Bakken CO_2 Storage and Enhanced Recovery Program

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ABSTRACT

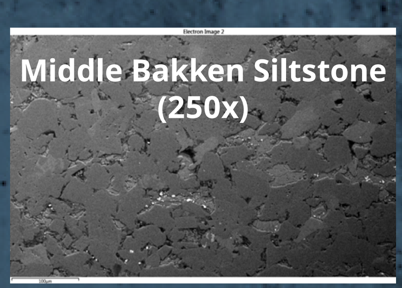
The Bakken Formation in the central region of North America is an unconventional tight oil resource with resource estimates ranging from 300 billion barrels (Bbbl) to 900 Bbbl of oil in place. However, primary recovery is typically below 10% and sustainable only with the use of stimulation because of the reservoirs' low porosity and nanodarcy-scale permeability. When considering this formation, or any tight unconventional formation, as a target for large-scale storage of carbon dioxide (CO_2) and enhanced oil recovery, much work is needed to understand the challenges associated with CO_2 injection, sustained oil production, and the implications for long-term CO_2 storage.

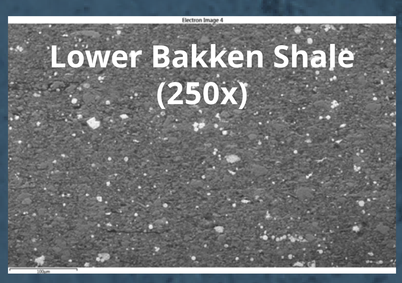
The Energy & Environmental Research Center (EERC) is conducting a research program to evaluate the Bakken Formation's ability to store CO_2 and realize improvements in oil productivity through CO_2 injection. A series of laboratory and modeling activities have been conducted in preparation for field-based activities currently being planned. The objective of these activities is to quantitatively determine the effects of injecting CO_2 into the Bakken Formation in North Dakota. The ultimate goal of the program is to develop knowledge to 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. The end result of this program will be a robust characterization data, modeling, and field experience package that will enable stakeholders to more accurately assess and predict the ultimate CO_2 storage capacity of tight, organic-rich rock formations.

BACKGROUND

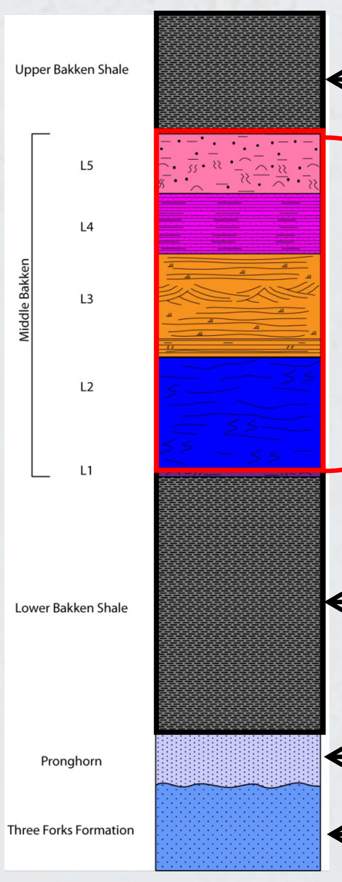
"Tight oil formations" are organic-rich, oil-saturated rocks characterized by extremely low-permeability (<0.1-mD) reservoir rock, which impedes the ability of the oil in the formation to flow freely. Tight oil formations are associated with organic-rich shale, which serves as the source rocks for the petroleum system. In some areas production may come directly from shales, but much tight oil production is from low-permeability siltstones, sandstones, and carbonates that are closely associated with oil-rich shale. Fluid flow is dominated by natural and artificially induced fractures. Because of the low matrix permeability, hydraulic fracturing of the rock is necessary to make production economic.

Scanning electron microscopy (SEM) images comparing a conventional reservoir rock to a Bakken unconventional tight rock. Black in the images represents porosity.





Bakken Petroleum System Lithology



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

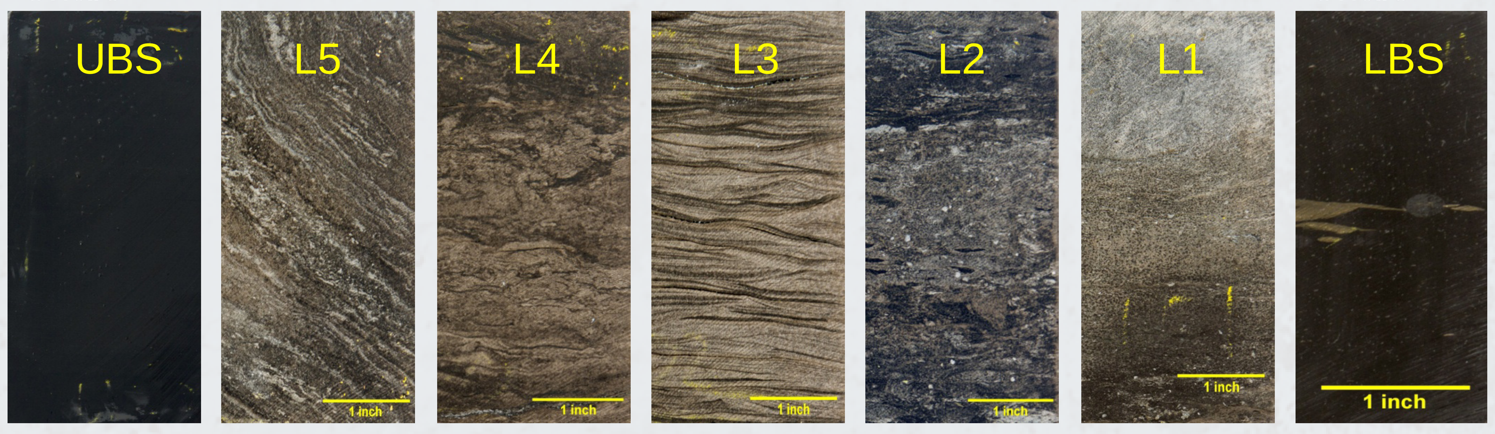
Middle Bakken: Variable lithology (up to nine lithofacies), ranging from silty sands to siltstones and tight carbonates.
- **Bakken tight reservoir rock (horizontal drilling target)**

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

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

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

The Rocks Within the Bakken Are Complex



Potential for CO_2 Storage and Enhanced Oil Recovery

While there is some degree of uncertainty in the amount of oil in the Bakken, the amount of oil in the system is on the order of magnitude of hundreds of billions of barrels. However, technically recoverable reserve estimates are on the order of tens of billions of barrels. Current recovery factors are estimated to be less than 15%. With such a huge resource, it is clear that even small improvements in recovery could yield over a billion barrels of oil. It also suggests there may be a tremendous opportunity for CO_2 storage.

To examine the potential size of the CO_2 storage capacity and enhanced oil recovery (EOR) opportunity in the Bakken in North Dakota, we applied the U.S. Department of Energy (DOE) methodology for estimating CO_2 EOR and storage capacity (DOE, 2007). This methodology includes two approaches, one based on cumulative production and another based on original oil in place (OOIP). Both approaches use estimated recovery factors as part of the calculation. It is important to note that the approaches use assumptions that were derived from the historical performance of CO_2 EOR operations in conventional oil fields.

- Using the approach that uses cumulative production/estimated recovery factor to calculate OOIP yields a Bakken storage capacity ranging from 121 to 194 million tons of CO_2 while producing 420 to 670 million barrels of incremental oil.
- The reservoir properties approach to calculate OOIP yields a Bakken storage capacity ranging from 1.9 to 3.2 billion tons of CO_2 while producing 4 to 7 Bbbl of incremental oil.

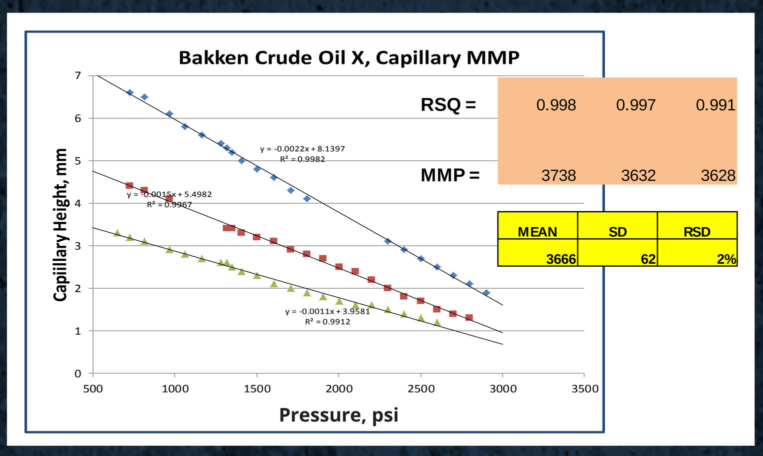
The broad ranges in these estimates, and the fact that the approaches are based on our knowledge of conventional oil reservoirs and therefore do not take into account the unique properties of tight oil formations, strongly suggest that a new methodology for estimating CO_2 storage capacity and EOR potential in tight oil formations is needed.

GOALS AND OBJECTIVES

The goals and objectives of the project are 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. The project goals and objectives relate to the goals and objectives of DOE's carbon storage program by supporting industry's ability to predict CO_2 storage capacity in geologic formations within ±30%. The project will also result in best practices manuals, especially with respect to site screening, selection, and initial characterization.

CO_2 and Bakken Oil Miscibility Study

MMP by Capillary Rise

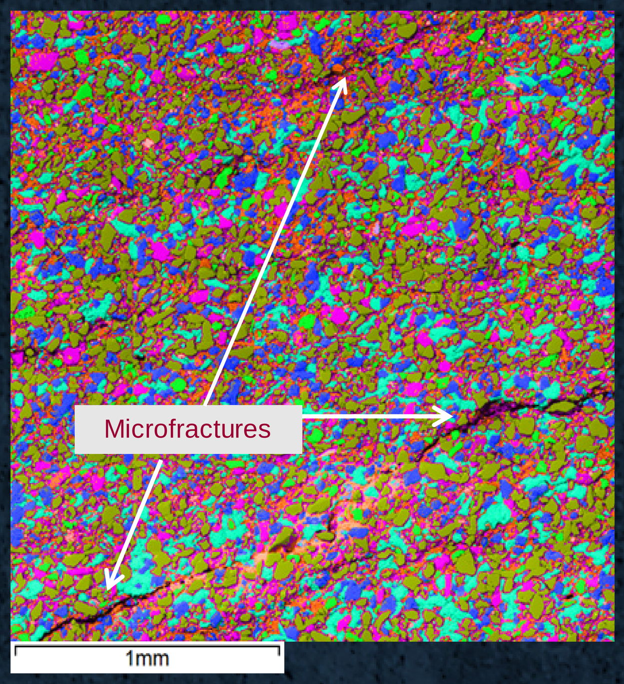


Partners provided "live" and "dead" oil samples, as well as slim-tube minimum miscibility pressure (MMP) and pressure, volume, temperature results.

These results agree very well with slim-tube and equation of state values.

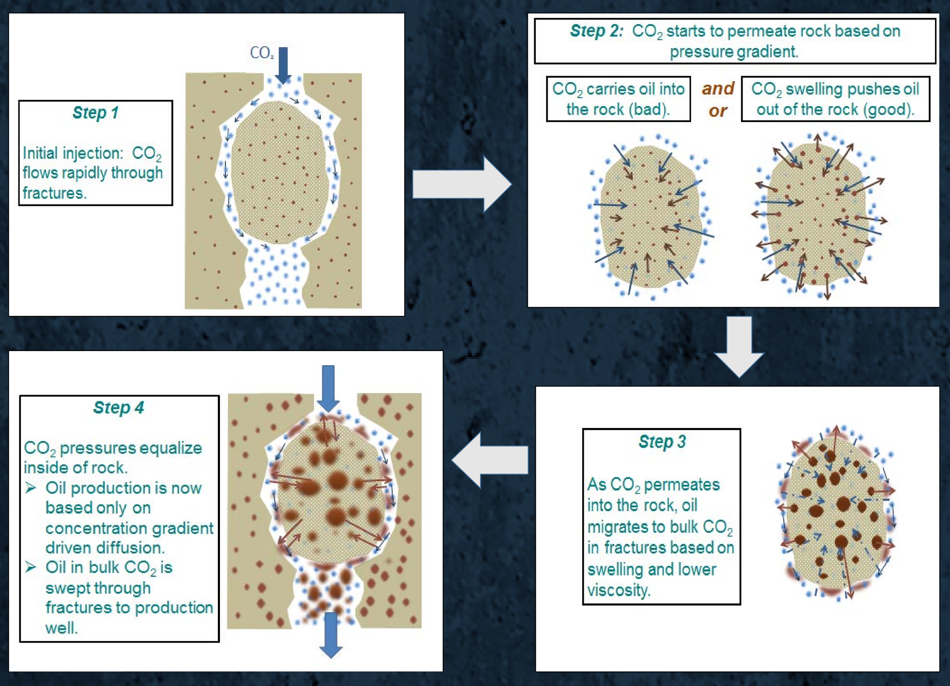
Reservoir Characterization – Fracture and Microfracture Analysis

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

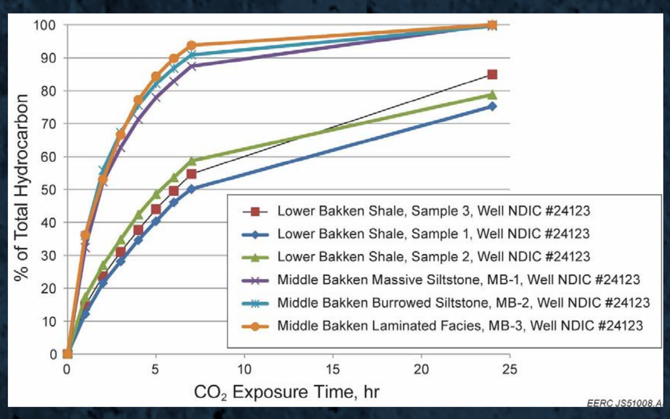


The image above is a SEM mineral map of a Middle Bakken sample (colors represent minerals; black represents porosity).

Laboratory Studies on the Ability of CO_2 to Permeate Bakken Rocks and Extract Oil

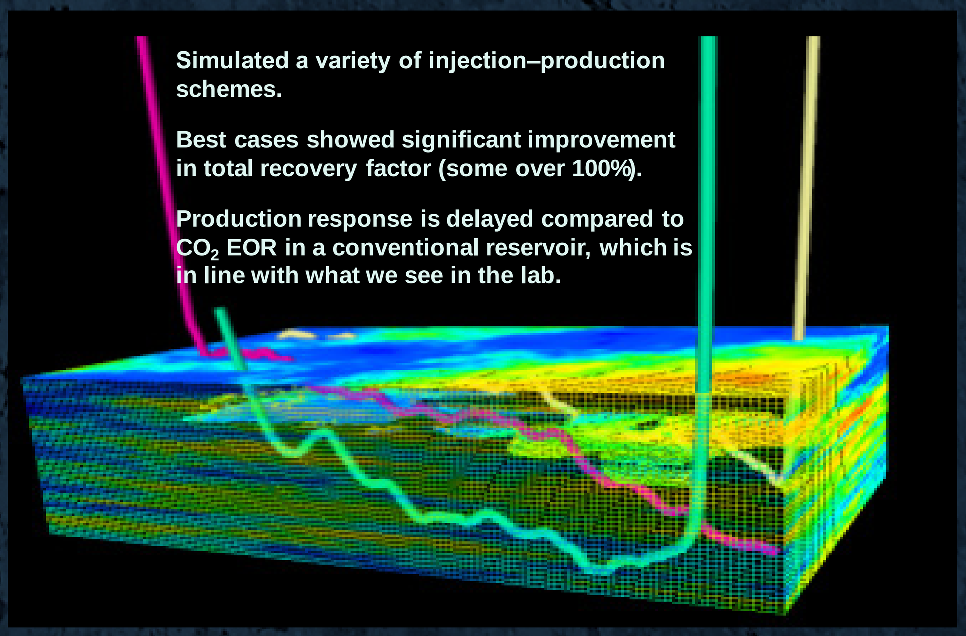


CO_2 permeation and extraction tests on Bakken shale and reservoir rock were designed to mimic fracture-dominated flow that is expected in tight oil formations. Laboratory exposures include >VERY small core samples (11-mm rod, to <3-mm crushed rock). Rock is "bathed" in CO_2 to mimic fracture flow, not swept with CO_2 as would be the case in confined flow-through tests. Recovered oil hydrocarbons are collected periodically and analyzed by gas chromatography/flame ionization detection (kerogen not determined): 100% recovery based on rock crushed and solvent extracted after CO_2 exposure. All exposures at 5000 psi, 110°C to represent typical Bakken conditions.



The image above shows a conceptual model of how injected CO_2, rock, and oil in a reservoir may interact. Results of the laboratory experiments indicated CO_2 can permeate into and oil can be recovered from Middle Bakken reservoir rock and Bakken shales in the laboratory, but rates are highly dependent on exposed rock surface areas and recoveries are highly dependent on relatively long exposure times. A much deeper understanding of the mechanisms controlling oil recovery processes in tight, hydraulically fractured systems MUST be obtained to exploit these laboratory-observations in the field.

Highlights of Geologic Modeling and Simulation Results



PROJECT ACCOMPLISHMENTS TO DATE

- A new method for measuring MMP of an oil sample has been developed.
- Laboratory experiments have demonstrated that CO_2 can effectively permeate and remove oil from upper middle, and lower Bakken rocks.
- Bakken core representing all of the different lithofacies from 13 wells have been characterized.
- Models have been constructed at the drill spacing unit and near-wellbore scales.
- A dozen injection–production scenarios have been simulated with models, with a sequential multiwell huff 'n' puff approach looking promising.
- Data from five prior field-based injection tests have been evaluated with respect to lessons learned.
- Injectivity has been demonstrated.
- Production responses have been observed, so fluid movement can be influenced.
- However, the improvements that have been predicted by models have NOT been observed.
- There are clearly large knowledge gaps between the modeling and reality in the field.
- A site has been identified in North Dakota that may serve as an injection test site. It is anticipated that the test will be conducted by the end of 2016.

Acknowledgments

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Bakken CO_2 Storage and Enhanced Recovery Program Sponsoring Partners

Other Supporters

Reference

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