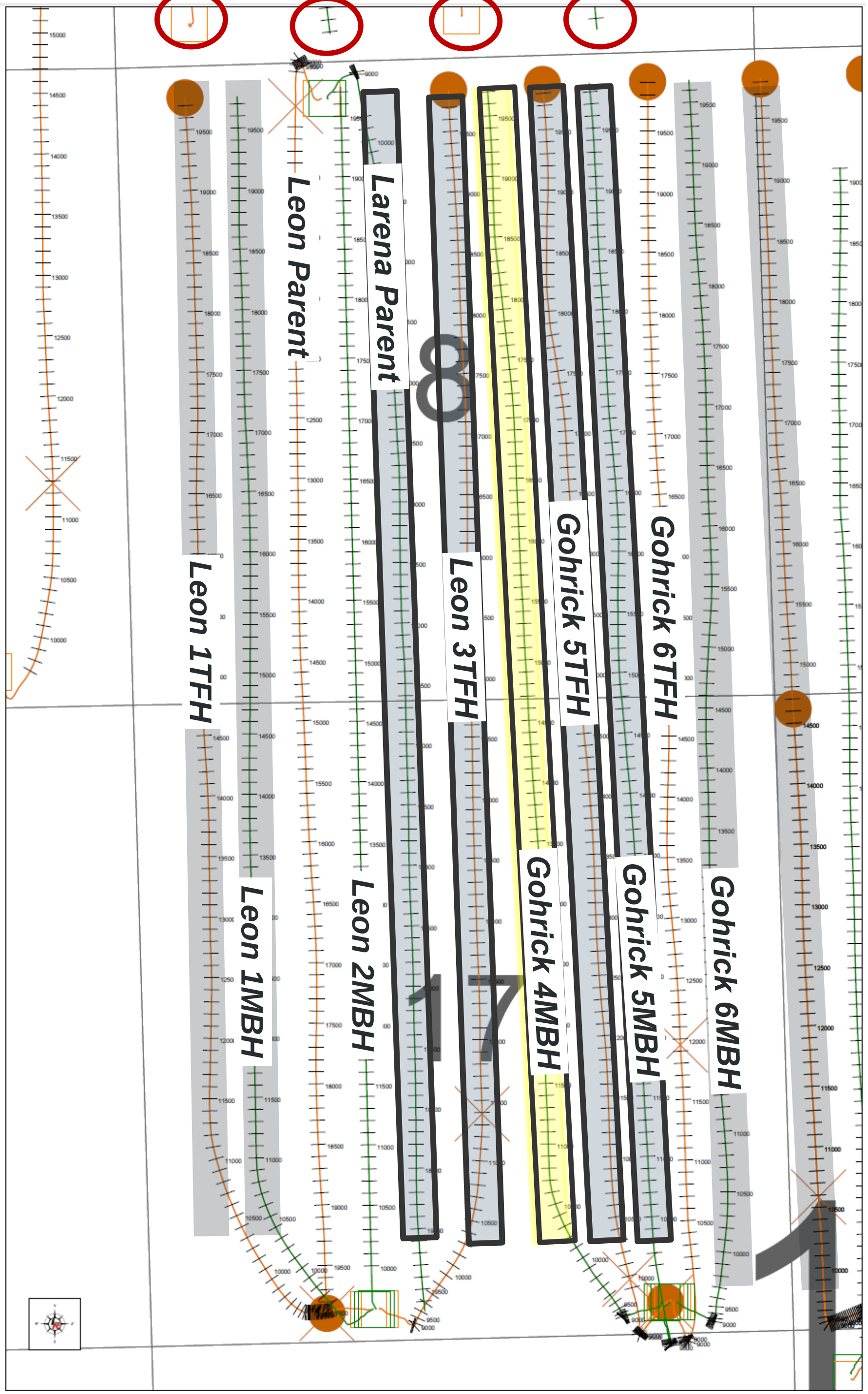






MULTIWELL PILOT LAYOUT

- Only gas from the DSU can be used for injection.
- Jet pumps are used for artificial lift.
  - Allow for quick switch from producer to injector.
  - Can complicate fluid data interpretation.
- Wells were completed using plug and perf, with cemented liners to improve conformance.



Leon & Gohrick Pads

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

PILOT TESTS - COMPRESSOR PACKAGES

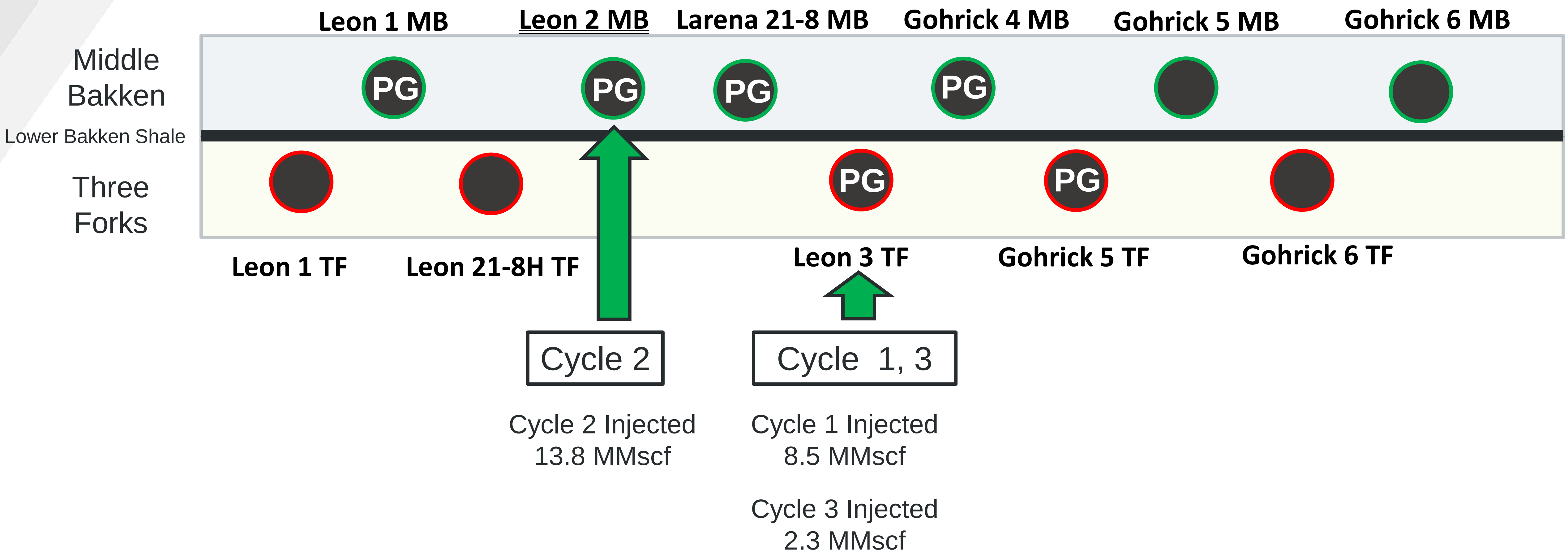
- **SUMMER 2018 TESTS**
  - Two rental gas lift compressors
  - 1400 psi wellhead pressure max.
  - 1.4 MMscfd max. design rate (2 units combined)
  - Max. rate achieved: 1.14 MMscfd

- **FALL 2018 to SPRING 2019 TESTS**
  - Refurbished compressor
  - Permitted max. allowed inj. P = 5000 psi
  - Max. design rate = 4200 psi
  - Max. design injection rate = 3.0 MMscfd

PILOT PERFORMANCE ASSESSMENT

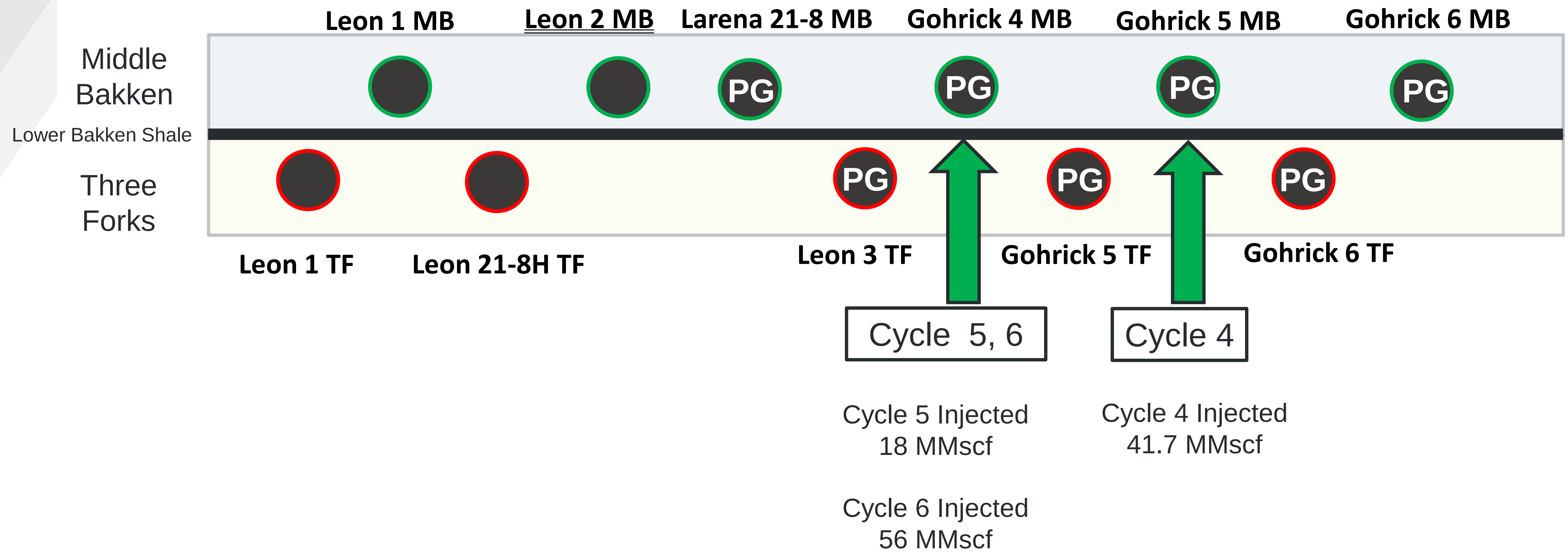
- **Reservoir surveillance and monitoring activities:**
  - ✓Oil, gas, and water rates are being monitored continuously from Liberty-operated wells.
  - ✓The four wellbores immediately offset the injector well have daily samples for gas chromatography (GC).
  - ✓The four wellbores immediately offset the injector (pattern allowing) are equipped with bottomhole pressure gauges.
  - ✓The offset operator to the north is providing operational information.
  - ✓Tracer studies.

SUMMER 2018 INJECTION TESTS



Average distance between two adjacent wells is ~400 ft.
Average distance between two wells in the same formation is ~800 ft.

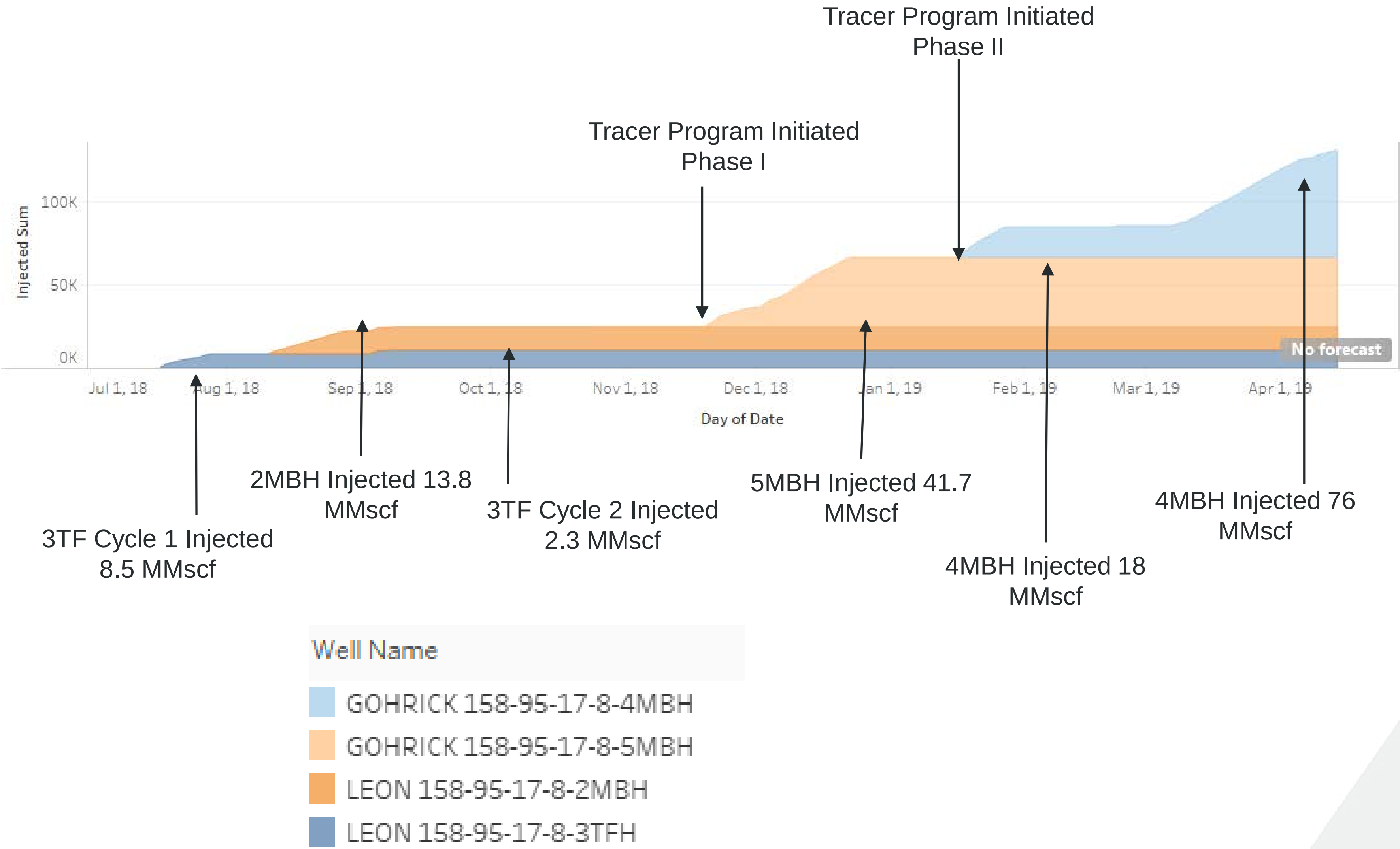
FALL 2018 – SPRING 2019 INJECTION CAMPAIGN



Average distance between two adjacent wells is ~400 ft.
Average distance between two wells in the same formation is ~800 ft.

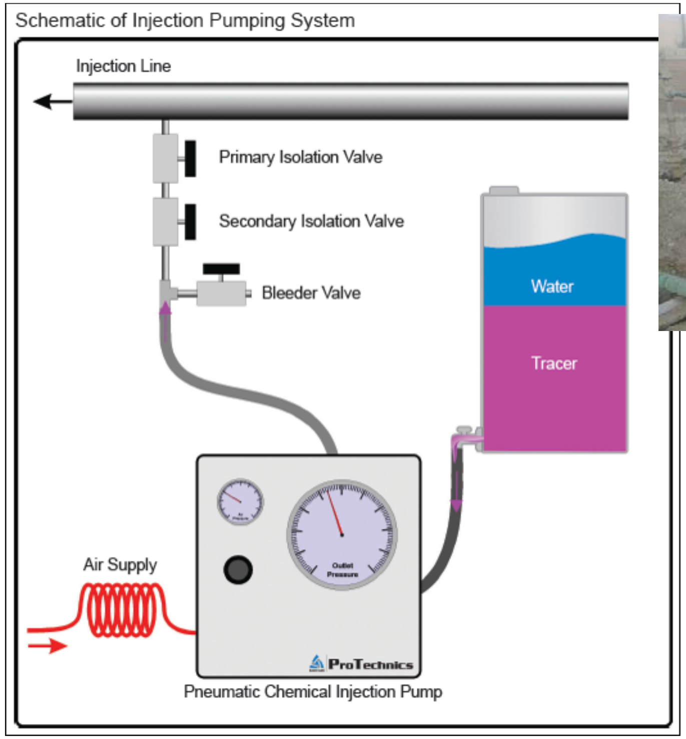
INJECTION TEST TIME LINE

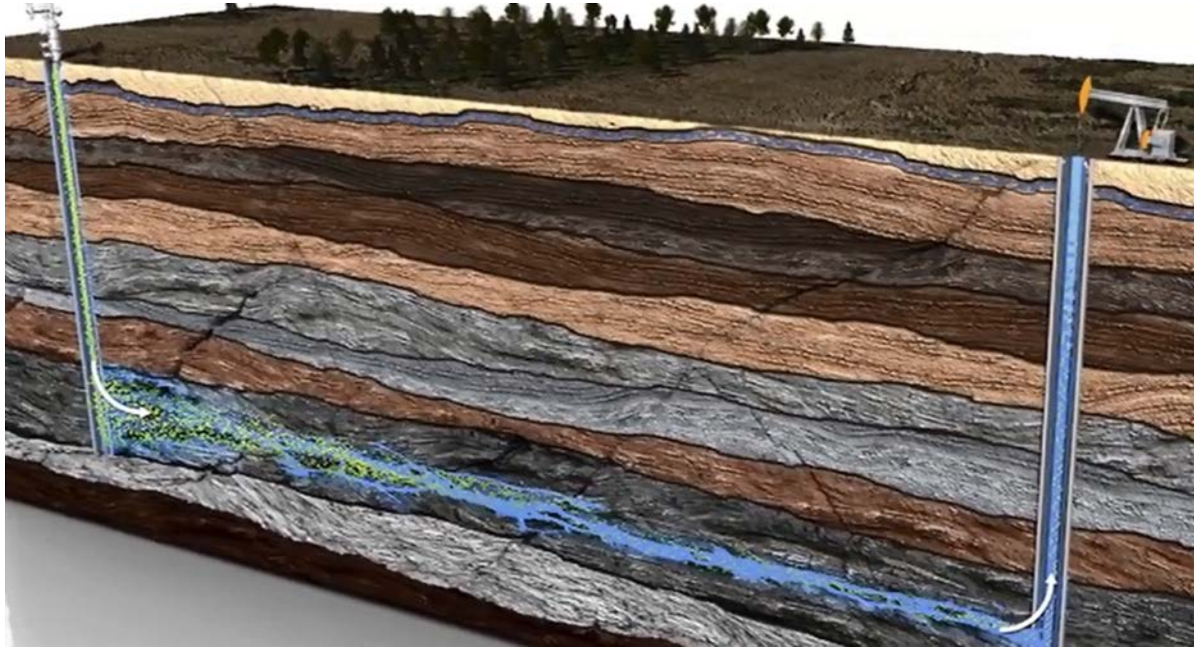
- Initial small-scale tests in Leon wells largely to investigate injectivity.
- Larger-scale injection in Gohrick wells to investigate pressure buildup and conformance.
- Tracer program initiated in Gohrick wells.
- **As of May, total of ~160 MMscf gas injected in five wells during six different injection periods.**



EOR INJECTION TRACER STUDY

- To help understand gas, oil, and water contact interactions and interwell flow dynamics during the EOR injection process.
  - The tracer compound injection was implemented in two phases.
    - **Phase I** was the injection of a **gas-specific tracer compound-only** during the first well injection activity using the large compressor (cycle 4).
    - **Phase II** was the injection of **gas-, oil-, and water-specific tracer compounds** during the second well injection activity using the large compressor (cycle 5).
    - **Results are pending.**





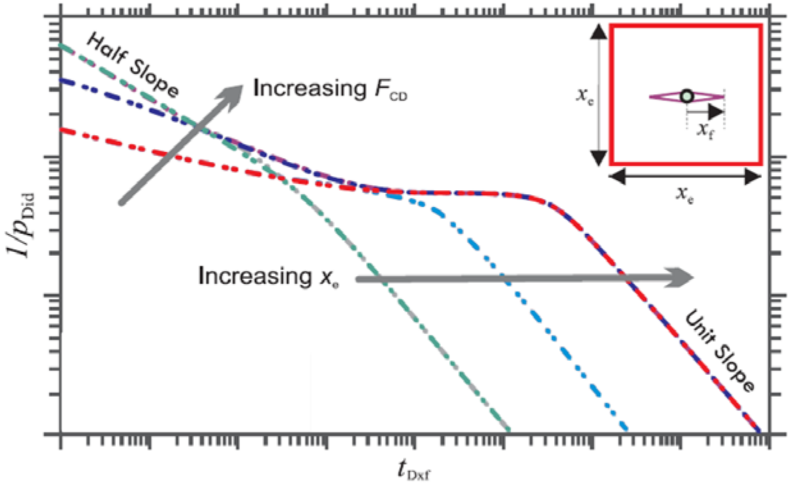
HOW DO WE ASSESS PILOT PERFORMANCE?

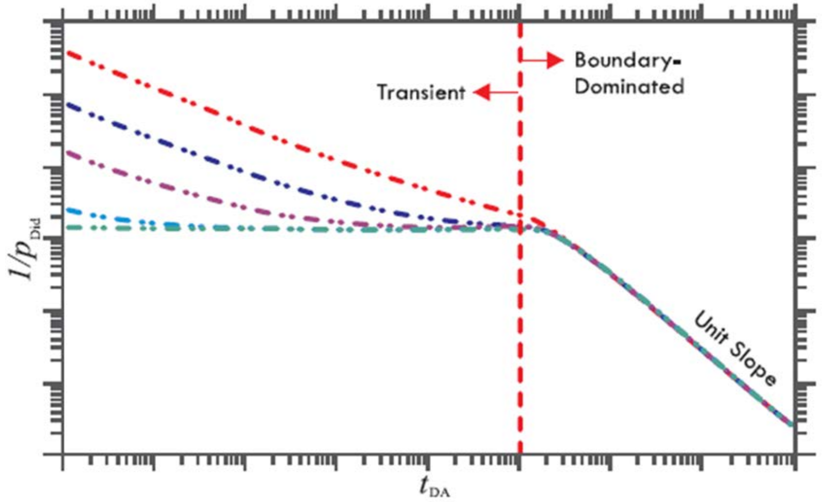
Monitoring Key Performance Indicators:

- Changes in injection pressure
- Changes in oil productivity
- Changes in gas/oil ratio (GOR)
- Changes in rich gas composition
- Changes in oil production rate
- Changes in produced gas composition
- Changes in molecular weight distribution in produced oil

Reservoir Analytical Approaches:

- Tracer analysis
- Material balance analysis
- Breakthrough analysis
- Decline analysis
- RTA/PTA continues as pressure data become available



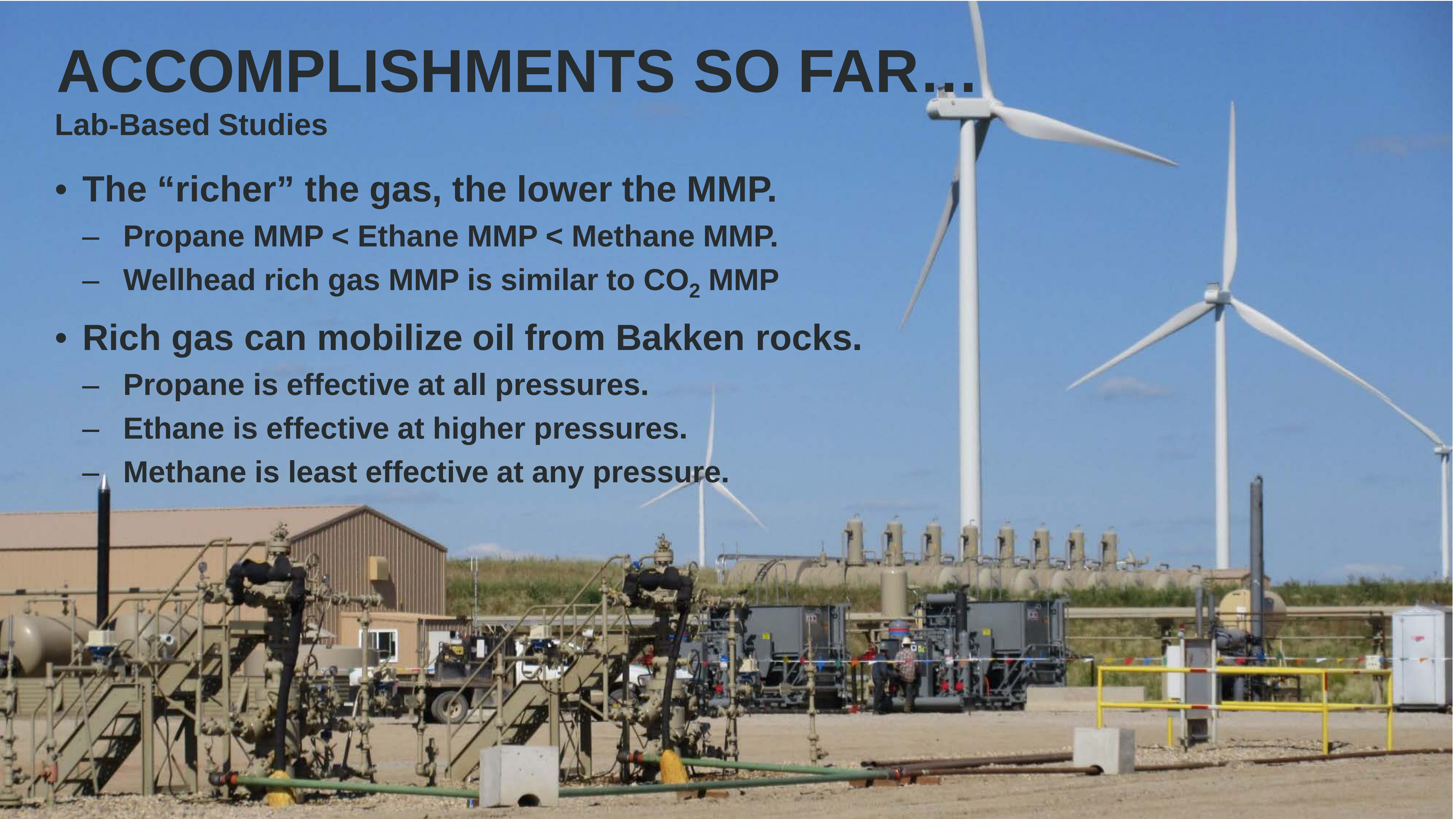


Example of Rate Transient Analysis

ACCOMPLISHMENTS SO FAR…

Lab-Based Studies

- **The “richer” the gas, the lower the MMP.**
  - Propane MMP < Ethane MMP < Methane MMP.
  - Wellhead rich gas MMP is similar to CO_2 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.



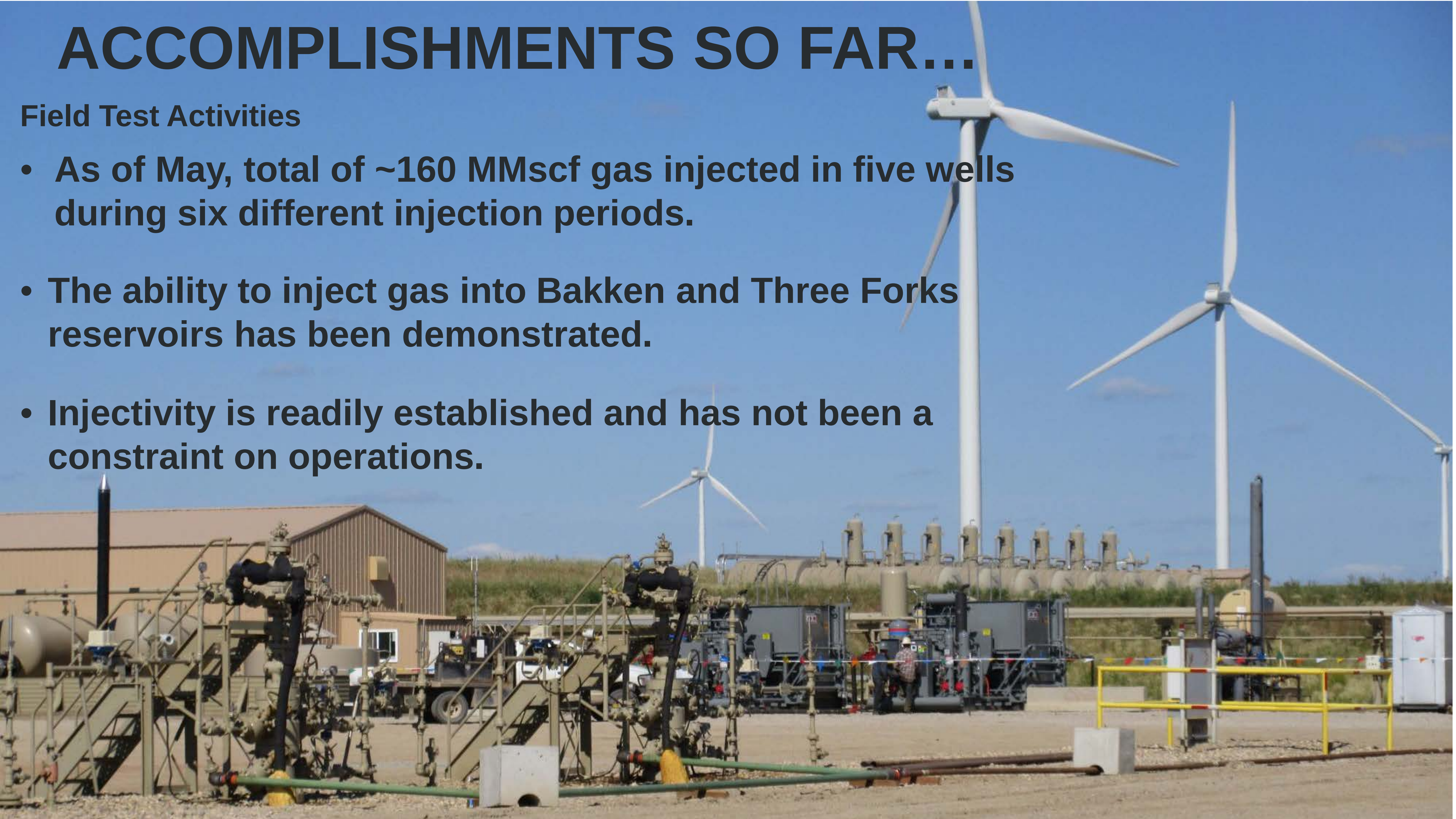
ACCOMPLISHMENTS SO FAR…

Field Test Activities

- As of May, total of ~160 MMscf gas injected in five wells during six different injection periods.

- The ability to inject gas into Bakken and Three Forks reservoirs has been demonstrated.

- Injectivity is readily established and has not been a constraint on operations.



ACCOMPLISHMENTS SO FAR…

Field Test Activities

- **Reservoir surveillance and monitoring demonstrate the injected gas can be controlled and has been contained within the DSU.**

- **Pressure buildup is occurring and is showing a positive trend towards achieving MMP.**

KEY LESSONS FOR FUTURE PILOTS IN UNCONVENTIONALS

- **Adequate supply of working fluid is essential.**
- **Start with reservoir pressures that are relatively close to MMP.**
- **The lab work has made valuable contributions to pilot design and operation.**
- **Real-time data coupled with big data analytics and machine learning would enable a framework to better monitor and enhance pilot analysis.**

Jim Sorensen
Interim Director for Subsurface R&D
jsorensen@undeerc.org
701.777.5287 (phone)

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

www.undeerc.org
701.777.5000 (phone)
701.777.5181 (fax)

THANK YOU

Critical Challenges. Practical Solutions.

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