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UNIVERSITY OF NORTH DAKOTA

Critical Challenges. Practical Solutions.

Energy & Environmental Research Center (EERC)

BAKKEN CO_2 STORAGE AND ENHANCED RECOVERY PROGRAM

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James Sorensen, Lonny Jacobson, Larry Pekot, José Torres, Lu Jin, John Hamling, Tom Doll, Agustinus Zandy, Steve Smith, Jib Wilson, Steve Hawthorne, Beth Kurz, John Harju, Ed Steadman, and Charlie Gorecki

U.S. Department of Energy
National Energy Technology Laboratory
Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
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Critical Challenges. Practical Solutions.

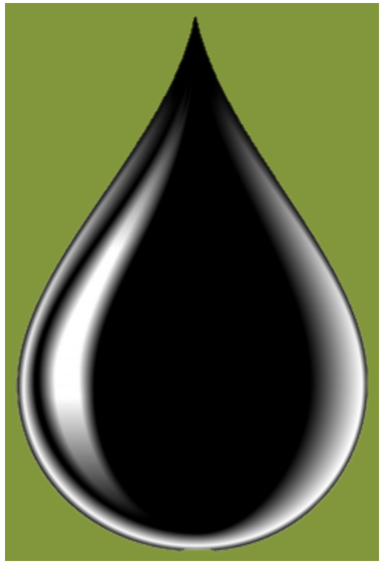
PRESENTATION OUTLINE

- **Background**
- **Project Overview**
- **Key Lessons Learned**
- **Project Summary**

TECHNICAL STATUS

BAKKEN PETROLEUM SYSTEM – 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)

- Currently, <10% recovery factor.
- Can CO_2 work in the Bakken?

BAKKEN CO_2 STORAGE AND EOR CONSORTIUM – PHASE I (2012-2014) AND PHASE II (2014–2018)

Goal: Generate data and insight regarding the use of CO_2 for Bakken EOR and CO_2 storage and support the deployment of CO_2 injection operations for storage and EOR.

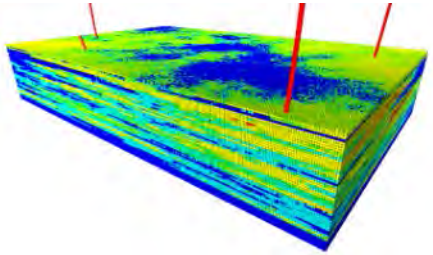
BAKKEN CO_2 STORAGE AND ENHANCED RECOVERY PROGRAM – LAB & MODELING

Laboratory evaluations:

- Rock matrix and natural fractures.
- Ability of CO_2 to mobilize oil from tight shale and nonshale.
- MMP testing.

Static and dynamic modeling.

Case study of pilot injection tests, including CO_2, in North Dakota and Montana Bakken wells.



ROCK EXTRACTION STUDIES

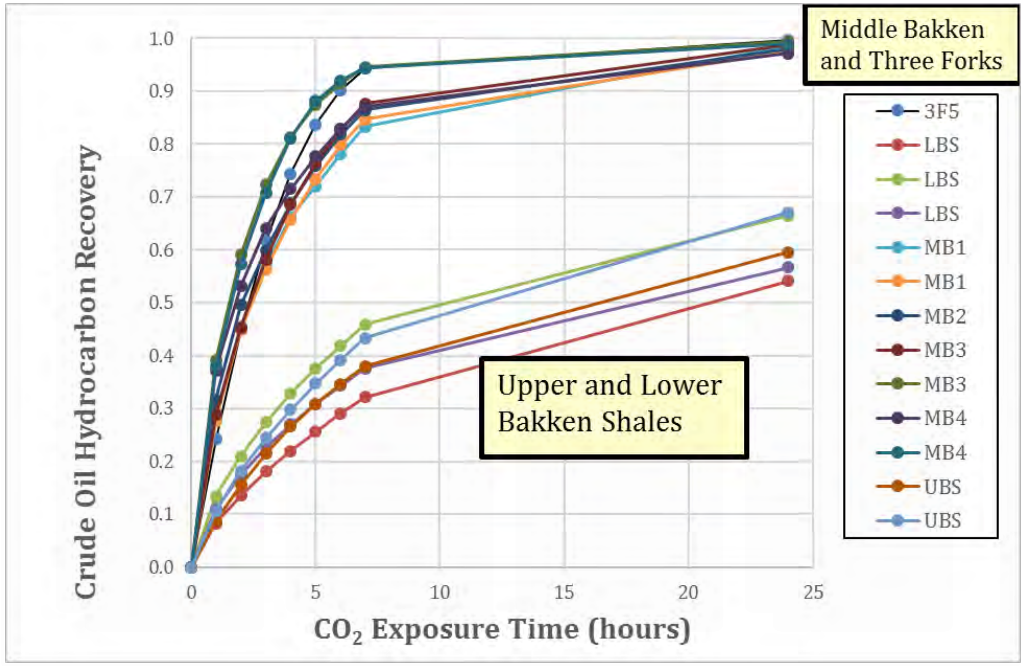
Determine ability of CO_2 to recover hydrocarbons from Middle Bakken and Bakken Shale rock samples

Laboratory Exposures Include:

>***VERY*** small core samples (11-mm rod for Middle Bakken and Upper and Lower shales).

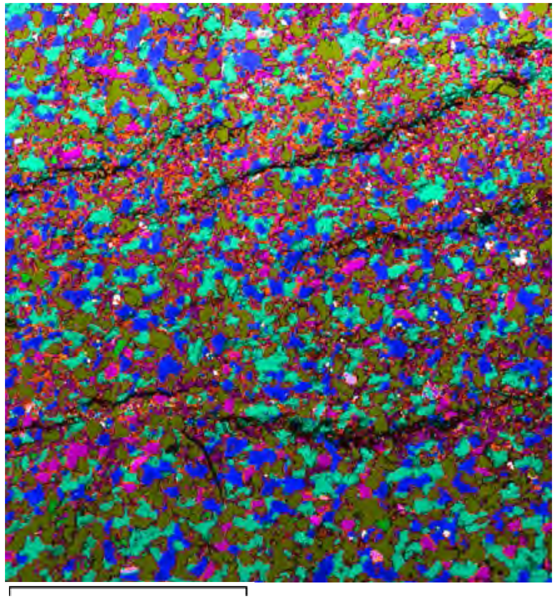
- Rock is "bathed" in the fluid to mimic fracture flow, not swept with the fluid.
- Recovered oil hydrocarbons are collected periodically and analyzed by gas chromatography/flame ionization detection (GC/FID) (kerogen not determined); 100% recovery based on rock crushed and solvent extracted after gas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

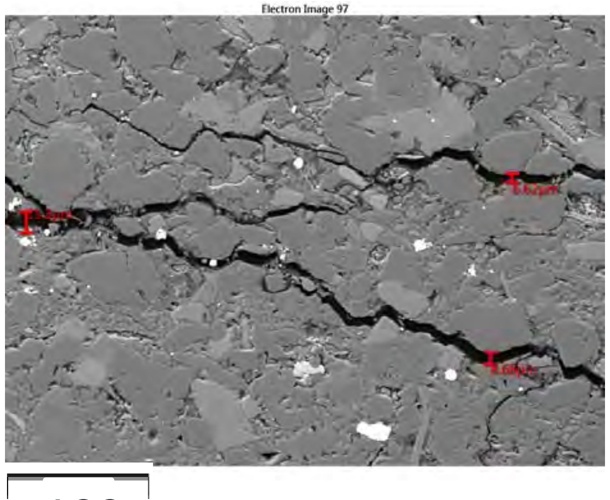
ROCK CHARACTERIZATION AND EXPERIMENTAL ACTIVITIES KEY LESSONS LEARNED



Within hours CO_2 mobilized oil from Middle Bakken and Bakken shale core plug samples in lab experiments.

(Hawthorne and others, 2013 SPE-167200-MS)



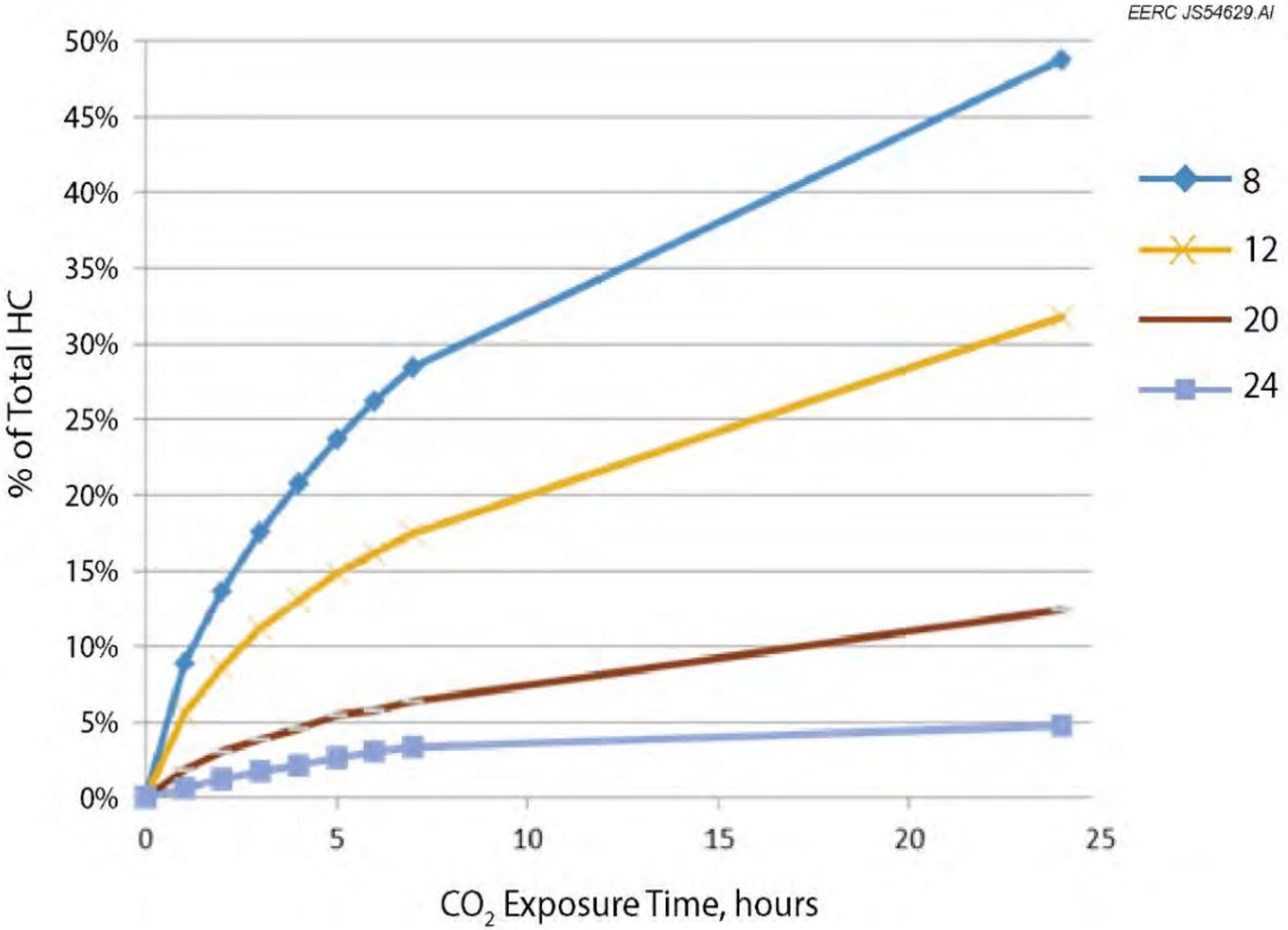


Microfracture networks make significant contributions to fluid mobility in tight formations.

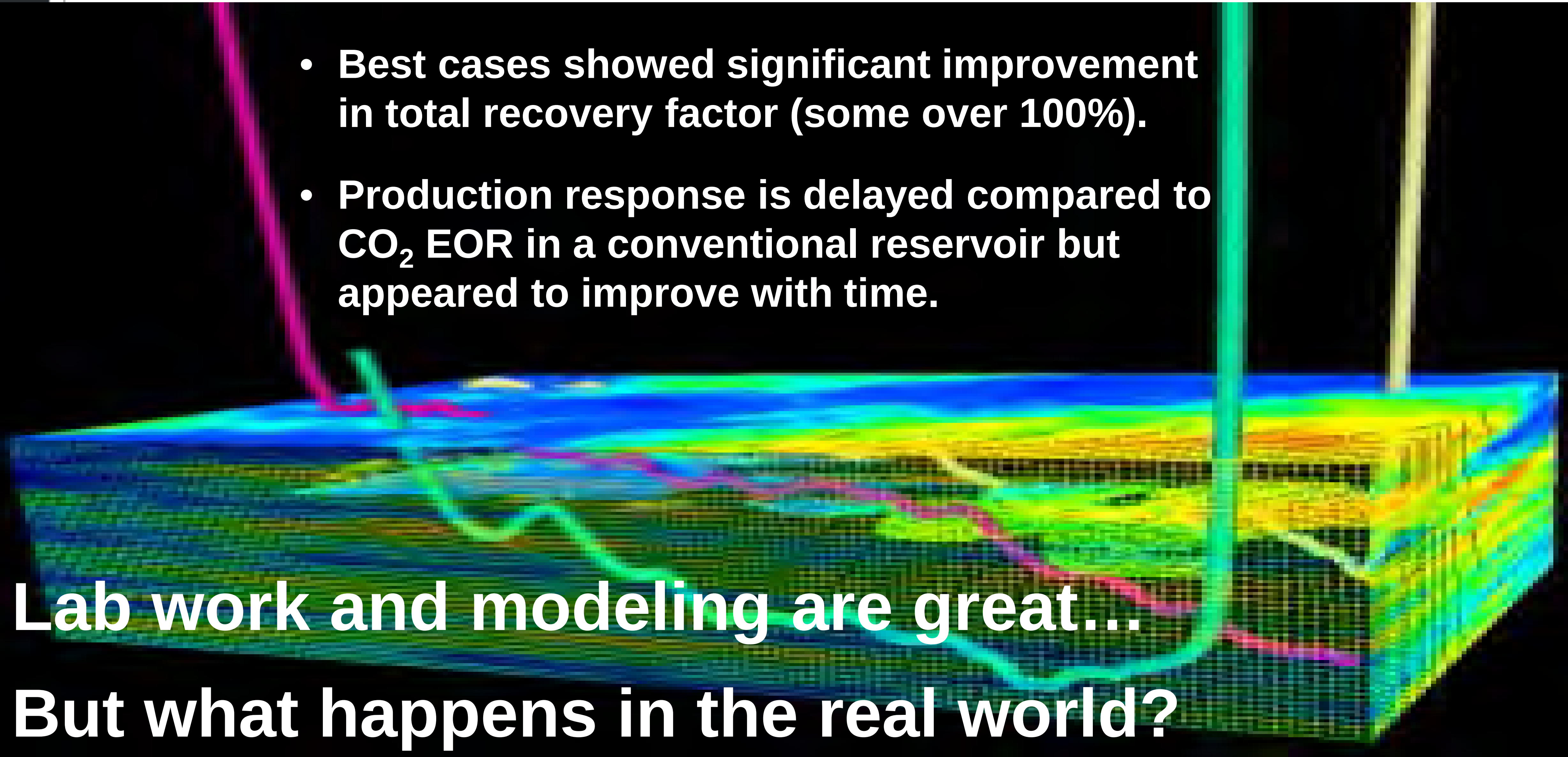
(Sorensen and others, 2015, URTeC: 2169871)

CHARACTERIZATION AND EXPERIMENTAL ACTIVITIES KEY LESSONS LEARNED

CO_2 preferentially mobilizes lighter-molecular-weight hydrocarbons from Middle Bakken and Bakken shale samples in lab experiments.



INITIAL MODELING OF HUFF ‘N’ PUFF AND INJECTOR–PRODUCER PAIR EOR SCHEMES



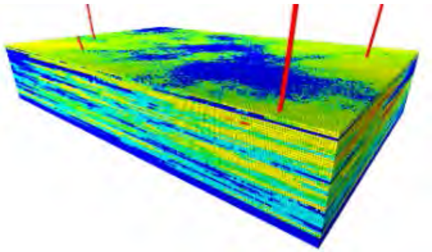
- **Best cases showed significant improvement in total recovery factor (some over 100%).**
- **Production response is delayed compared to CO_2 EOR in a conventional reservoir but appeared to improve with time.**

Lab work and modeling are great…

But what happens in the real world?

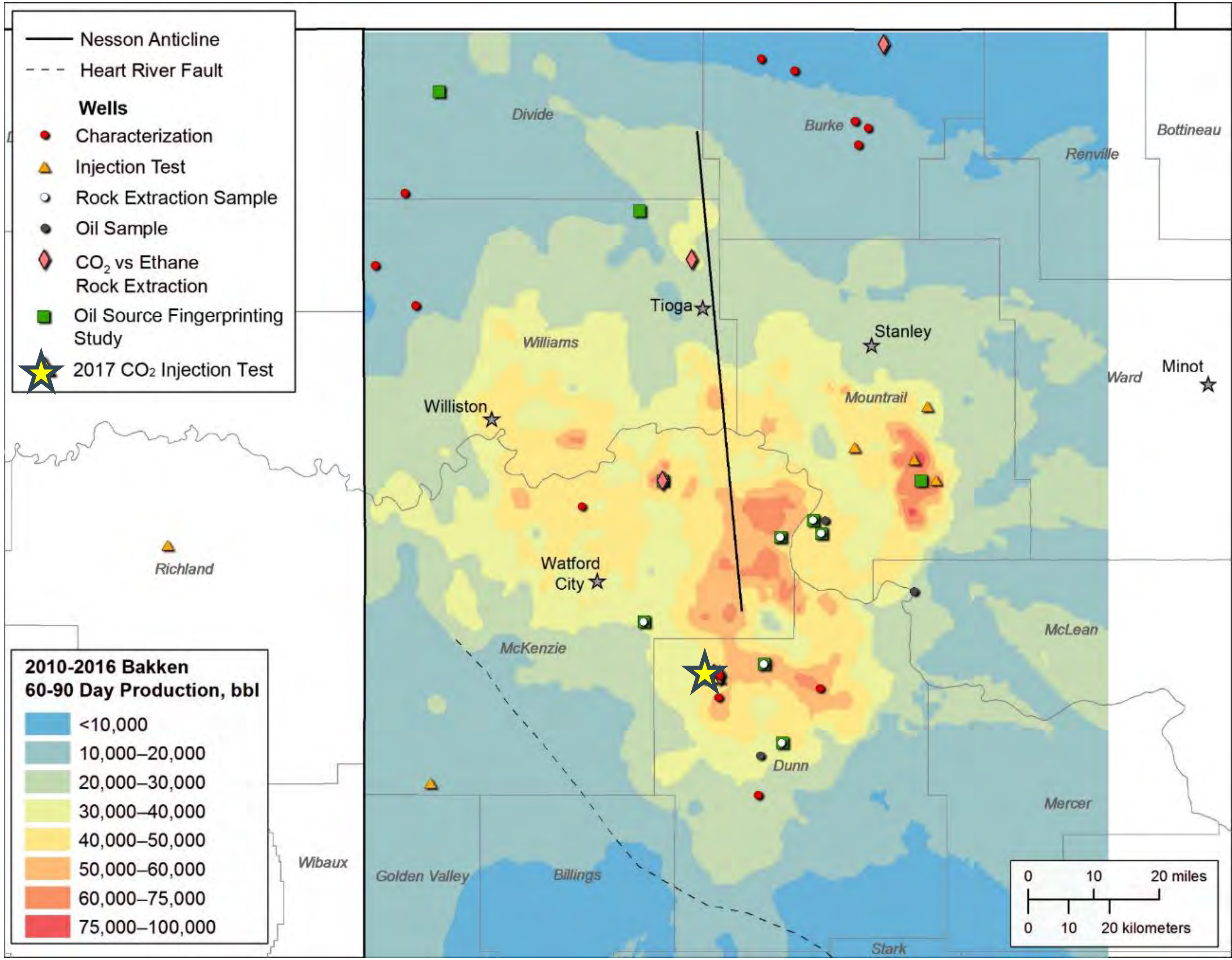
BAKKEN CO_2 STORAGE AND ENHANCED RECOVERY PROGRAM – FIELD INJECTION TEST

XTO ENERGY



INJECTION TEST LOCATION

- Owned and operated by XTO Energy.
- Vertical well originally completed in 1985 into a conventional reservoir below the Bakken.



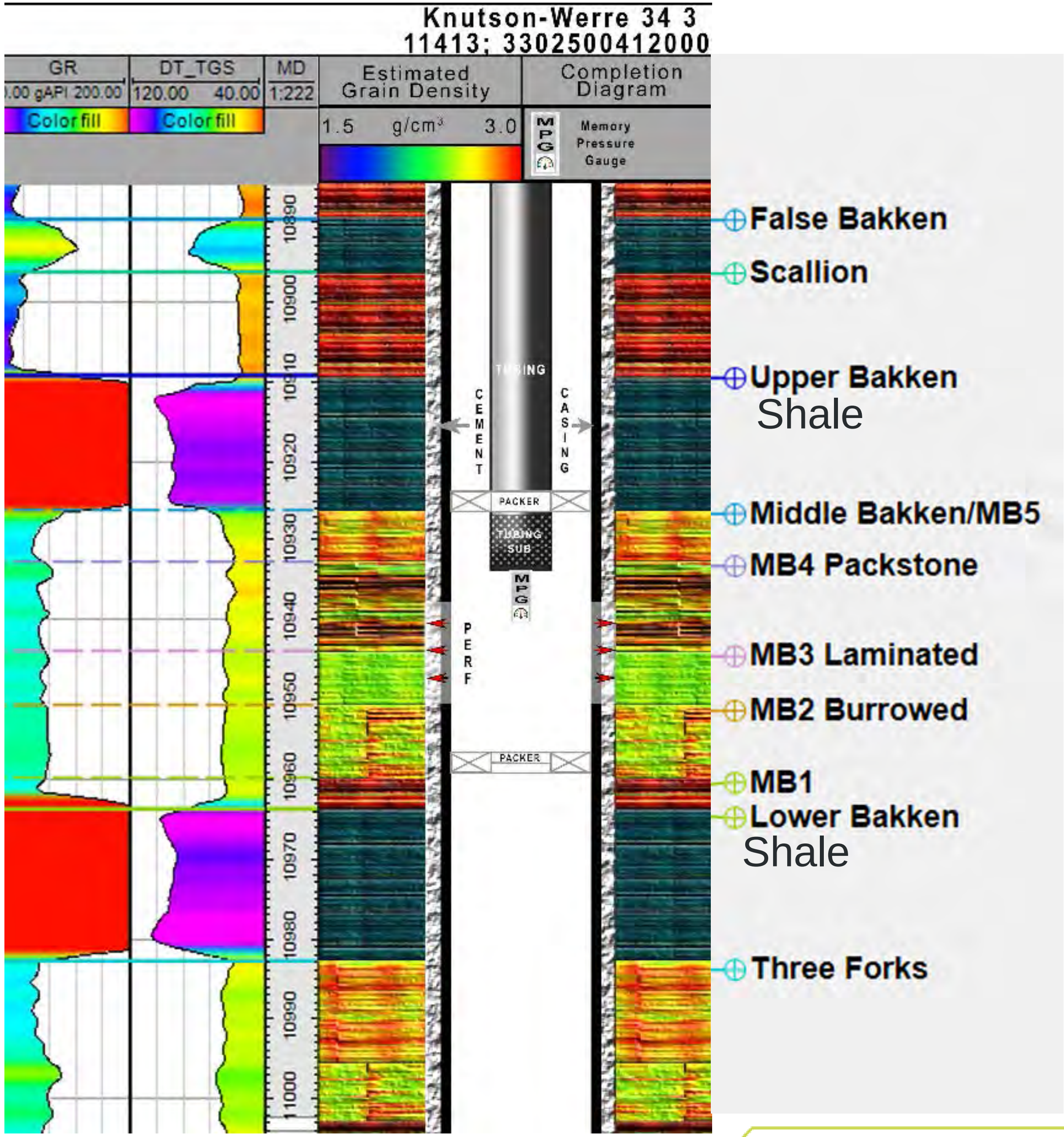
FIELD TEST HYPOTHESIS

Past pilot-scale CO_2 injection tests into horizontal, hydraulically fractured Bakken wells have shown little to no effect on oil mobilization.

- CO_2 likely moved so quickly through fractures that it did not have enough contact time, or became too dispersed, to interact with stranded oil in the matrix.

Hypotheses to be tested in a vertical well:

1. CO_2 can be injected into an unstimulated Bakken reservoir (tight non-shale Middle Bakken).
2. The injected CO_2 can interact with the in-place fluids, resulting in subsequent mobilization of hydrocarbons and storage of CO_2.



ATTRIBUTES TO KEEP IN MIND

This was virgin reservoir:

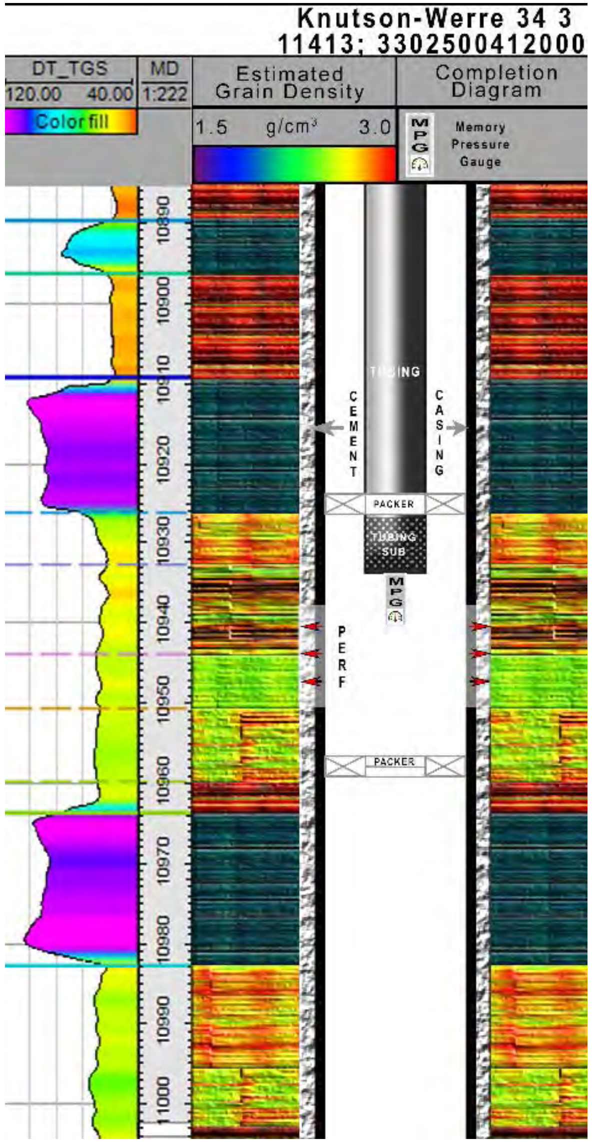
- Lack of previous production means pore pressure is high (~8600 psi).
- No production history to which results can be matched.
- Test judged by changes in hydrocarbon molecular weight distribution, comparing pre-test oil to post-test oil.

The well was not stimulated (i.e., no hydraulic fracturing to enhance permeability and improve injectivity):

- Relies on preexisting fractures and matrix permeability for injectivity.

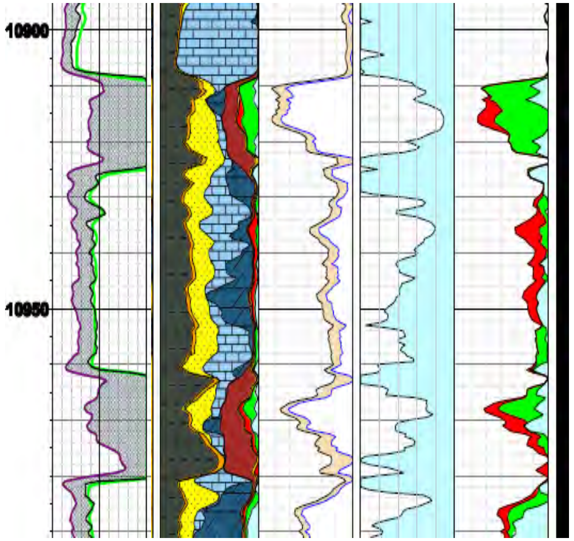
This field test serves as a bridge from the lab to a future larger-scale field test in a stimulated horizontal well.

- Results may represent the most conservative end member with respect to injectivity, oil mobilization, and CO_2 storage.



RESERVOIR AND WELLBORE CHARACTERIZATION AND TEST MONITORING

- Integrity of the wellbore casing and cement through logging.
- Lithology and estimates of reservoir porosity through logging.
- Near-wellbore distribution of oil, gas, and water saturation using pulsed-neutron logs.
- Bottomhole gauges provide real-time monitoring of pressure and temperature.



INJECTION TEST

- **Injection over 5 days in June 2017**
- Initial BHP ~7500 psi
- Stable injection rates between 6 and 12 gpm
- Maximum BHP ~9480 psi
- BHP during continuous injection ~9400 to ~9470 psi
- Temperature ranged from 251° to 257°F
- **Total of 98.4 tons injected**

FLOWBACK PERIOD

First opened on July 7, 2017.

- 100% CO_2 for the first 5 hours, mix of CO_2 and natural gas for last 3 hours.
- **No oil or water flowed.**
- Approximately 13 tons of CO_2 was produced during this initial flowback period.

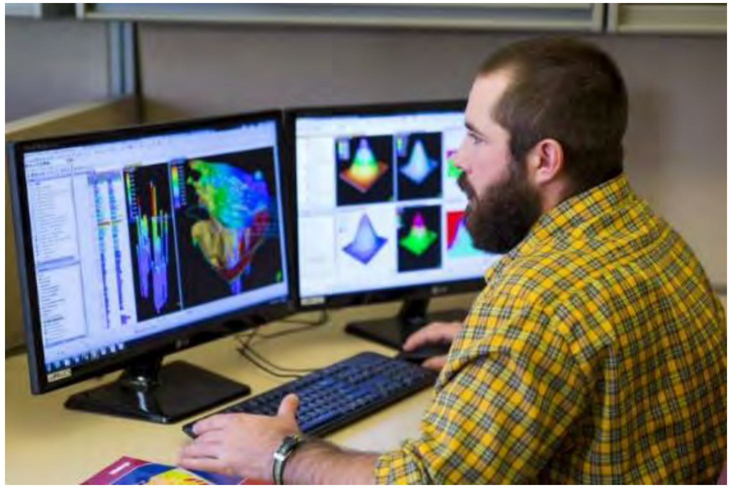
FLOWBACK PERIOD

Opened second time on July 13, 2017

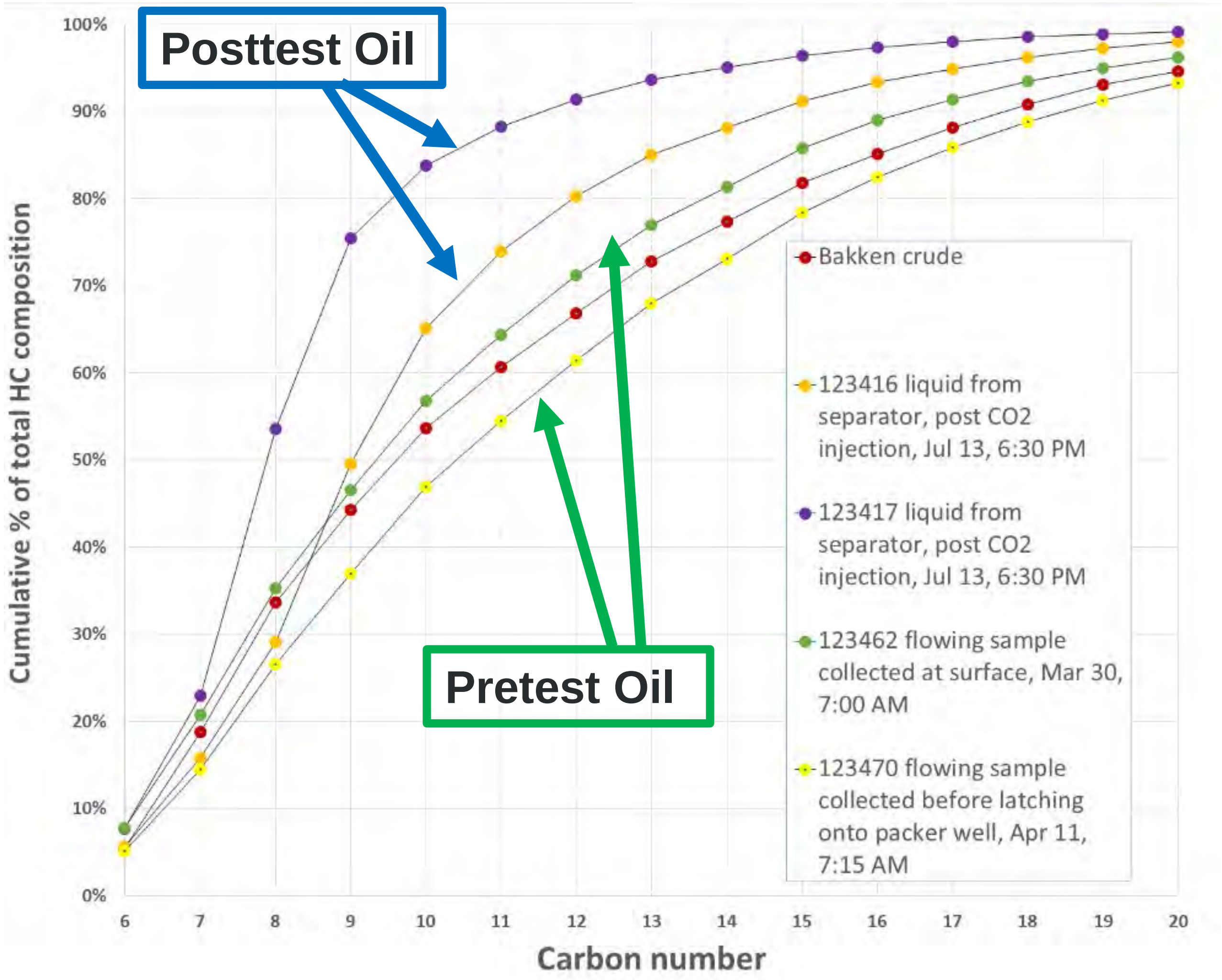
- Mix of natural gas and CO_2 produced (2.7 tons of CO_2).
- 11 hours after opening, **9 bbl oil produced over 45 minutes, then flow stopped**.
- Fluid and gas samples collected.
- **Total of 15.7 tons of CO_2 was produced during both flowback periods.**

DID CO_2 PENETRATE THE RESERVOIR MATRIX AND MOBILIZE OIL?

- Analyze hydrocarbon composition of the oil samples collected during the various stages of the test (preinjection vs. postsoak).
  - **Shifts in molecular weight distribution of the oil samples toward the lighter end would be an indicator of CO_2 influence on oil mobility.**
- Use the pressure, temperature, and fluid compositional data to refine our models.

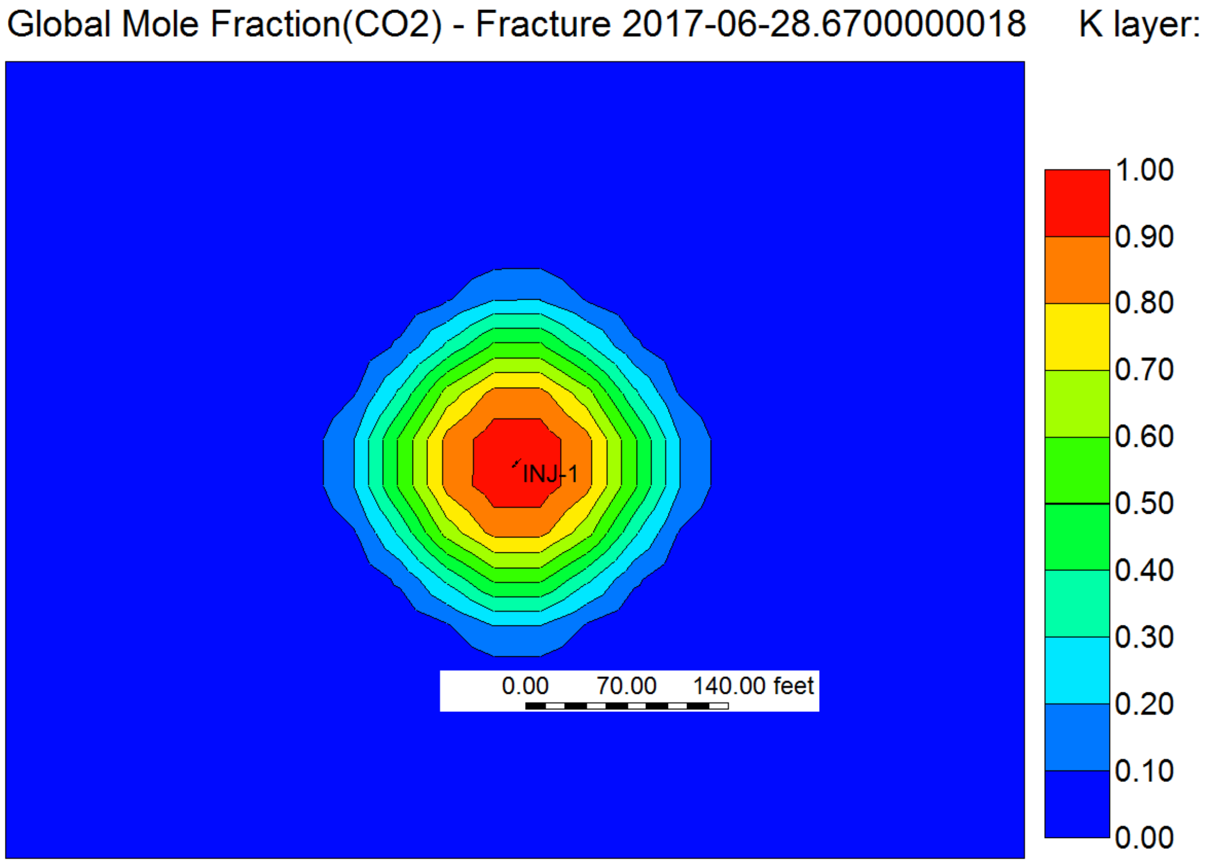


PRE- AND POST-INJECTION OIL COMPOSITIONAL ANALYSIS



- **Data indicate there was an observable shift toward the lower-molecular-weight hydrocarbons as a result of CO_2 injection.**
- **These data suggest that the CO_2 penetrated the matrix of the Middle Bakken, interacted with the oil therein, and mobilized a lighter oil.**

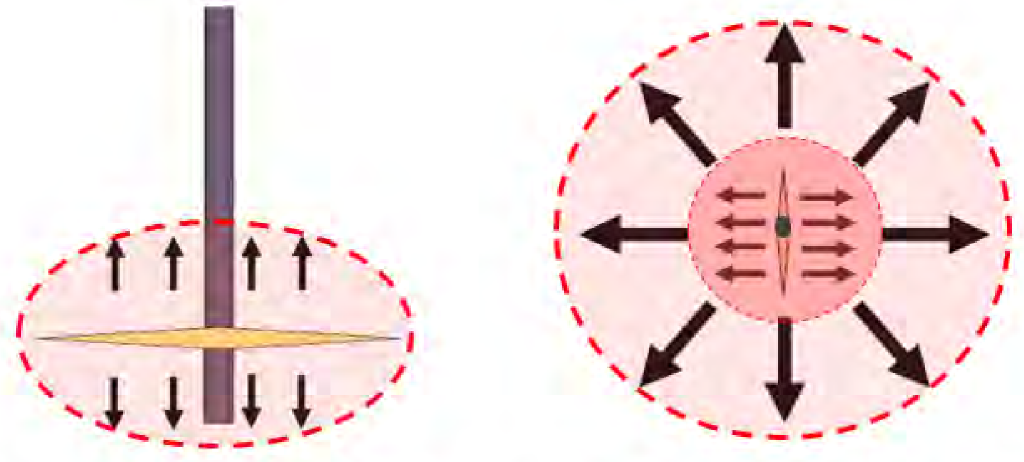
ESTIMATE OF CO_2 PENETRATION BASED ON PREDICTIVE SIMULATIONS



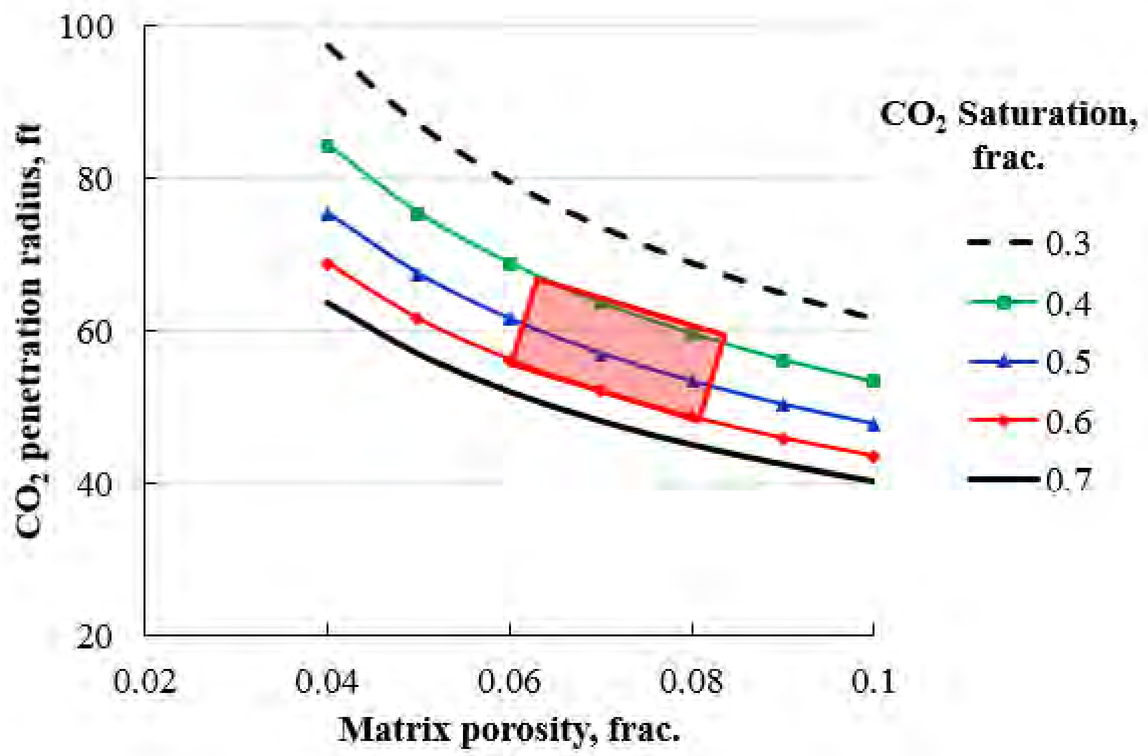
Reservoir simulations using relatively simple layer-cake lithofacies distribution and dual permeability (matrix and fractures) model predict a CO_2 saturation radius of ~140 ft.

- **Likely represents the upper bound of saturation plume size for the injected volume.**

ESTIMATE OF CO_2 PENETRATION BASED ON FIELD DATA ANALYSIS



(a) During injection: viscous flow via mini-fractures; (b) Post-injection: diffusion flow in matrix due to the closure of fractures;



Pressure transient analysis indicates:

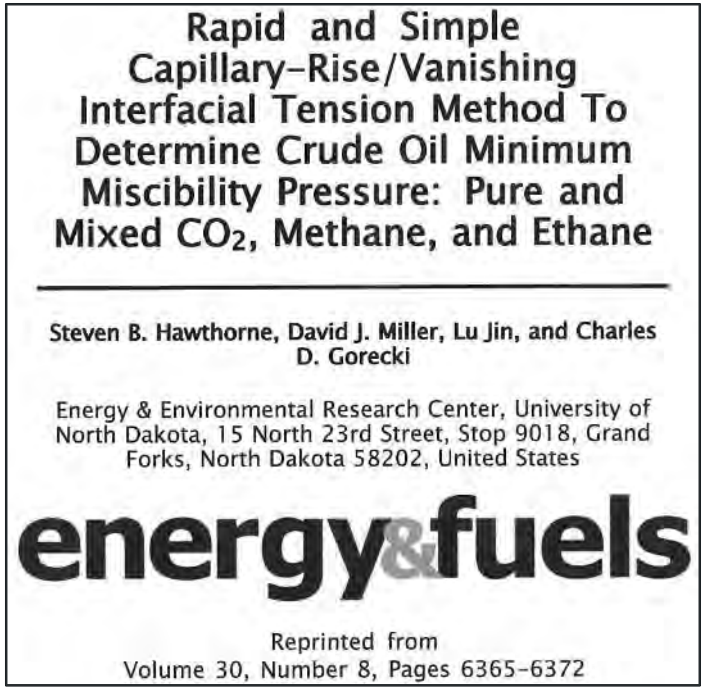
- **Preexisting fractures were open for 10 hours, viscous flow dominated.**
- **Diffusion was primary mechanism in the time after the fractures closed.**

Well flow data and material balance analysis indicate CO_2 penetrated 50 to 70 ft based on possible ranges of matrix porosity and CO_2 saturation.

This is considered to be the most likely saturation plume size.

ACCOMPLISHMENTS

- Developed a new method for studying phase behavior and estimating minimum miscibility pressure (MMP).
- Lab testing demonstrated the ability of CO_2 to permeate and mobilize oil from Bakken organic rich shale and tight non-shale rock.
- Generated insight on the key characteristics and mechanisms controlling CO_2 permeation and oil mobility in tight shale and non-shale rocks.


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

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ACCOMPLISHMENTS

Field test generated a wealth of real-world data:

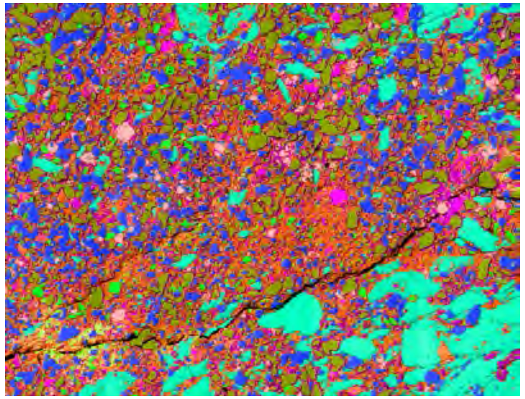
- **Injectivity into unstimulated Bakken reservoir.**
- **Evidence that CO_2 mobilized oil from the matrix.**
- **Evidence that CO_2 can be retained.**
- **Validated observations in the lab.**

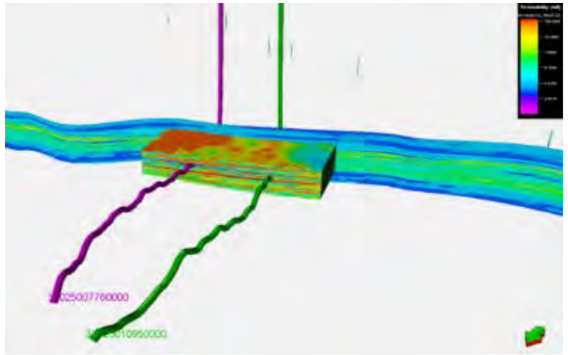
LESSONS LEARNED

- Research gaps/challenges
  - Upscaling the insight obtained from lab data and core analysis to larger-scale reservoir simulations.
- Unanticipated research difficulties
  - The impact of Murphy's law in the field.
- Technical disappointments
  - Inability to conduct any injection test into a shale member of the Bakken.
- Changes that should be made next time
  - Try to find a newer well, or drill a new well, for field testing.

SYNERGY OPPORTUNITIES

- Methods and insights developed by this project can be directly applicable to projects in many North American tight oil formations.
  - Micro- to nano-scale fracture analysis techniques.
  - Novel approaches to rock CO_2 permeation and hydrocarbon extraction and MMP studies.
  - **Guidance for future field tests.**





PROJECT SUMMARY

- <u>**Key findings**</u>
  - **Laboratory experiments, modeling exercises, and field tests indicate tight oil formations such as the Bakken may be suitable targets for CO_2 storage and EOR opportunities.**
  - **Products, results, and data generated during the project have been uploaded to EDX.**

CONTACT INFORMATION

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

www.undeerc.org
701.777.5287 (phone)
701.777.5181 (fax)

Jim Sorensen
Assistant Director for Subsurface Strategies
jsorensen@undeerc.org

THANK YOU!

Critical Challenges. **Practical Solutions.**

APPENDIX

BENEFIT TO THE PROGRAM

- Program goal being addressed:
  - Support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30%.
    - ♦ Characterize geologic settings in the United States that are "nonconventional CO_2 EOR targets that have the potential to accept and store CO_2 while producing hydrocarbon resources.

- Project benefits statement:
  - The project is developing data through laboratory- and field-based investigations, including a CO_2 injection test into a vertical Bakken well, that yields insight regarding the mechanisms controlling CO_2 transport and fluid flow in the unconventional tight oil reservoirs of the Bakken. This information will provide invaluable guidance toward the design and implementation of future pilot-scale field-based technology tests. It will also serve as the basis for developing an improved approach to estimating the suitability and storage capacity of unconventional tight oil formations for CO_2 storage and EOR. This effort supports industry's ability to predict CO_2 storage capacity in geologic formations within ±30%.

PROJECT OVERVIEW – GOALS AND OBJECTIVES

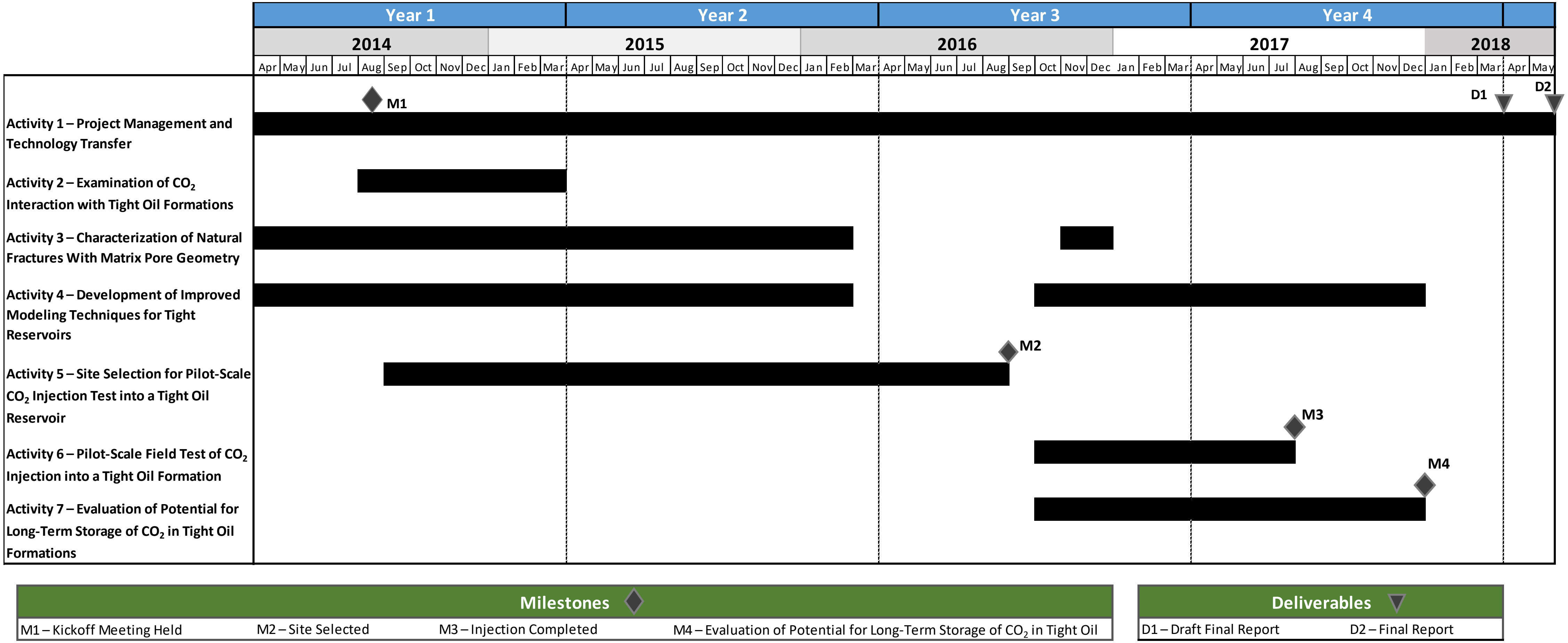
- Goals:
  - To develop knowledge that will support the deployment of commercially viable CO_2 injection operations to simultaneously enhance oil recovery and geologically store CO_2 in tight oil-bearing formations.
  - These goals relate to the Program goals in that:
    - ♦ Tight oil and gas plays 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 CO_2 within and/or through these tight formations is critical to understanding their roles in carbon capture and storage (CCS) (sinks or seals?).
    - ♦ Supports industry's ability to predict CO_2 storage capacity in geologic formations within ±30%.
- Success criteria
  - Results of examinations of CO_2 permeation into and hydrocarbon extraction from the Bakken petroleum system reservoirs provide guidance in the use of CO_2 for EOR, and thus facilitating long-term storage in tight oil formation systems. This will be evidenced if additional efforts to validate the results are funded, at least in part, by industry.
  - The field-based activities have utility in guiding the further use of tight oil formations for geological storage of CO_2. This will be evidenced if efforts by industry result in the pursuit of additional field-based CO_2 injection tests.

ORGANIZATION CHART

- **EERC Project Team**
  - As shown in Table 1, James Sorensen, Assistant Director for Subsurface Strategies, will be the subtask manager and principal investigator on this program. Other key personnel include Dr. Steven Hawthorne (Distinguished Scientist), Bethany Kurz (Assistant Director for Integrated Analytical Solutions), Charles Gorecki (Director of Subsurface R&D), John Hamling (Assistant Director for Integrated Projects), John Harju (EERC Associate Director for Research), and Edward Steadman (Deputy Associate Director for Research).

- **Project Partners (providing cash and in-kind contributions)**
  - North Dakota Industrial Commission Oil & Gas Research Program (cash cofunding)
  - XTO Energy (cash and in-kind contributions, including providing a well for the injection test and field activities in support of the injection test)
  - Continental Resources (cash cofunding)
  - Hess (cash cofunding)
  - Marathon (cash cofunding)
  - Schlumberger (in-kind contributions in the form of field activities in support of the injection test, and computer software)
  - Computer Modelling Group (in-kind contributions in the form of computer software)
  - Baker Hughes (in-kind contributions in the form of computer software)

GANTT CHART



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