Latest Developments at the EERC and CO_2 Enhanced Oil Recovery (EOR) in Bakken Shale

12th Annual EOR Carbon Management Workshop, Session I
Midland, Texas
December 9, 2014

John Harju
Associate Director for Research

Energy & Environmental Research Center (EERC)

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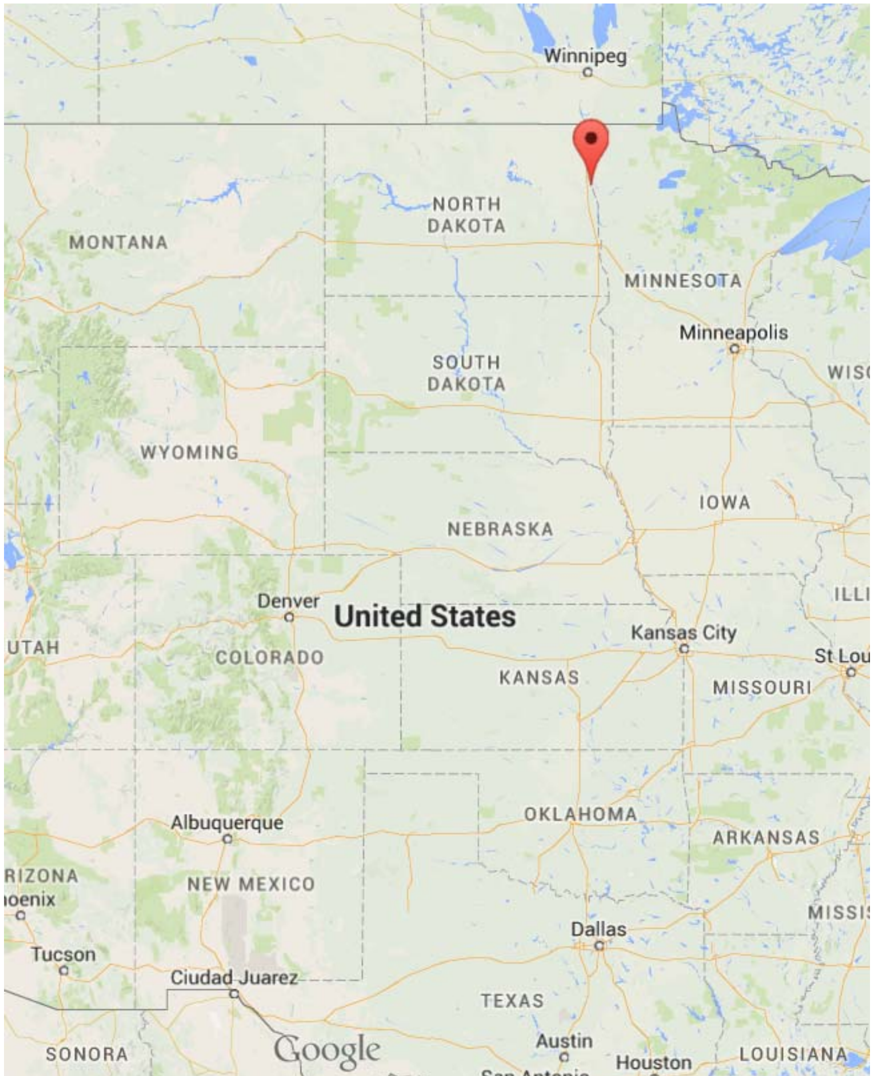

The EERC is recognized as one of the world's leading developers of:

- Cleaner, more efficient energy technologies to guarantee clean, more reliable energy supplies for the United States and the world.
- Environmental technologies to protect and clean our air, water, and soil.

New EERC Director

- Mr. Thomas A. Erickson
- Named Director in October 2014
  - Interim Director since July 2014
  - Acting Director since May 2014
  - Nearly 30 years experience at the EERC

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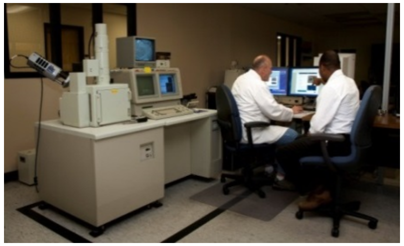
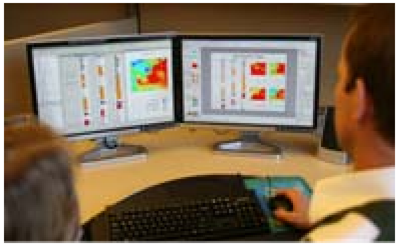
Pre-Bakken North Dakota Traffic Jam

Bakken Boom Traffic

Bakken CO_2 Storage and Enhanced Recovery Program

- Examinations of Hydrocarbon Extraction from Tight Oil Formations Using CO_2
- Fracture Characterization and Modeling
- Pilot-Scale Field Test of CO_2 Injection into a Tight Oil Reservoir





Bakken CO_2 Storage and Enhanced Recovery Program

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Phase II Partners

Continental Resources

Department of Energy, United States of America

NETL

Kinder Morgan Inc.

Marathon Oil

North Dakota DMR Department of Mineral Resources

Schlumberger

CMG Computer Modelling Group Ltd.

XTO Energy

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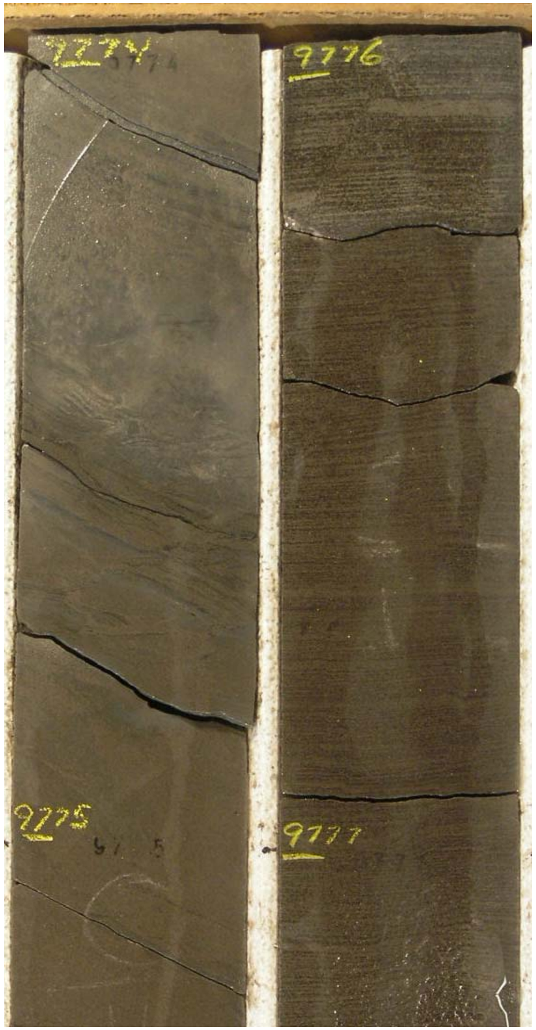
Hess

What Is Tight Oil?

- “Tight” refers to the extremely low permeability of the reservoir rock, which impedes the ability of the oil in the formation to flow freely.
- Tight oil is found in rock formations associated with organically rich shale at unminable depths.
- Some produce directly from shales, but much tight oil production is from low-permeability siltstones, sandstones, and carbonates that are closely associated with oil-rich shale.



Core from Bakken Middle Member

“How Many Bakkens Are There?”

Source: Energy Information Administration based on data from various published studies.
Updated: March 21, 2011

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Tight Oil – Projections

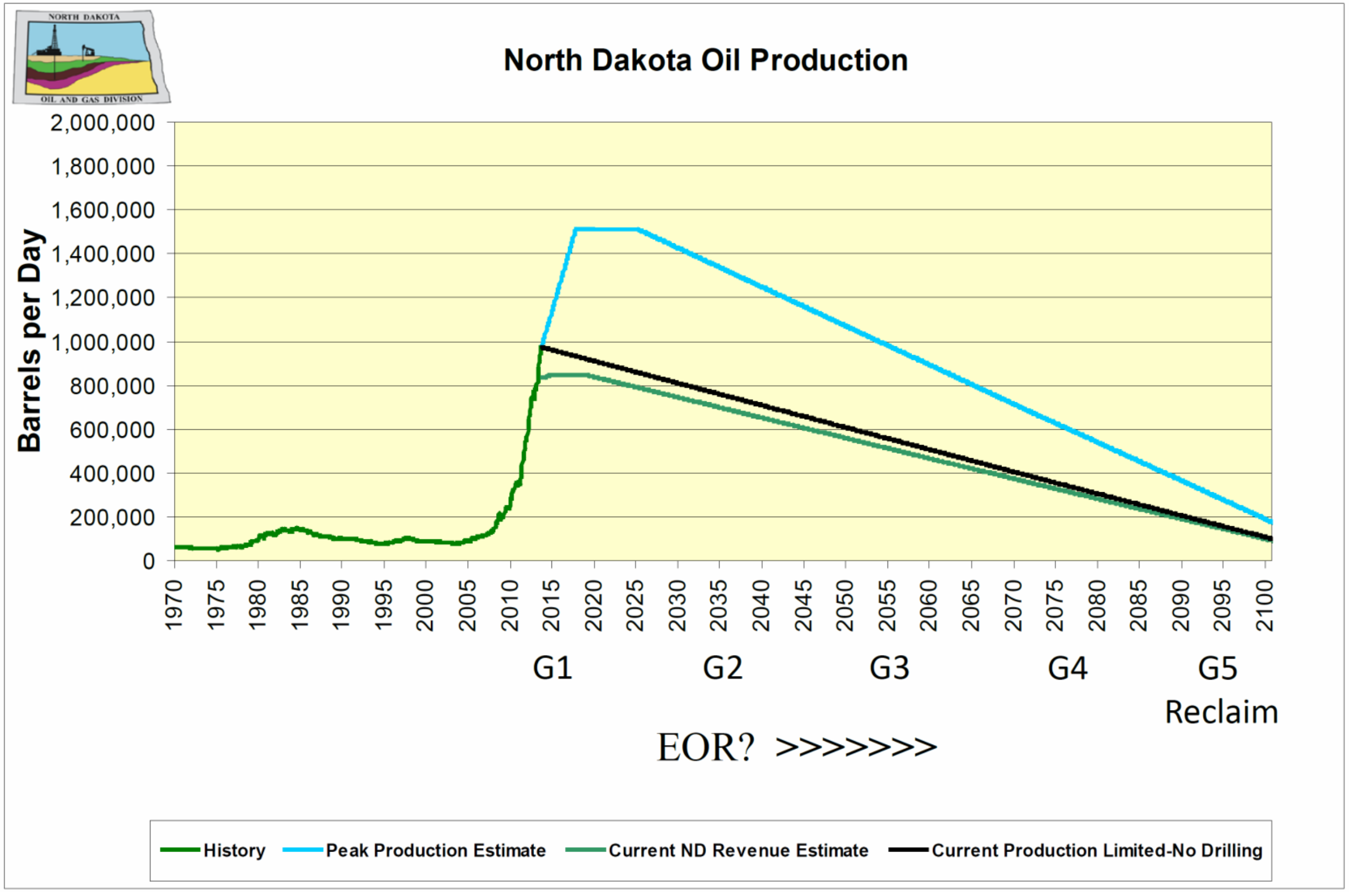
2014
Bakken and Three Forks tight oil production is over **1,200,000 bpd***.

Eagle Ford is over **1,500,000 bpd***.

*Bentek Energy report, August 2014.

2020 North American tight oil production could be over **5,000,000 bpd**.

2050 North American tight oil production could be over **3,000,000 bpd**.



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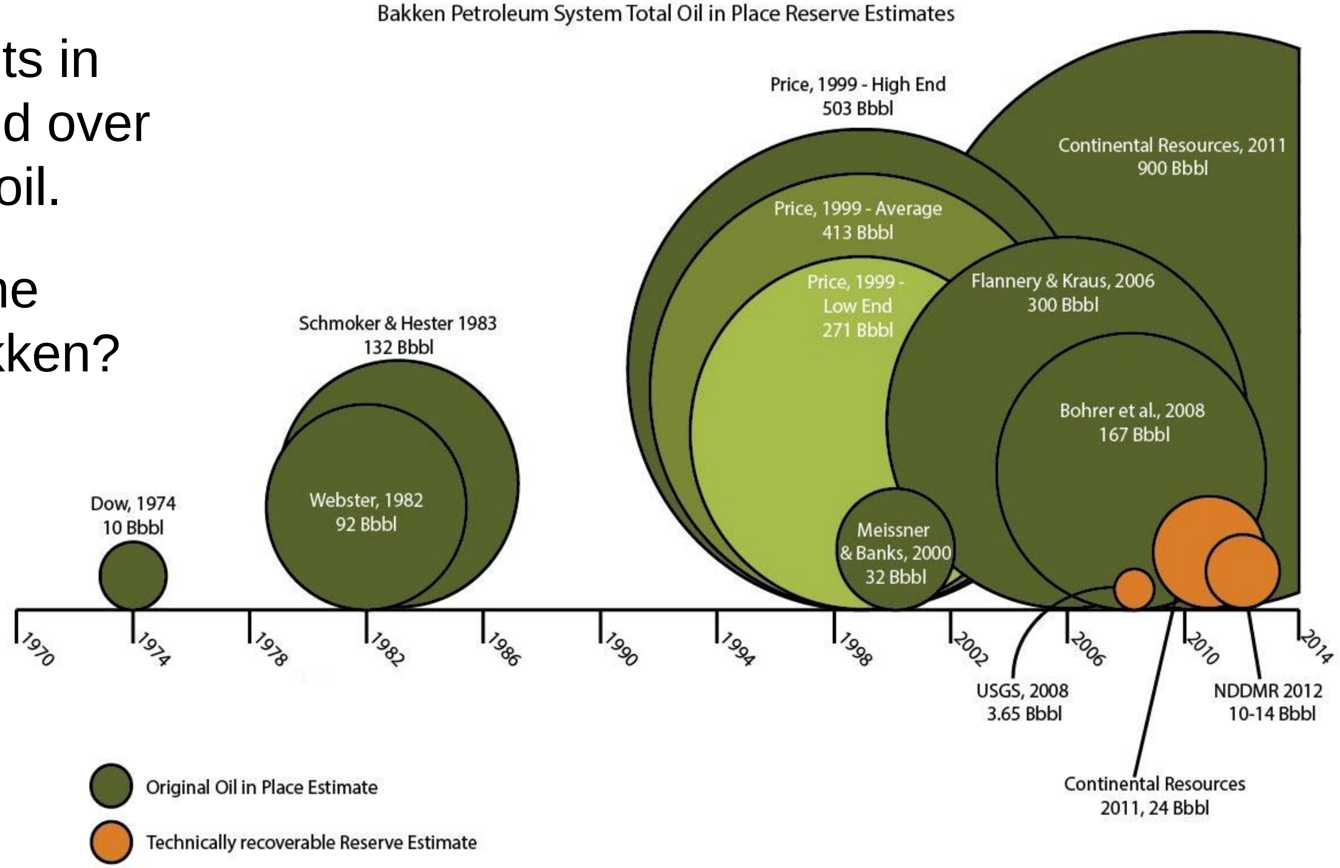
How Much Bigger Can Bakken Get?

- Currently, only a 4%–6% recovery factor.
- Small improvements in recovery could yield over a billion barrels of oil.
- Can CO_2 be a game changer in the Bakken?



Challenges of EOR in Tight Oil

- Mobility and effectiveness of fluids through fractures relative to very low matrix permeability.
- How will clays react to CO_2?
- Oil-wet nature of many tight oil reservoirs minimizes effectiveness of waterflooding.
- High vertical heterogeneity of the lithofacies complicates our understanding of flow regimes (fractures and matrix).
- Multiphase fluid flow behavior varies substantially depending on the size of the pore throats.
- Fluid viscosity and density are much different in nanoscale pores than in macroscale pores.
- How does the sorptive capacity of the organic carbon materials affect CO_2 mobility, EOR, and storage?

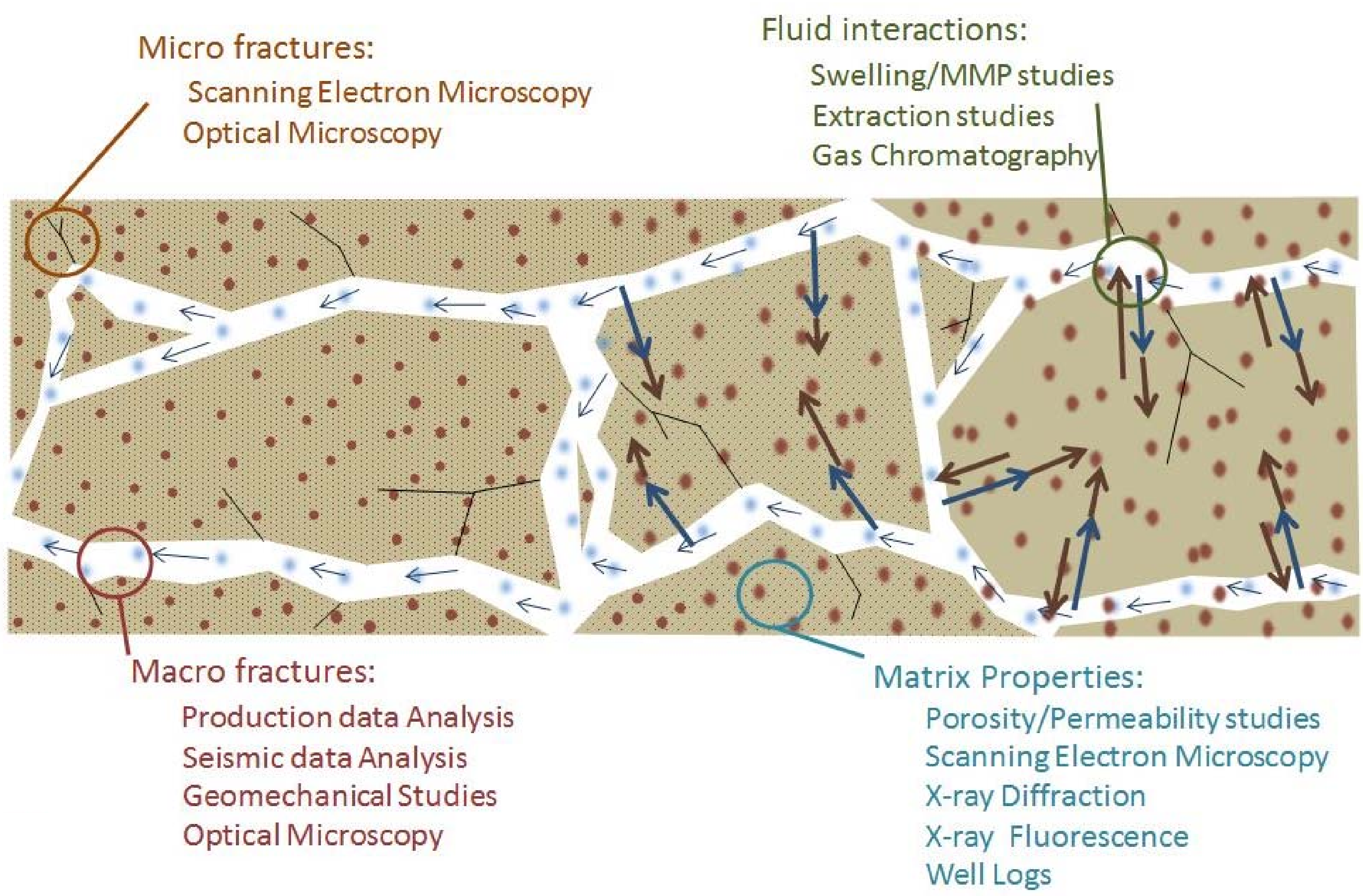
How Does CO_2 Interact with a Tight Oil Reservoir?

We need to understand:

Rock matrix

Nature of fractures (macro and micro)

Effects of CO_2 on oil



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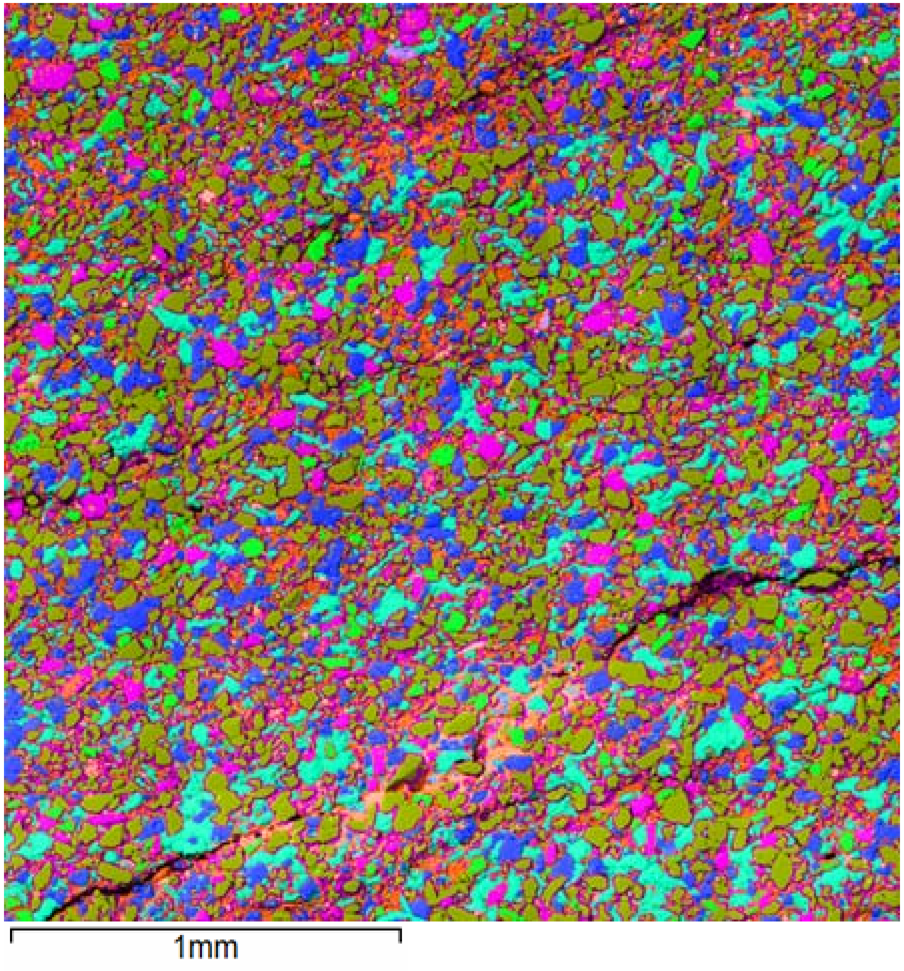
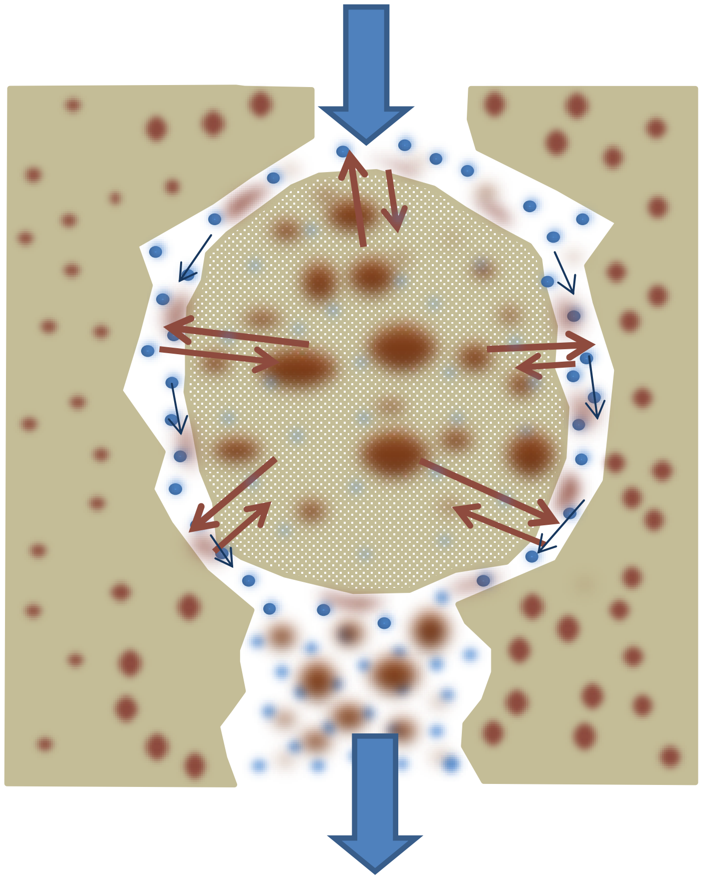
Reservoir Characterization Is Key

- Movement of fluids (CO_2 in and oil out) relies on fractures.
- Microfractures accounted for most of the porosity in the most productive zones of the Bakken.
- Generating macrofracture and microfracture data and integrating that data into modeling are essential to develop effective EOR strategies.

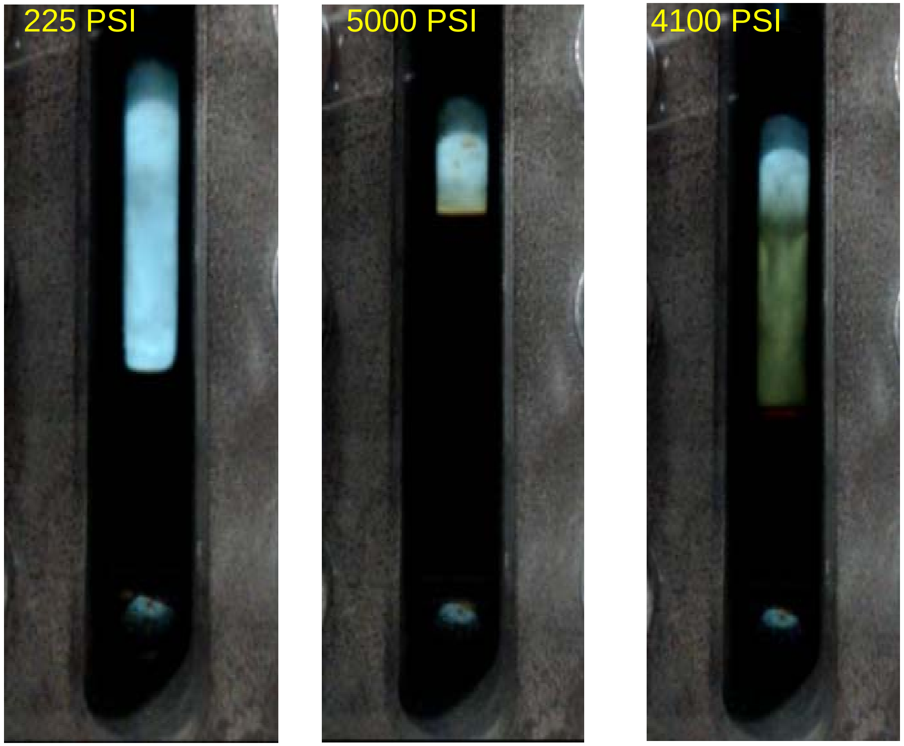
Scanning Electron Microscopy (SEM) Mineral Map of a Middle Bakken Sample (colors represent minerals; black represents porosity)



CO_2 Interactions with Tight Formation Rocks and Oil



Ability of CO_2 to Extract Oil from Lower Bakken Shale and Middle Bakken



Phase Behavior of CO_2 and Bakken Oil

Minimum miscibility pressure (MMP) is not a “bright line” number.

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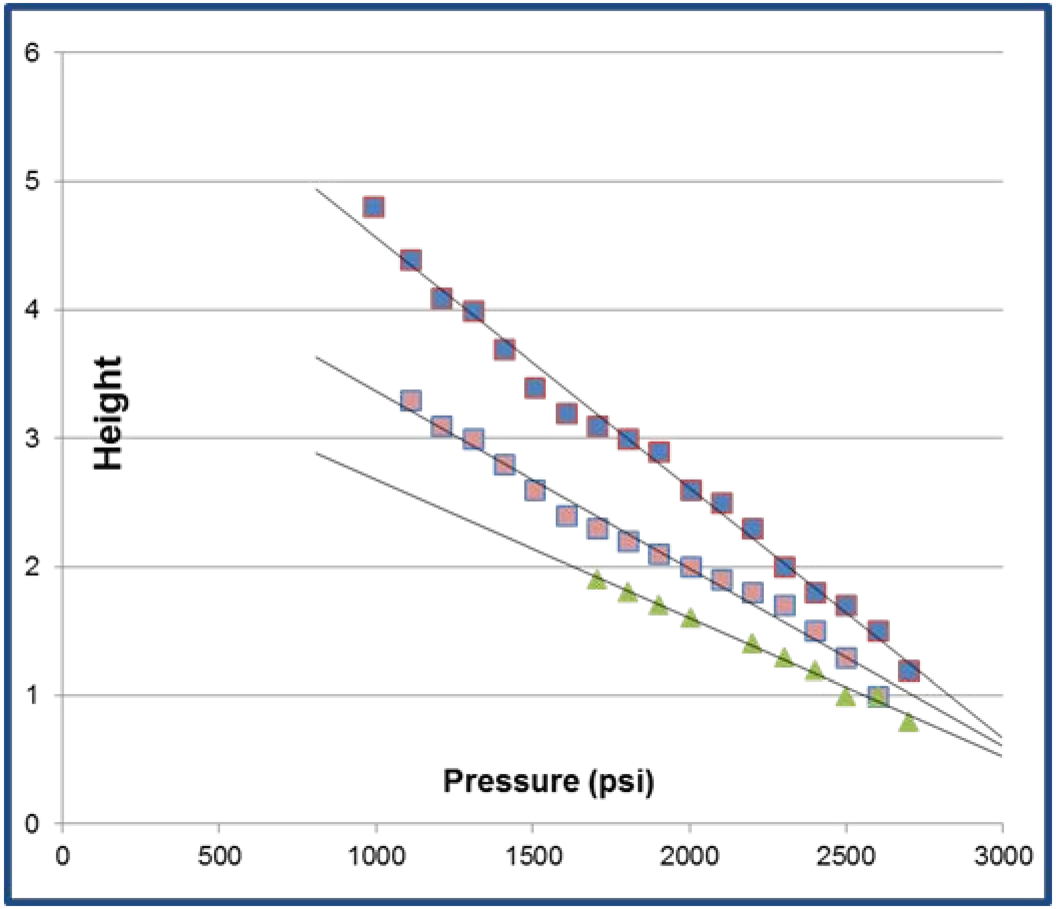
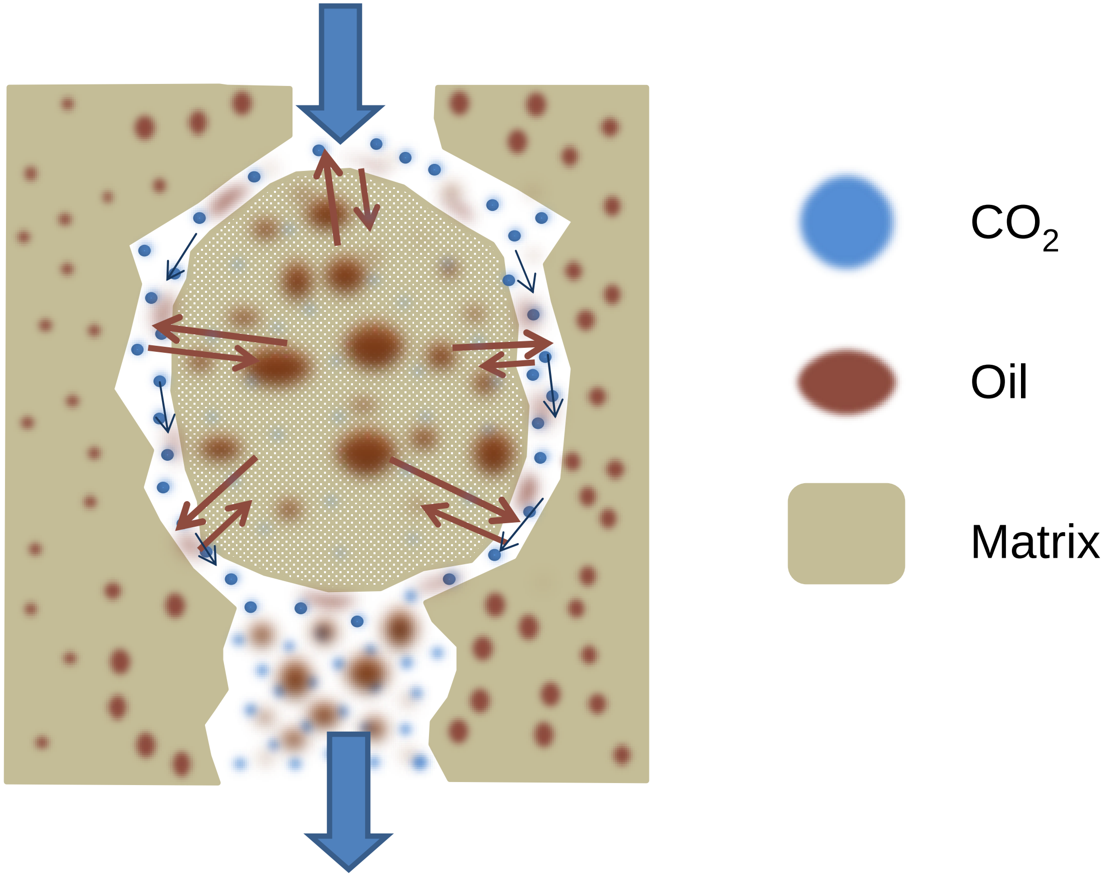
Highlights of CO_2 and Bakken Oil Miscibility Results



- Capillary rise approach appears to be cost-effective, quick-turnaround means of studying effects of CO_2 on oil.
- MMP for two "live" Bakken oils was measured to be 3180 and 3196 psi, respectively.
- These laboratory test results agree very well with equation-of-state (EOS) values determined by commercial partner.
- This technique will enable us to examine the effects that other gases (e.g., methane, ethane) have on MMP.

CO_2 Interactions with Bakken Rocks and Oil

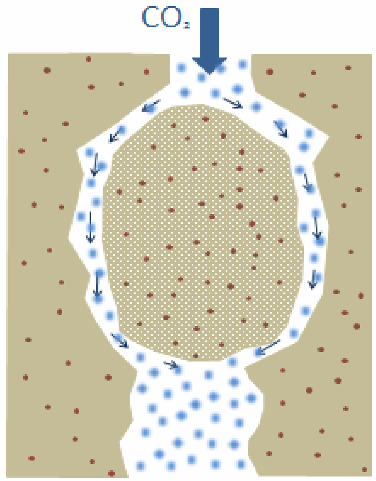
Laboratory Experiments to Examine the Ability of CO_2 to Extract Oil from Lower Bakken Shale and Middle Bakken Silty Packstone



CO_2 Extraction of Oil from Tight Rocks

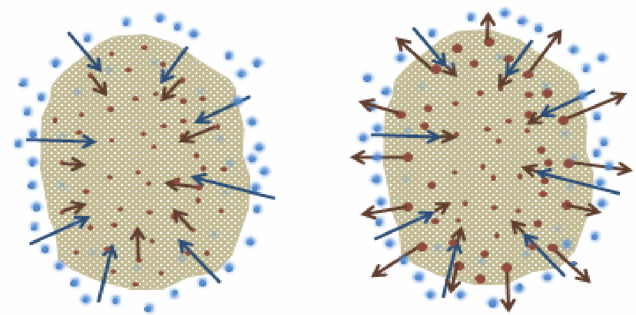
Step 1

Initial injection: CO_2 flows rapidly through fractures.



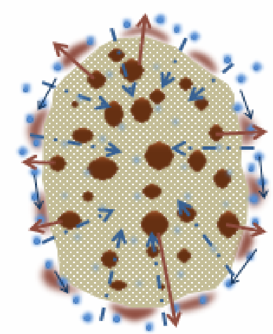
Step 2: CO_2 starts to permeate rock based on pressure gradient.

CO_2 carries oil into the rock (bad). ***and or*** CO_2 swelling pushes oil out of the rock (good).



Step 3

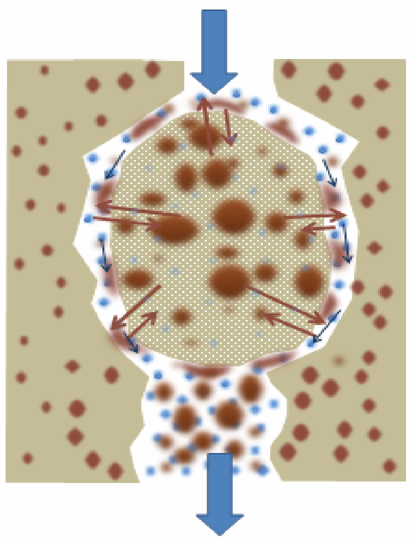
As CO_2 permeates into the rock, oil migrates to bulk CO_2 in fractures based on swelling and lower viscosity.



Step 4

CO_2 pressures equalize inside of rock.

- Oil production is now based only on concentration gradient driven diffusion.
- Oil in bulk CO_2 is swept through fractures to production well.

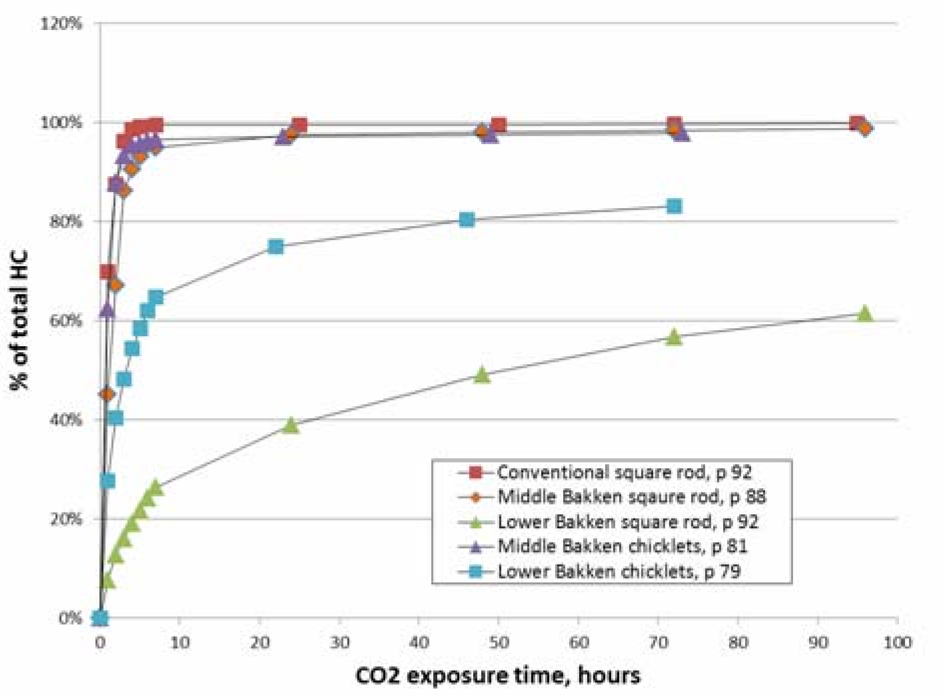


Lab-Scale CO_2 Extraction of Oil from Tight Rocks (Bakken)

CO_2 extraction of oil from samples of Middle and Lower Bakken rock.

5000 psi, 110°C (230°F) – examine effect of "unit cell" rock size and matrix lithology.

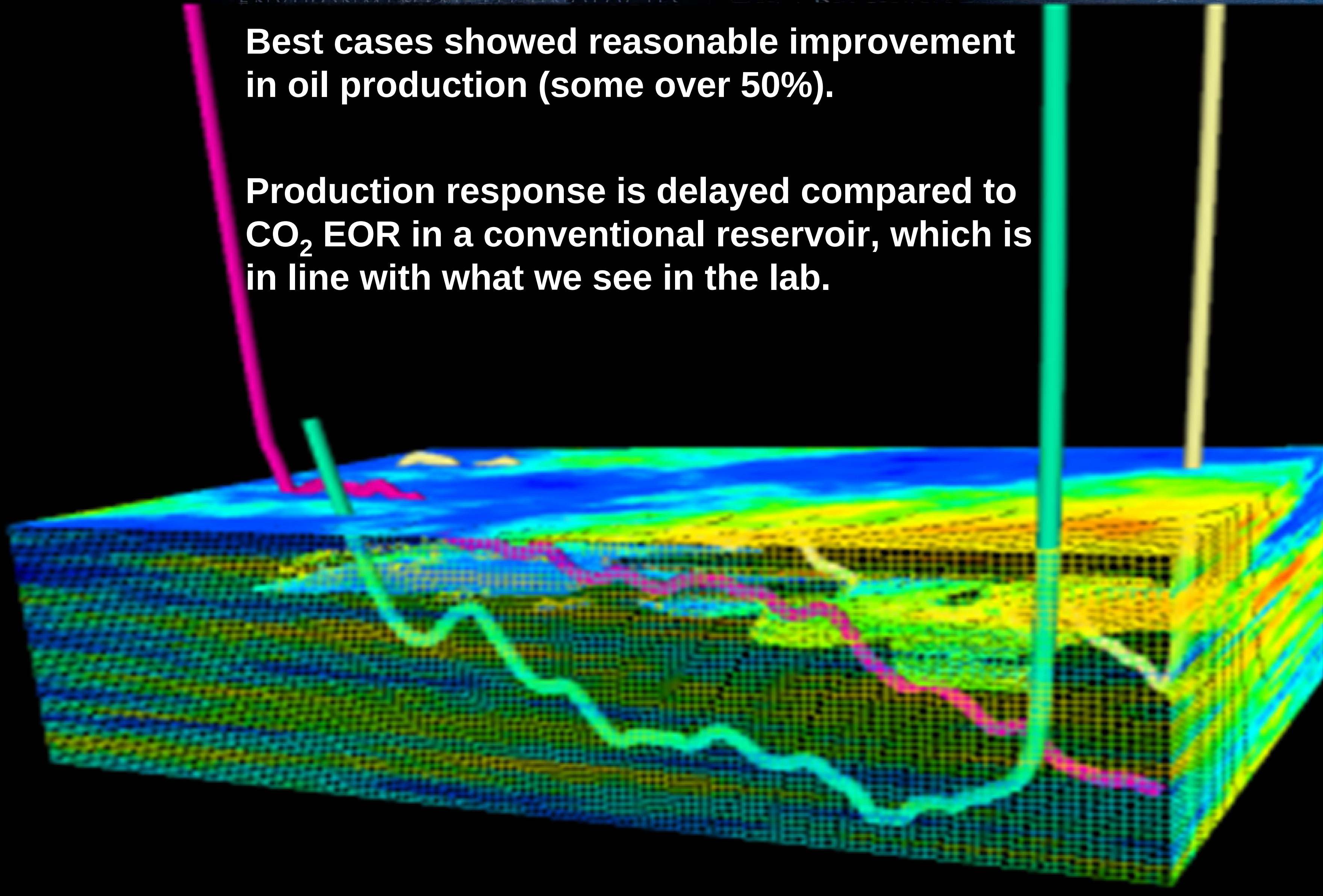
- **Over 90% from Middle Bakken.**
- **Over 60% from Lower Bakken shale.**
- **Primary mechanism is likely diffusion.**



Simulation Results Highlights

Best cases showed reasonable improvement in oil production (some over 50%).

Production response is delayed compared to CO_2 EOR in a conventional reservoir, which is in line with what we see in the lab.



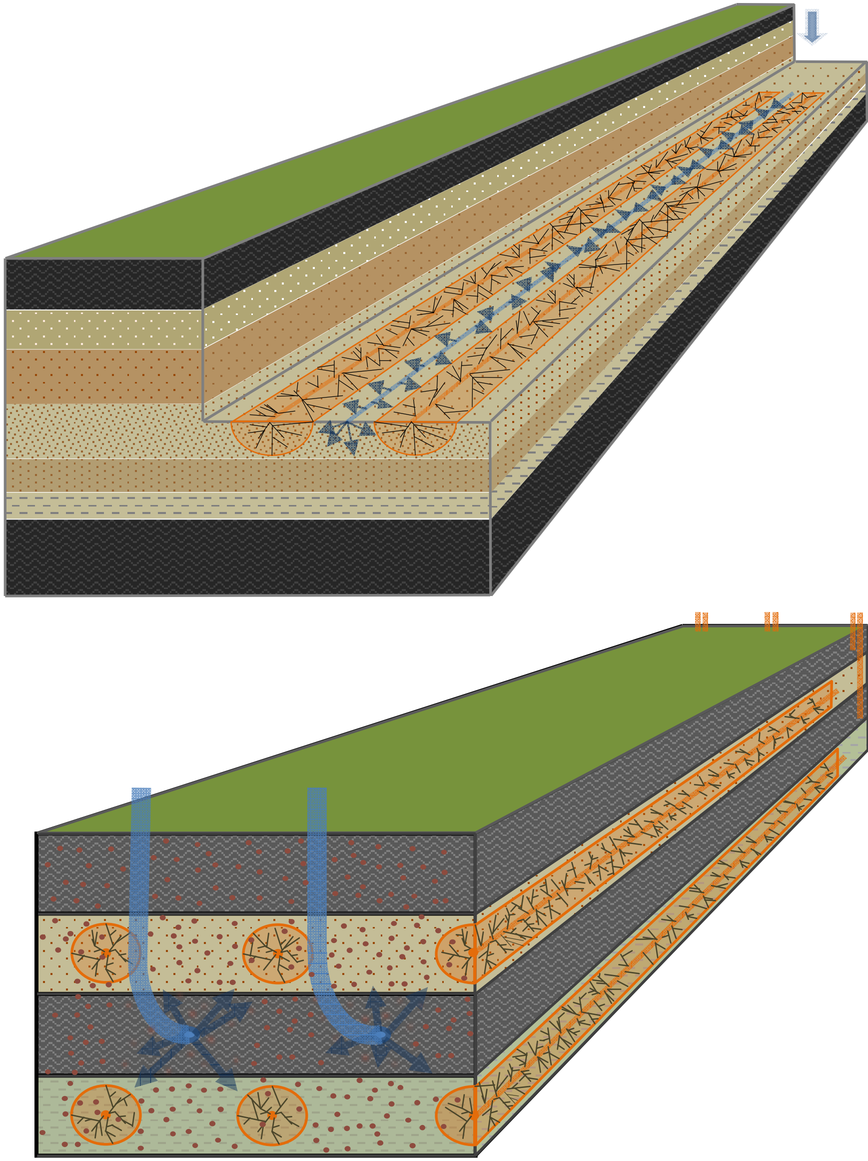
Bakken CO_2 EOR and Storage Capacity Potential

The U.S. Department of Energy (DOE) methodology for estimating CO_2 EOR and storage capacity (Carbon Sequestration Atlas of the United States and Canada, 2007) was applied to the Bakken:

- Preliminary estimate suggests that the demand to fully apply EOR in the Bakken is **2 to 3.2 billion tons of CO_2**.
- This would yield **4 to 7 billion barrels** of incremental oil.
- Potential sources of CO_2 in North Dakota may include:
  - Coal-fired power plants.
  - Dakota Gasification Company's Great Plains Synfuels Plant.
  - Refineries.
  - Natural gas-processing plants.
  - Ethanol plants.
  - Extension of Denbury Resources, Inc., pipeline from Wyoming gas plants.

"Take Home" Thoughts

- Unconventional resource will take unconventional approach to EOR.
  - Diffusion is more important than displacement.
  - Patience required, but reward may be substantial.
- Innovative injection and production schemes.
  - Use unfractured wells as injectors; rely on natural fracture system for slower movement of CO_2 through the reservoir and improved matrix contact time.
  - Injectors in the shale paired with producers in the Middle Bakken and/or Three Forks.



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"Take Home" Thoughts

- Detailed reservoir characterization will be key.
  - Microfracture characterization to improve the accuracy of dual-porosity–dual-permeability reservoir models.
  - Hydrocarbon extraction data from the various lithofacies to derive a realistic range of diffusion rates.
  - Knowledge of CO_2–oil multiphase behavior to improve modeling and scheme designs.
- Existing modeling and simulation software packages do not adequately address or incorporate the unique properties of tight oil formations:
  - Microfractures
  - High organic content
  - Combined diffusion, adsorption, and Darcy flow mechanisms
  - Physical interactions between injected CO_2 and formation fluids

Bakken Production Optimization Program

- EERC research program with goal of simultaneously improving Bakken system oil recovery while reducing its environmental footprint.
  - Consortium of producers and State of North Dakota

Bakken Production Optimization Program

www.undeerc.org/bakken

- VISIT US -

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