BAKKEN CO_2 STORAGE AND ENHANCED RECOVERY PROGRAM

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Energy & Environmental Research Center

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 1–3, 2017

Critical Challenges. Practical Solutions.

PRESENTATION OUTLINE

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

BAKKEN CO_2 STORAGE AND ENHANCED RECOVERY PROGRAM – PHASE II PARTNERS

NETL

North Dakota oil & gas research program

Marathon Oil

Continental RESOURCES

XTO ENERGY

HESS

BAKER HUGHES

CMG COMPUTER MODELLING GROUP LTD.

Schlumberger

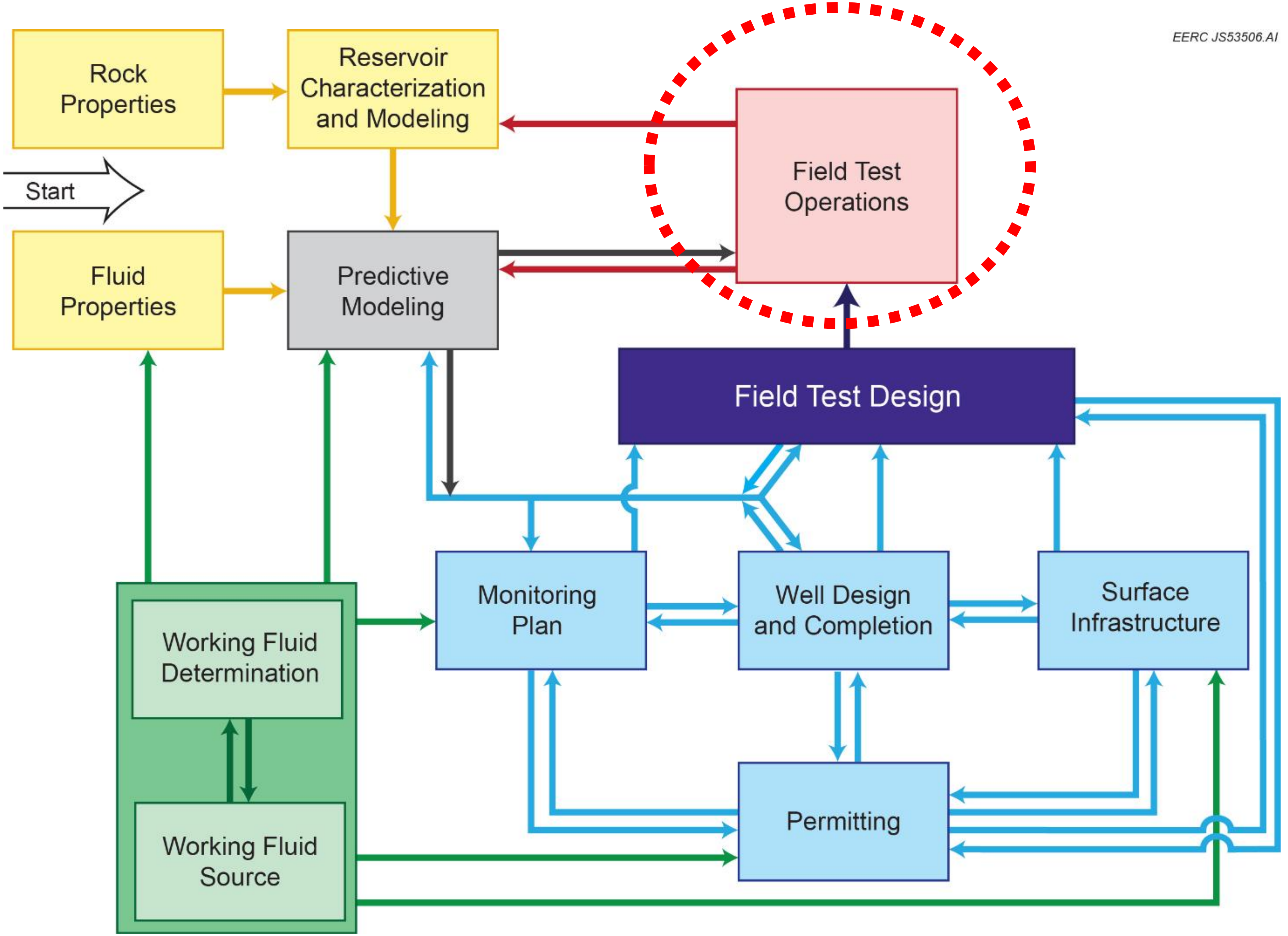
KINDER MORGAN INC.

NORTH DAKOTA DMR Department of Mineral Resources

NORTH DAKOTA PETROLEUM COUNCIL

TECHNICAL STATUS

WHAT DOES IT TAKE TO DO A FIELD TEST?



EERC

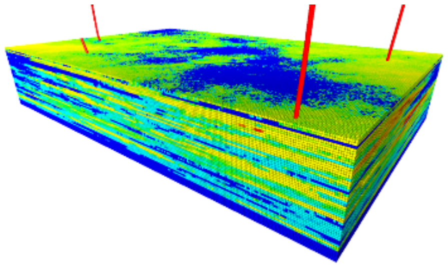
PHASE I – ELEMENTS OF THE PROGRAM

Laboratory work to evaluate:

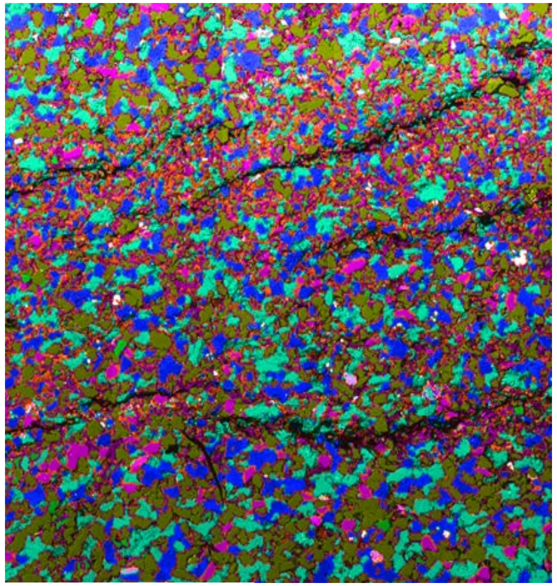
- **Rock matrix**
- **Nature of fractures**
- **Effects of CO_2 on oil**
- **Ability of CO_2 to remove oil from rock**

Static and dynamic modeling

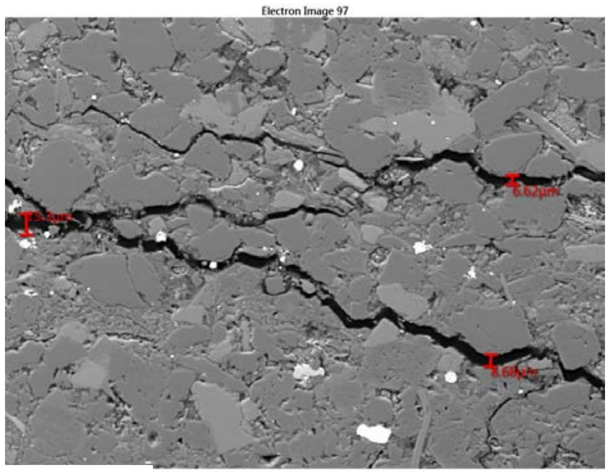
Case study of a CO_2 huff 'n' puff (HnP) test in Montana



PHASE I CHARACTERIZATION AND EXPERIMENTAL ACTIVITIES KEY LESSONS LEARNED (2014)

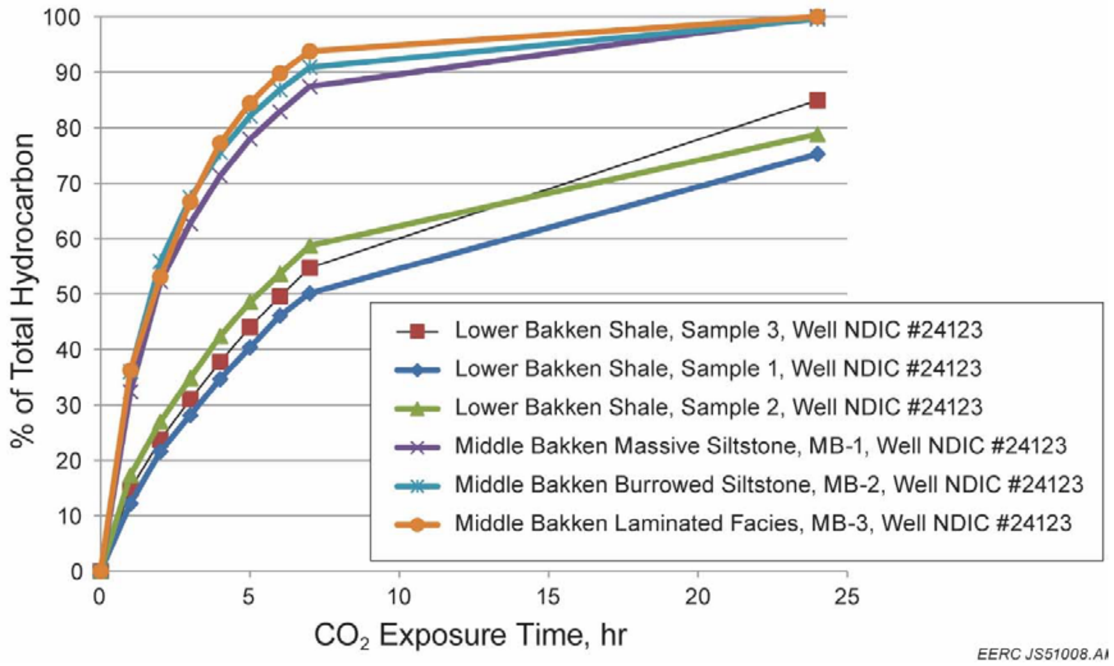


1 mm



100 µm

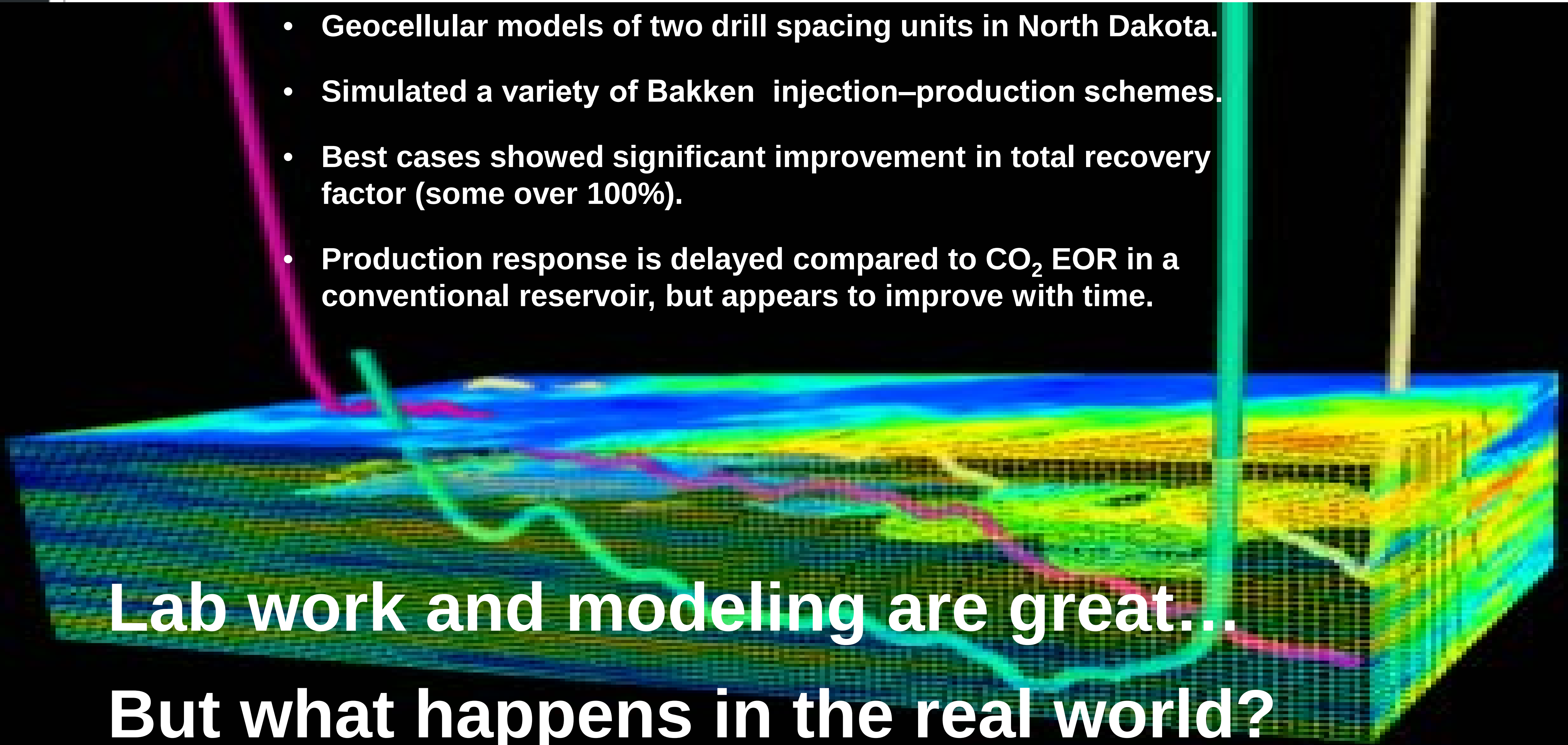
Microfracture networks make significant contributions to fluid mobility in tight formations.



CO_2 mobilized oil from Middle Bakken reservoir and Bakken shale samples in lab experiments.

PHASE I MODELING RESULTS (2014)

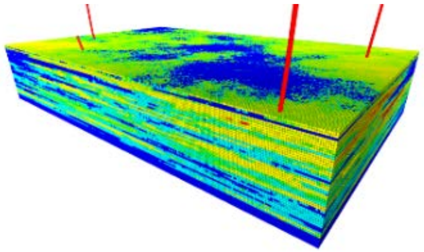
- Geocellular models of two drill spacing units in North Dakota.
- Simulated a variety of Bakken injection–production schemes.
- Best cases showed significant improvement in total recovery factor (some over 100%).
- Production response is delayed compared to CO_2 EOR in a conventional reservoir, but appears 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 – PHASE II – FIELD INJECTION TEST 2017



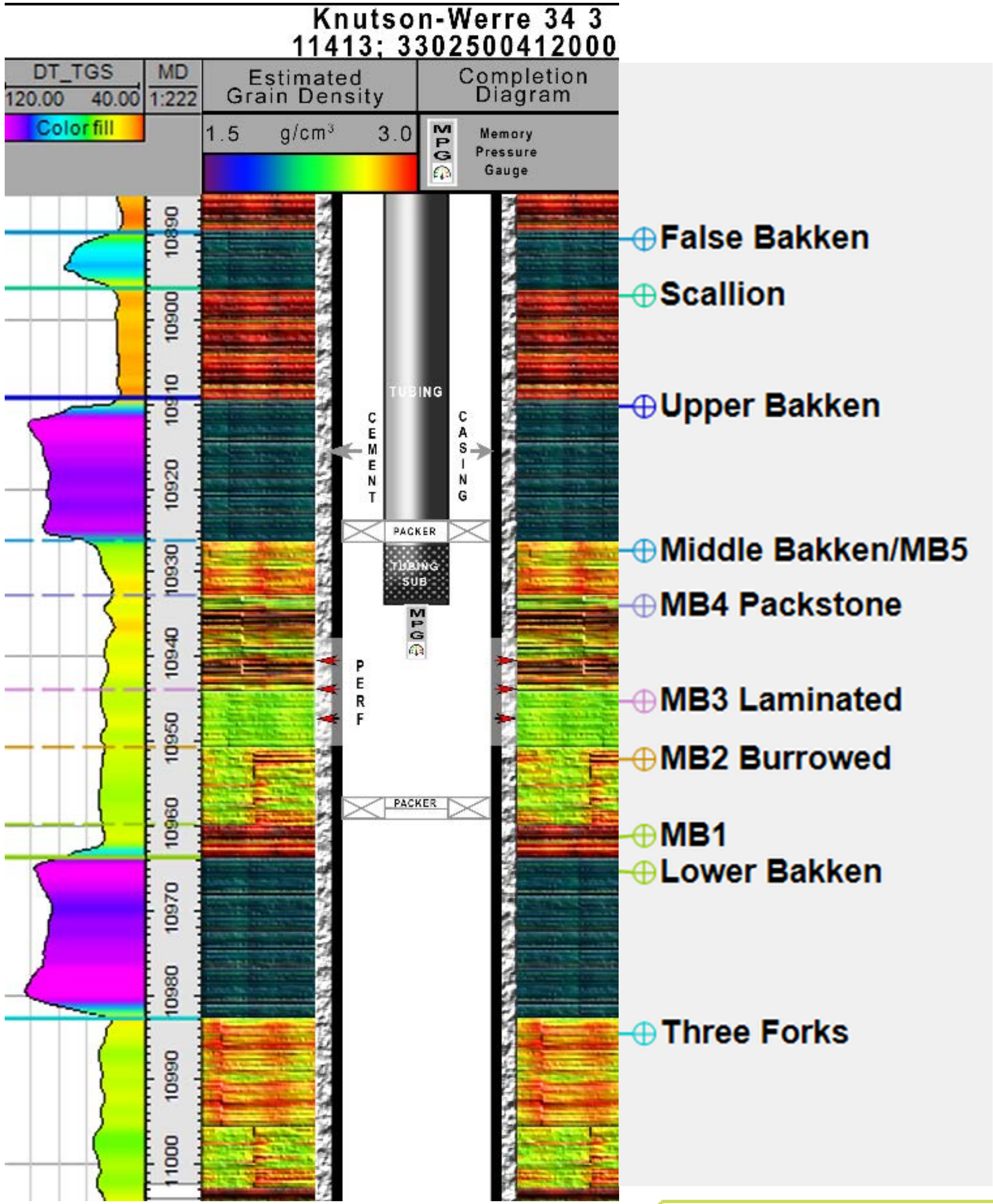
TEST CONCEPT & HYPOTHESIS

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

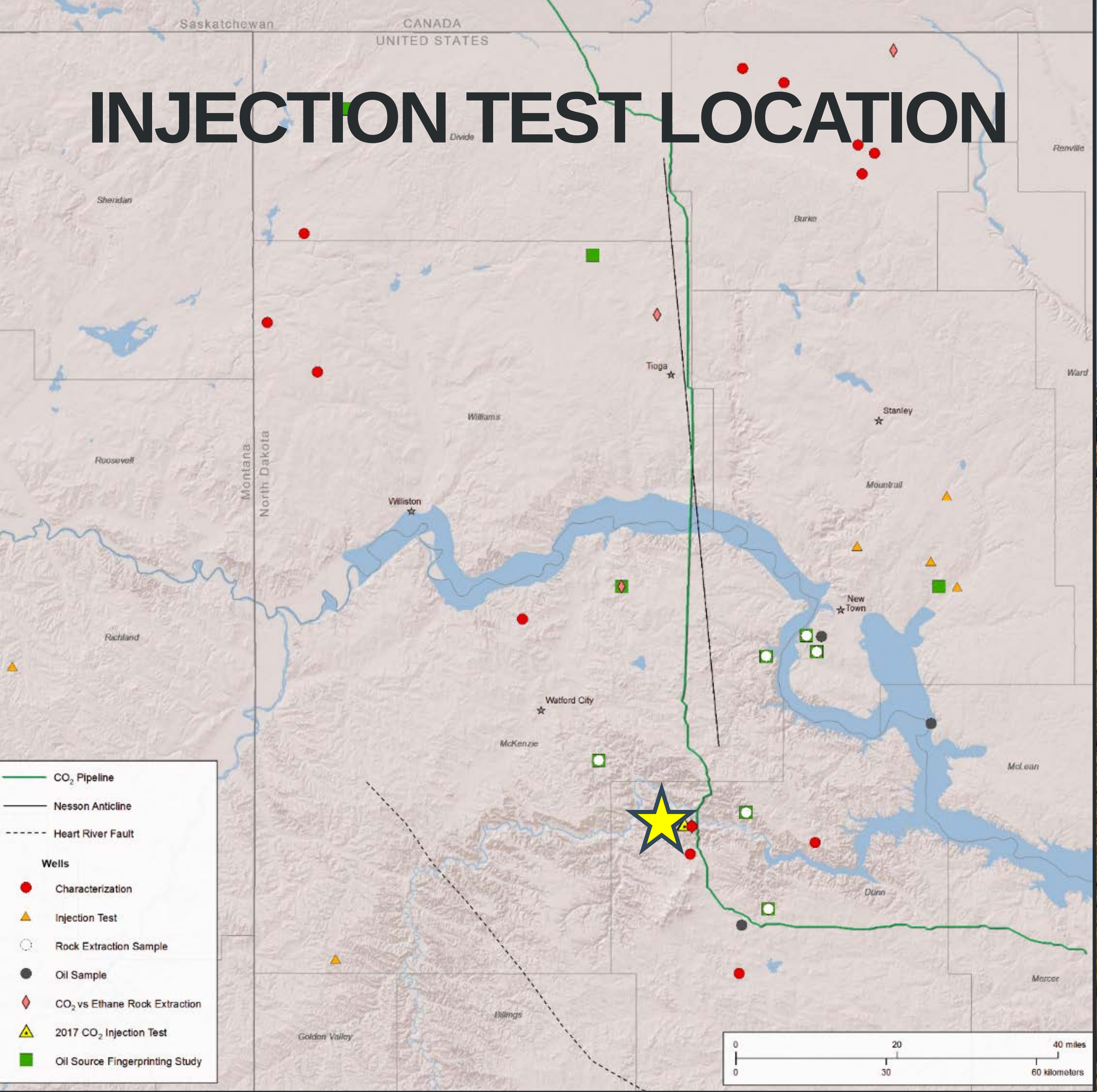
- CO_2 likely moved so quickly through fractures that it did not have enough contact time, or became too dispersed, to interact with stranded oil in the matrix.

Hypotheses to be tested in a vertical well:

1. CO_2 can be injected into an *unstimulated* Bakken reservoir.
2. The injected CO_2 can interact with the matrix fluids, resulting in subsequent mobilization of hydrocarbons and storage of CO_2.

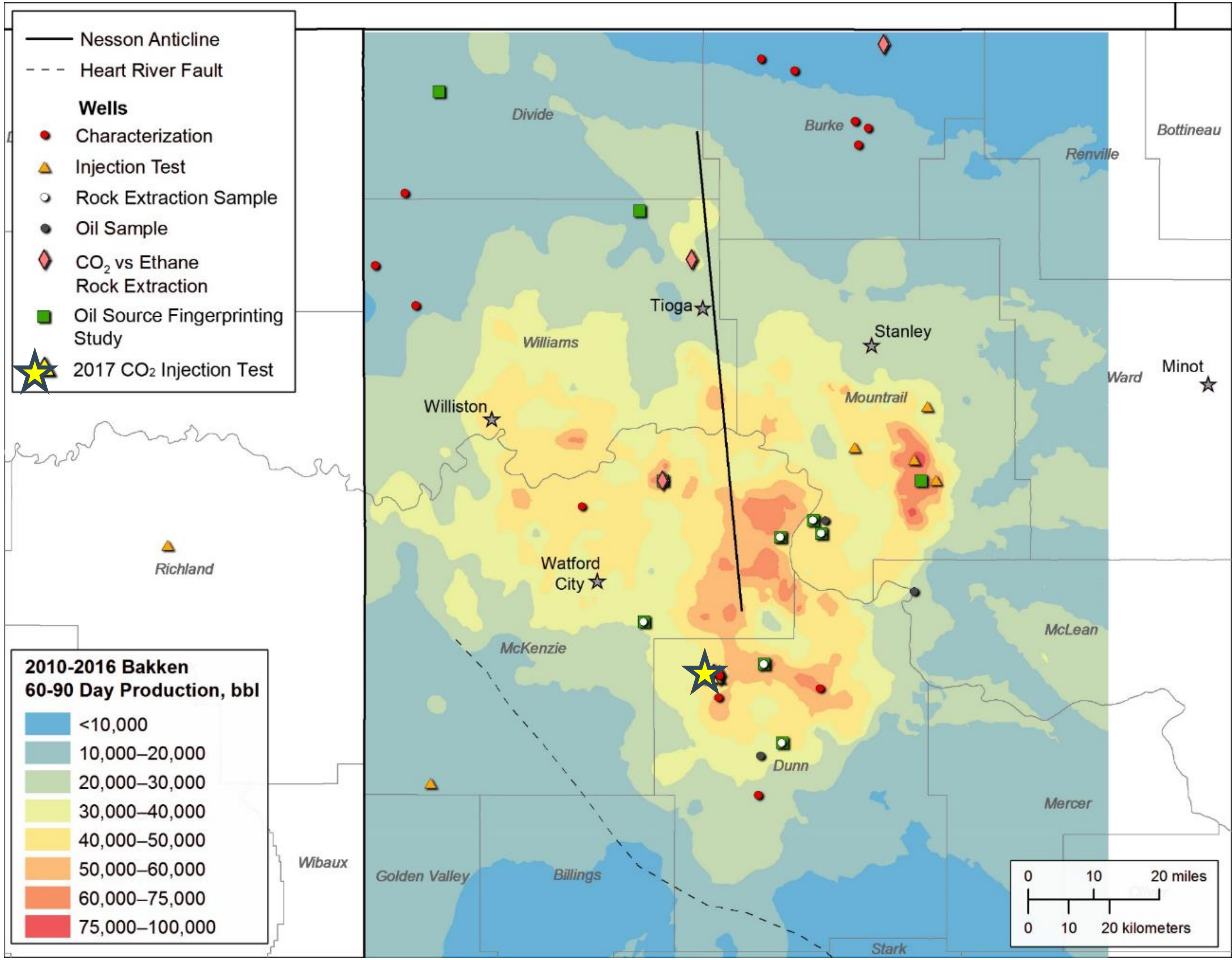


INJECTION TEST LOCATION



INJECTION TEST LOCATION

- Knutson-Werre 34-3 well.
- Owned and operated by XTO Energy.
- Vertical well originally completed in the Duperow Fm, below the Bakken, in 1985.
- Located in one of the more highly productive areas of the Bakken.



WELL PREPARATION WORK

WELLBORE INTEGRITY AND RESERVOIR CONDITIONS LOGGING

- Integrity of the wellbore casing and cement.
- Lithology and estimates of reservoir porosity.
- Near-wellbore distribution of oil, gas, and water saturation using pulsed-neutron logs.

PERFORATING THE BAKKEN

- Logging indicated the presence of a channel in the cement that appeared to cut across the injection zone, possibly serving as a leakage pathway.

- A “zero degree” perforation configuration was chosen to minimize the chance of perforating into the channel.

BOTTOMHOLE PRESSURE AND TEMPERATURE GAUGES

- Bottomhole gauges were installed to monitor pressure and temperature during all major stages of the test (pretest baseline, injection, soak, flowback).

BRING IN THE CO_2

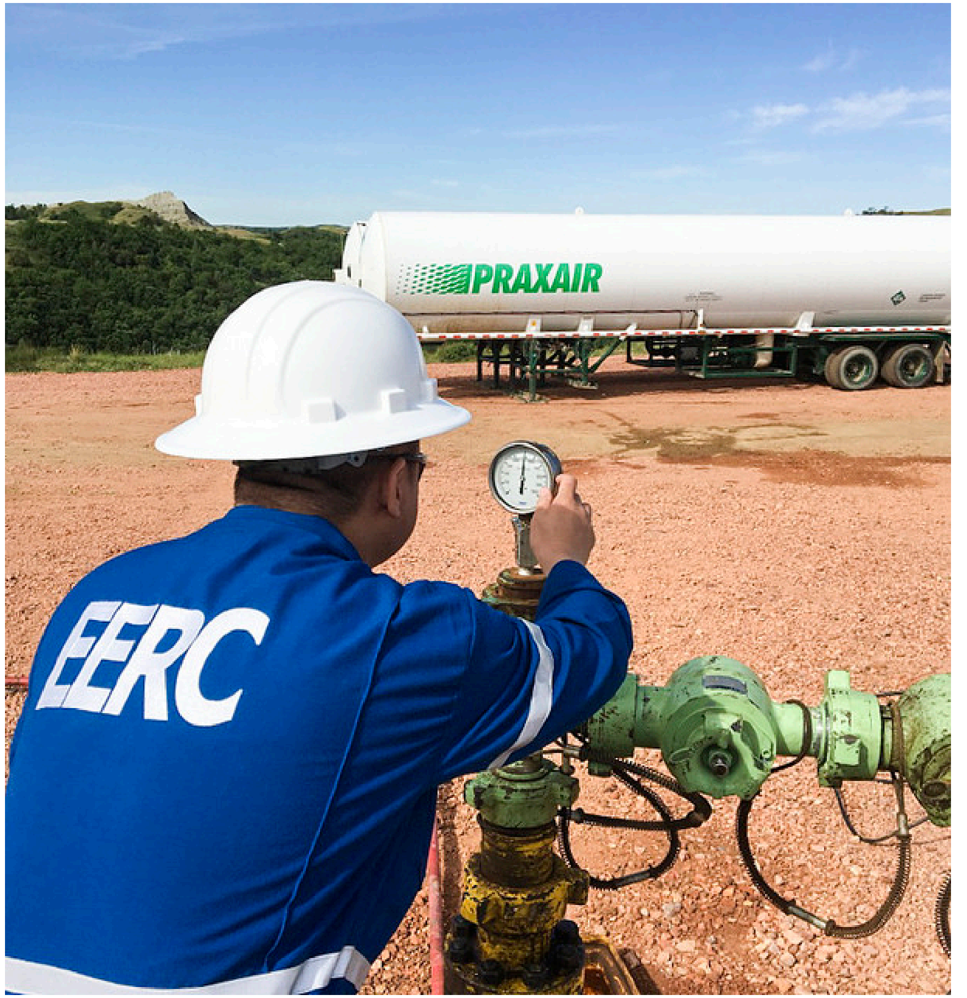
- Praxair
- “Pretest” injection in April 2017
- “Main” injection June 2017

ON-SITE DATA COLLECTION AND MONITORING

- Real-time monitoring of bottomhole pressure (BHP) and bottomhole temperature (BHT).

LESSONS LEARNED FROM THE "PRETEST" INJECTION INTO BAKKEN

- Maximum BHP achieved was 9113 psi.
- BHT was 255°F.
- Minimum injection rate of the equipment was 4.5 to 5 gallons/minute.
- Tubing held up to the injection pressure.
- Downhole gauges worked very well!
- Fluid influx into the well is low but consistent.
- Packer failed before injection into the reservoir could be established.



MAIN INJECTION TEST

- Injection started on June 24
- Completed on June 28

- Main test included:
  - Tube filling and pressure building (16 hours)
  - Two periods of cyclic injection (16 and 32 hours)
  - One period of continuous injection (32 hours)
  - Shut-in period for pressure falloff data (4 hours)

MAIN INJECTION TEST STATISTICS

- Initial BHP ~7500 psi
- Stable injection rates between 6 and 12 gpm
- Maximum BHP ~9480 psi
- BHP during continuous injection ~9400 psi to ~9470 psi
- Temperature ranged from 251° to 257°F

Day	Date	Total Cum [gal]	Cum Mass [tons]	Period
1	24-Jun	2236.7	10.4	Filling
1	24-Jun	50.8	0.2	BHP from 8200 to 8600
1	24-Jun	207	1.0	Cyclic inj- Part 1
2	25-Jun	1160.5	5.4	Cyclic inj- Part 1
2	25-Jun	904.5	4.2	Cyclic inj- Part 2
2	26-Jun	1009.4	4.7	Cyclic inj- Part 2
3	26-Jun	1752.6	8.1	Cont. Inj
4	27-Jun	11131	51.8	Cont. Inj
5	28-Jun	2806.2	13.0	Cont. Inj
		TOTAL	**98.9**	**tons of CO_2 injected**

SOAK PERIOD

- Soak period lasted for 9 days.
- Pressure and temperature were monitored.
- The view was enjoyed…

FLOWBACK PERIOD 1

First opened on July 7.

- BHP at start was 8740 psi.
- Flowed gas for 8.5 hours.
- CO_2 with shows of hydrocarbons in the last 2 hours.
- BHP dropped to 100 psi.
- Decided to shut in again and extend the soak.

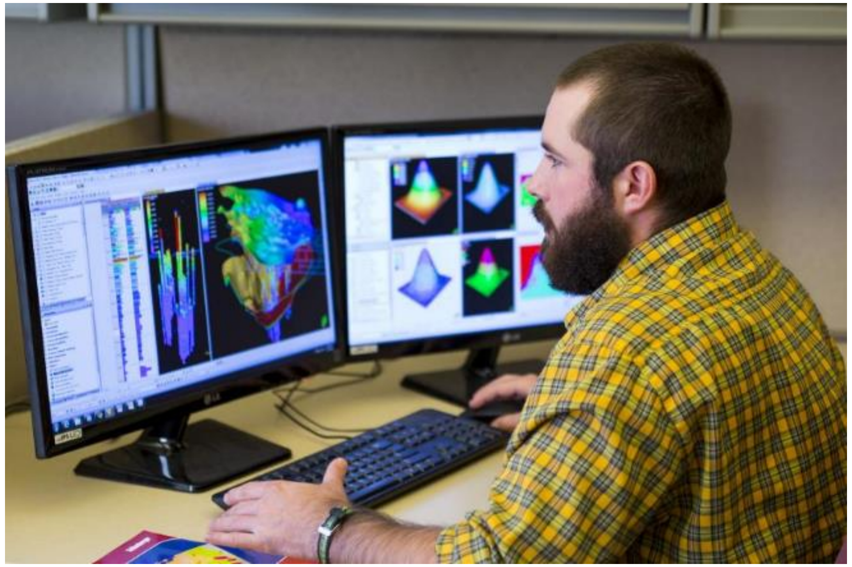
FLOWBACK PERIOD 2

Opened second time at 7:30 a.m. July 13.

- BHP at start was 3116 psi.
- Bailer returned saltwater, no oil.
- At 6:00 p.m., the well started flowing an eighth of a barrel/min of oil.
- Nine bbl produced over 45 minutes, then it stopped flowing.
- Oil, gas, and water samples collected.

NEXT STEPS

- Analyze hydrocarbon composition of the oil samples collected during the various stages of the test.
  - 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, injectivity, production, and fluid compositional data to refine our models and conduct history match exercises.



ACCOMPLISHMENTS TO DATE

- Collaborated with XTO Energy to design and implement a CO_2 injection test.
- Injected nearly 100 tons of CO_2 into a vertical Bakken well.
- Generated a wealth of real-world data:
  - Reservoir pressure and temperature
  - Fluid composition
  - Injectivity
  - Flowback

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
  - Unable 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.

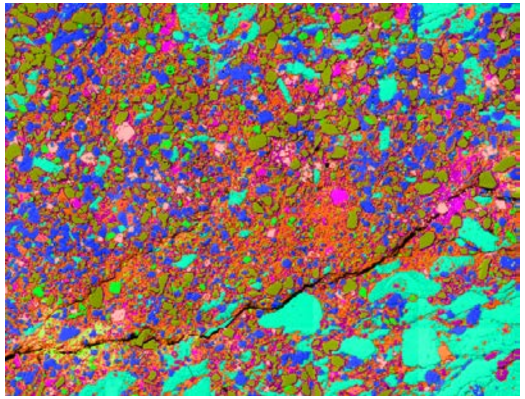
PROJECT SUMMARY

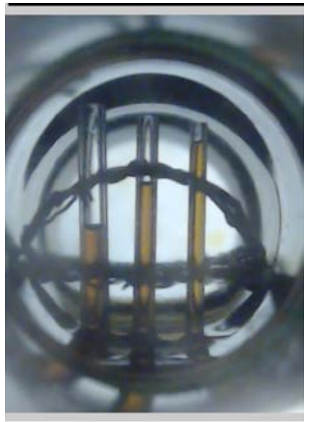
- Key findings
  - Laboratory experiments, modeling exercises, and field tests indicate tight oil formations such as the Bakken may be suitable targets for CO_2 storage and EOR opportunities.

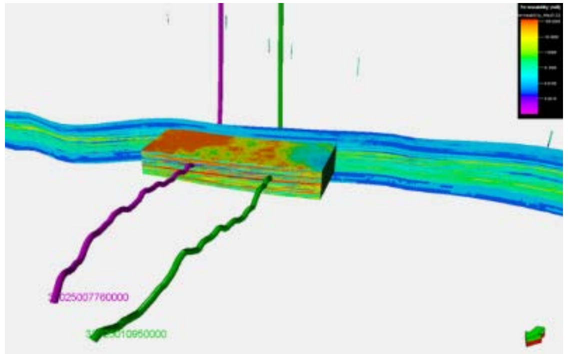
- Next steps
  - Analyze pre- and posttest oil samples for hydrocarbon compositional changes that may be indicative of CO_2 interactions with the matrix.
  - Incorporation of the field-based data into models for history matching.
  - Development of a best practices manual on the potential for injection of CO_2 into tight oil formations for simultaneous storage and EOR.

SYNERGY OPPORTUNITIES

- Methods and insights developed by this project can be directly applicable to projects in many North American tight oil formations.
  - Novel approaches to rock CO_2 permeation and hydrocarbon extraction and MMP studies.
  - Improved modeling workflows and enhancements to existing software packages.
  - **Guidance for future field tests.**







Thanks!

ACKNOWLEDGMENT

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Disclaimer

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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 percent.
    - ♦ Characterize geologic settings in the United States that are "non-conventional CO_2-EOR targets that have the potential 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 percent.

PROJECT OVERVIEW – GOALS AND OBJECTIVES

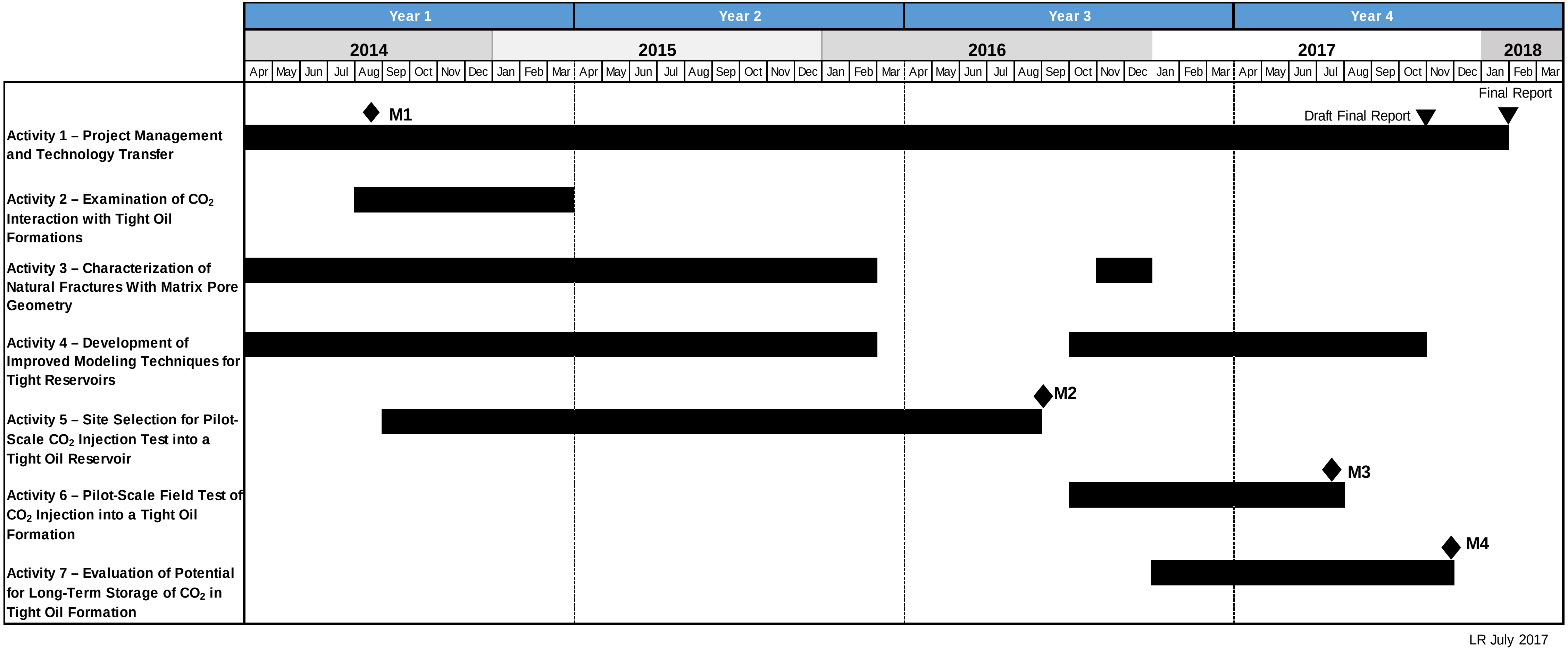
- Goals:
  - To develop knowledge that will support the deployment of commercially viable CO_2 injection operations to simultaneously enhance oil recovery and geologically store CO_2 in tight oil-bearing formations.
  - These goals relate to the Program goals in that:
    - ♦ Tight oil and gas plays 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 CO2 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 CO2 injection tests.

ORGANIZATION CHART

- **EERC Project Team**
- As shown in Table 1, James Sorensen, EERC Senior Research Manager, will be the subtask manager and principal investigator on this program. Other key personnel include Dr. Steven Hawthorne (Senior Research Manager, hydrocarbon elution experiments and oil property testing leader), Bethany Kurz (Senior Research Manager, leader of the EERC AGL), Charles Gorecki (Senior Research Manager, modeling leader), John Hamling (Senior Research Manager, leader of injection test design and monitoring activities), John Harju (EERC Associate Director for Research), and Edward Steadman (Deputy Associate Director for Research).

- **Project Partners (providing cash & 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



M1 – Kickoff Meeting Held

M2 – Site Selected

M3 – Injection Completed

M4 – Evaluation of Potential for Long-Term Storage of CO_2 in Tight Oil Formations

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