Integration of Enhanced Oil Recovery with CO$_2$ Storage in Mature Oil Fields of the Ordos Basin, China: Opportunities and Challenges

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Outline

What we have accomplished in Wyoming
- Determined CO$_2$-EOR potential in Wyoming
- Monitored CO$_2$-EOR activities in Wyoming
- Developed an integrated approach for CO$_2$ EOR and geological storage project

Opportunities of the CO$_2$ EOR/storage in the Ordos Basin
- The CO$_2$-EOR potential of major oil fields in the Ordos Basin
- The capture-ready, cost affordable CO$_2$ sources
- Favorable environments for applying the integrated approach to CO$_2$ EOR/geological storage

Challenges of the CO$_2$ EOR/storage in the Ordos Basin
- Low reservoir pressure, low porosity, low permeability
- High reservoir heterogeneity
- Absent infrastructures
Wyoming Oil and Gas Map
Enhanced oil recovery opportunities in Powder River Basin – the Minnelusa

- Approximately 150 candidate Minnelusa oil fields. Many have gone through secondary recovery water flood stage and appear ideal for CO₂ miscible flooding

- 1.2 billion barrels of original oil in place (OOIP), CO₂ flooding adds 15% additional production, 180 million barrels @ $80/barrel = $14.4 billion

- Final CO₂ storage capacity is available in EOR projects after stranded oil recovery is complete
CO₂ flood enhanced oil recovery returns and CO₂ requirements, WY

<table>
<thead>
<tr>
<th>Recovery 15% OOIP (barrels)</th>
<th>180 million barrels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value @ $80/barrel</td>
<td>$14.4 billion</td>
</tr>
<tr>
<td>CO₂ required @ 10 mcf/barrel</td>
<td>1.8 billion mcf (1.8 TCF)</td>
</tr>
<tr>
<td>Tonnes of CO₂ needed</td>
<td>93 million tonnes</td>
</tr>
<tr>
<td>(19.3 mcf/tonne)</td>
<td></td>
</tr>
<tr>
<td>CO₂ cost @ $2/mcf</td>
<td>$3.6 billion</td>
</tr>
</tbody>
</table>
CO₂ projects and pipelines in Wyoming

Fields:
- Salt Creek
- Monell
- Los Solder
- Beaver CR
- Wertz

Pipeline:
- 33 mile, 8”
- 125 mile, 16”

CO₂ Supply:
- Moxa Arch/ Shut Creek
Salt Creek CO₂ flooding performance

Incremental oil production increase 12,000 barrels/day in 2010
Beaver Creek Madison Limestone
CO$_2$-EOR production

Pre-Flood
320 Bopd
32000 Bwpd

Initiated CO$_2$ Injection 7/3/08

Current Rate
1200 Bopd
22000 Bwpd

Oil Cut Increase from 1% to 5%
As a CO₂-EOR project proceeds:

- About two thirds of the CO₂ is recycled
- About one third of the CO₂ stays in the reservoir
<table>
<thead>
<tr>
<th>Field</th>
<th>Formation</th>
<th>CO₂ Capacity (million tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amos Draw Complex</td>
<td>Muddy</td>
<td>13.8</td>
</tr>
<tr>
<td>Kitty</td>
<td>Muddy</td>
<td>18.8</td>
</tr>
<tr>
<td>Hartzog Draw</td>
<td>Shannon</td>
<td>18.5</td>
</tr>
<tr>
<td>Buck Draw North</td>
<td>Dakota</td>
<td>15.6</td>
</tr>
<tr>
<td>Powell</td>
<td>Frontier</td>
<td>38.0</td>
</tr>
<tr>
<td>Spearhead Ranch</td>
<td>Frontier</td>
<td>6.9</td>
</tr>
<tr>
<td>Sand Dunes</td>
<td>Muddy</td>
<td>12.4</td>
</tr>
<tr>
<td>House Creek</td>
<td>Sussex</td>
<td>8.2</td>
</tr>
<tr>
<td>Scott</td>
<td>Parkman</td>
<td>5.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td><strong>137.6 million tons</strong></td>
</tr>
</tbody>
</table>
Development of a Integrated Approach

Coal Mine → CBM H₂O → Coal > Liquids, Gases, Electrons

Electrons → Gases → CO₂

CBM H₂O → Liquids → Diesel

→ Compression and CO₂ Injection

→ CO₂ Storage in Depleted Compartmentalized Gas Fields

→ Production/Compression

→ CO₂ Injection

→ Oil

→ 120 Million Barrels of Stranded Oil

→ Enhanced Oil Recovery or CO₂ Final Storage
Resource overlap makes integrated planning possible.
Opportunities of the CO\textsubscript{2} EOR/Geological Storage in the Ordos Basin

- Lower primary and second recovery rate provide a huge potential for the tertiary CO\textsubscript{2}-EOR

- The capture-ready, cost affordable CO\textsubscript{2} sources

- Favorable environments for applying the integrated approach CO\textsubscript{2} EOR and storage strategy
The Ordos Basin Oil and Gas resources

Resource:
- Oil $8.58 \times 10^9$ tonnes
- Gas $10.7 \times 10^{12}$ m$^3$

Reserves (approximately):
- Oil $4.5 \times 10^9$ tonnes
- Gas $2.5 \times 10^{12}$ m$^3$

Average recovery (preliminary and secondary) is from 10 to 15%
Potential investment returns from CO₂ EOR Projects in the Ordos Basin

(Proven Oil Reserves 4.5 billion tonnes or 32 billion barrels)

<table>
<thead>
<tr>
<th>Recovery 10% OOIP (barrels)</th>
<th>3.2 billion barrels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value @ $80/barrel</td>
<td>$257 billion</td>
</tr>
<tr>
<td>CO₂ required @ 10 mcf/barrel</td>
<td>32 billion mcf (32 TCF)</td>
</tr>
<tr>
<td>Tonnes of CO₂ needed (19.3 mcf/tonne)</td>
<td>1665 million tonnes</td>
</tr>
<tr>
<td>CO₂ Cost @ $2/mcf</td>
<td>$64 billion</td>
</tr>
</tbody>
</table>
Captured-Ready, High-Concentration CO$_2$ from Coal Conversion Plants

An Example from a methanol Plant at Yulin, Shaanxi Province

- Methanol: 0.6 Mt/y
- Coal utilized: 1.8 Mt/y
- CO$_2$ emitted: 4.7 Mt/y
- Water used: 6.0 Mt/y
Unique Characteristics of the Triassic Oil Reservoirs in the Ordos Basin

- Low reservoir porosity (<10%)
- Low reservoir permeability (<1 md)
- Low oil saturation
- Abnormally low reservoir pressure
- Higher reservoir heterogeneity
Comparisons of the Targeted CO2-EOR Reservoirs (Miserable Flooding)

<table>
<thead>
<tr>
<th></th>
<th>Pressure</th>
<th>Porosity</th>
<th>Perm</th>
<th>Facies</th>
<th>Gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>US</td>
<td>Over/normal</td>
<td>10–25</td>
<td>&gt; 1</td>
<td>Marine</td>
<td>Medium/light</td>
</tr>
<tr>
<td>Ordos</td>
<td>Under</td>
<td>&lt;10</td>
<td>&lt;0.5</td>
<td>Fluvial</td>
<td>Light</td>
</tr>
</tbody>
</table>
Challenges for CO$_2$-EOR practices in the Ordos Oil Fields: Reservoir Heterogeneity

A typical fluvial facies distribution for the Triassic reservoirs in the Ordos Basin
Challenges for CO$_2$-EOR practices in the Ordos Oil Fields: Reservoir Heterogeneity

A typical fluvial porosity distribution for the Triassic reservoirs in the Ordos Basin

Porosity model
What for Next: to Facing the Challenges

Pre-CO2 Injection to Establish Reservoir Pressures

Graph showing the change in reservoir pressure and CO2 injection over time.
What for next: to Facing the Challenges

Design a CO₂ EOR Project in the Ordos Basin

- Reservoir and targeted pay zones screening
- 3-D Geological Modeling
- Reservoir Hydrologic modeling
- Lab CO₂ displacement experiments
- Compositional CO₂ Coreflood Simulation
- Compositional CO₂ Reservoir Simulation
- Economic analysis
- CO₂-EOR project implementation design