Enhanced Oil Recovery in North Dakota: Opportunities and Challenges

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Fundamentals of Oil Reservoirs
Conventional vs. Bakken
Conventional Clastic Reservoir
- Dominant pore sizes fall within expectations of traditional petroleum reservoirs.

“Poor Quality” Reservoir/ Lower Seal
- Pore sizes considered to be a geological barrier to injected fluids, including CO₂.
Conventional Sandstone Reservoir vs. Bakken

Muddy Fm Sandstone (250x)

Middle Bakken Siltstone (250x)

Lower Bakken Shale (250x)

Black in the images represents pore spaces.
Conventional Oil Reservoirs Require “Traps”

- Unconformity Oil Trap
- Dome Oil Trap
- Pinchout Oil Trap
- Pinnacle Reef Oil Trap
- Updip Plug Oil Trap
Bakken Reservoirs Are Not Conventionally Trapped

Typically little to no structure.

The extremely tight nature of the rock keeps the oil in place.

Hence, the need for hydraulic fracturing.

- 14 wells drilled in one 1,280-acre unit (Mar 2013-Mar 2014)
- 4 MB, 3TF1, 4 TF2, 3 TF3
- 660' interwell spacing between same-zone wells
Stages of Conventional Oilfield Maturity

Primary recovery
• Oil is brought to the surface by natural pressure or simple mechanical pumping.
• Can last a few years to decades, depending on reservoir conditions.

Secondary Recovery
• Also called enhanced oil recovery (EOR).
• Involves injection of water to improve oil mobility.
• Also known as “waterfloods.”
• Typically lasts multiple decades.

Tertiary Recovery
• EOR that occurs after waterflood is no longer economically effective.
• EOR using a different fluid, most commonly CO₂.
• Typically planned to last at least 20 years.
Maturity of North Dakota Oil Production

- Conventional Primary Stage
- Bakken Primary Stage
- Conventional Secondary Stage

Graph showing production in million barrels per day and number of producing wells from 1950 to 2010.
Maturity of the Permian Basin
Primary, Secondary, Tertiary, and “Unconventional Oil” Projections

* Courtesy of Oxy Permian (9/05) ** “Unconventional Oil Projections”

Melzer Consulting 2005
Tertiary Recovery

**CO₂ EOR – How It Works**

- CO₂ dissolves in oil, lowers oil viscosity, and swells the oil, thereby allowing oil to flow more freely.

- CO₂ injection repressures the reservoir, thereby reestablishing a drive mechanism.

- A portion of the injected CO₂ will be produced with the oil and water, separated at the surface, and recycled to be used again in the reservoir.

- Typically 90%–100% of the purchased CO₂ volume is retained in the reservoir (dead end pores and channels).
U.S. CO$_2$ EOR

- **Production (2013)**
  - 350,000 BOPD from CO$_2$.
  - *Increasing production and expansion to more fields.*

- **Projections**
  - DOE estimates a U.S. recoverable resource from CO$_2$ EOR of up to 137 billion barrels.

- **Policy Issues/Questions**
  - Current shortage of CO$_2$.
  - Encourage capture and transportation of anthropogenic CO$_2$?
## Comparison of Reservoir Characteristics
(BLDU and SSAU data courtesy of Hess Corporation)

<table>
<thead>
<tr>
<th></th>
<th>North Dakota (BLDU)</th>
<th>Permian (SSAU)</th>
<th>Weyburn</th>
<th>Bakken (Dunn Co. field)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OOIP (mmbbls)</td>
<td>280</td>
<td>1,000</td>
<td>1,400</td>
<td>245</td>
</tr>
<tr>
<td>Depth (ft)</td>
<td>10,170</td>
<td>5300</td>
<td>4760</td>
<td>10,830</td>
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<tr>
<td>Lamination</td>
<td>High</td>
<td>Med</td>
<td>Low</td>
<td>Low to High</td>
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<tr>
<td>Min. Misc. Press. (psi)</td>
<td>3000</td>
<td>1300</td>
<td>1740</td>
<td>3200</td>
</tr>
<tr>
<td>Temperature (deg. F)</td>
<td>251</td>
<td>104</td>
<td>139</td>
<td>230</td>
</tr>
<tr>
<td>Ult. Rec. Factor w/ CO2 (%)</td>
<td>35-45</td>
<td>&gt;63</td>
<td>36</td>
<td>Unknown</td>
</tr>
<tr>
<td>Tertiary Rec. Factor (%)</td>
<td>5-10</td>
<td>~14</td>
<td>~10</td>
<td>Unknown</td>
</tr>
<tr>
<td>Oil Gravity (API)</td>
<td>42</td>
<td>35</td>
<td>25-34</td>
<td>36-44</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>13</td>
<td>12</td>
<td>15-26</td>
<td>2-10</td>
</tr>
<tr>
<td>Initial Water Saturation (%)</td>
<td>21</td>
<td>16</td>
<td>32</td>
<td>1-53</td>
</tr>
<tr>
<td>Permeability (mD)</td>
<td>3-6</td>
<td>9</td>
<td>10-30</td>
<td>0.07-0.009</td>
</tr>
<tr>
<td>Well Spacing</td>
<td>80-160 acres</td>
<td>20 acres</td>
<td>79 acres (Initial) Infill Drilled Later</td>
<td>640 or 1280 acres spacing units 8 to 20 wells per 1280</td>
</tr>
</tbody>
</table>
For oil fields with multiple operators, unitization of the field is needed to:

1. Implement secondary and tertiary EOR projects within an established field.
2. Ensure coordinated fluid injection and production.
3. Protect correlative mineral rights.
Oilfield Unitization Process in North Dakota

North Dakota Department of Mineral Resources (ND DMR) must find:

- Unitization is necessary to increase ultimate recovery of oil.
- Proposed method of operation is technically feasible.
- Estimated cost of operations will not exceed value of incremental oil.
- Unitization is for the common good.
- 60% participation threshold.
North Dakota Oilfield Unitization
Requires Exceptional Technical Knowledge

Geological Characterization
- Lithology
- Porosity
- Permeability
- Geohydrodynamics
- Geochemistry
- Geophysical data

Reservoir Engineering
- Reservoir performance history
- Pressure history
- Original oil in place calculations
North Dakota Oilfield Unitization Decision-Making Process

• Petition to form unit is submitted to DMR by operators:
  – Operational plan
  – Economics
  – Supporting documentation

• Public hearings with testimony:
  – Petitioners
  – Expert witnesses
  – Stakeholders and interested parties

• DMR accepts or rejects petition based on technical, economic, legal, and regulatory considerations.
Example ND Conventional CO\textsubscript{2} EOR Candidate Beaver Lodge Devonian Unit (Williams Co.)

Geological structure defines the surface footprint of the unit.

Geological structure ensures injected CO\textsubscript{2} is contained within the unit.

Projected 14 to 28 million bbl of incremental oil from use of CO\textsubscript{2}.

Anticline structure traps oil.
Conventional Oilfield CO₂ EOR Opportunities in North Dakota

KLJ (2014) report shows:

- In 86 conventional unitized oil fields:
  - 280 to 631 million bbl of incremental oil
  - 47 to 283 million metric tons of CO₂ needed
What About the Bakken?

300 to 900 BILLION bbl in place.

- Currently, only a 4–6% recovery factor.
- Small improvements in recovery could yield over a billion barrels of oil.
- Can CO₂ work in the Bakken?
Estimation of Bakken CO₂ EOR Potential

The DOE methodology for estimating CO₂ EOR and storage capacity (2007) was applied to the Bakken in North Dakota:

- The approach that uses cumulative production/estimated recovery factor to calculate original oil in place (OOIP) yields an EOR resource potential ranging from **420 to 670 million bbl** of incremental oil.
  - This would require 121 to 194 million tons of CO₂.
- The reservoir properties approach to calculate OOIP yields an EOR resource potential ranging from **4 to 7 billion bbl** of incremental oil.
  - This would require from 1.9 to 3.2 billion tons of CO₂.

The Size of the Prize Is Tremendous!
Primary Technical Challenges of EOR in the Bakken

• Highly fractured nature of the reservoirs and lack of structure make controlling the movement of injected fluids difficult.
  ♦ Major contrast between fracture and matrix permeability allows CO₂ “short circuiting”
• Presence of swelling clays in some Bakken reservoirs means injection of water can cause reduction in permeability and impede oil production.
• Oil-wet nature of much of the Bakken will also minimize effectiveness of waterflooding.
• Fluid flow behavior can be much different in nanoscale pores than in macroscale pores, and the consequences of that behavior on oil production are poorly understood.
• Development of solutions to these challenges is in the early R&D stages.
EERC Efforts to Address Bakken EOR Challenges
Oil can be recovered from Middle Bakken rock and Bakken Shales in the lab, but:

• Rates are *highly* dependent on exposed rock surface areas.
• Recoveries are *highly* dependent on 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 LAB-scale observations in the field at reservoir scale.
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, which is in line with what we see in the lab.

Simulation is great...

But what happens in the real world?
Six Bakken Field Injection Tests to Date

- CO$_2$, water, and field gas have been tested.
- Lessons learned:
  - Injectivity has been demonstrated.
  - Production responses have been observed, so fluid movement can be influenced.
  - But the improvements that have been predicted by models have NOT been observed.

- Clearly there are gaps between the modeling and reality in the field.
Primary Legal Issues Facing EOR in the Bakken

- Unitization process is based on over 100 years of history and experience regulating thoroughly understood conventional reservoirs throughout the United States.

- Unconventional tight oil production as we know it today is less than 10 years old, and adaptation of the legal process to the unique conditions of the Bakken has only just begun.

- Highly fractured nature of the reservoirs and lack of geologic structure make controlling the movement of injected fluids difficult, which means it is difficult to ensure protection of neighbors’ correlative rights.

- Lack of geologic structure and inability to predict fluid movement make it difficult for a unitization boundary to be defined.
Bakken EOR “Take Home” Thoughts

• Unconventional resource will take unconventional approach to EOR.

• Patience required, but reward may be substantial.

• Innovative injection and production schemes need to be developed and tested.

• Legal and regulatory adaptation is necessary.

• Widespread deployment of EOR in the Bakken is years away.

• The price of oil, CO₂ availability, and the size of the prize will be the drivers.
Conventional Wisdom: ND CO₂ EOR Opportunities Are Limited

• North Dakota’s reservoirs are more compartmentalized, more heterogeneous, deeper (high T, high P), and have less reserve base, leading to higher risk and cost per incremental bbl than those in Texas and Saskatchewan…

• But There Is Some Good News Too!

• The size of the prize in conventional fields is substantial.

• In the past, oil revenue has had to pay for everything (source, PL, field infrastructure).

• In the coming world of CCS/CO₂ EOR, capture and possibly transportation may be at least covered by others, leaving economics of the field to control new implementation of EOR projects.

• Low oil prices have not precluded the initiation of big CO₂ EOR projects. Weyburn started in 2000, when Williston Basin crude oil was selling for $10 (or less) per barrel.

• North Dakota conventional reservoir modeling suggests several fields are amenable.

• The Bakken resource is enormous and continues to attract interest from major players.
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