Storage of CO₂ with CO₂-EOR: Potential, Issues and Commercial Drivers

Prepared for:
ARB Technical Discussion Series:
CO₂ Enhanced Oil Recovery (EOR)

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Main Topics of Presentation

- Overview of CO\textsubscript{2}-EOR
- Potential for expanding CO\textsubscript{2}-EOR to other resources and applications
  - With focus on potential residual oil zones (ROZs)
- CO\textsubscript{2} storage associated with CO\textsubscript{2}-EOR
- Other issues and considerations
CO$_2$-EOR: A Closed-Loop System

- Purchased CO$_2$ from Anthropogenic and/or Natural Sources
- Injected CO$_2$
- Recycled CO$_2$ from Production Well

- CO$_2$ Dissolved (Sequestered) in the Immobile Oil and Gas Phases
- CO$_2$ Stored in Pore Space
- Zone of Efficient Sweep

- Immobile Oil
- Driver Water
- CO$_2$
- Water
- Miscible Zone
- Oil Bank
- Additional Oil Recovery
- Additional Oil Recovery
Projected CO₂-EOR Operations and CO₂ Sources (2020)

Oil Production (2020)
- CO₂-EOR Projects: 147
- Oil Production (MBbl/d): 638

CO₂ Supplies (2020)
- Number of Sources: 30
  - Natural: 6
  - Industrial: 24
- CO₂ Supply (Bcf/d)
  - Natural: 3.4
  - Industrial: 3.1

Source: Advanced Resources International, Inc., based on Oil and Gas Journal, 2014 and other sources.
Current CCS Activities and Project Plans are Dominated by CO₂-EOR Applications

- Globally, 15 large-scale CCS projects are in operation, with a further 7 under construction.
  - represents a doubling since the start of this decade
  - total CO₂ capture capacity - ~ 40 million tonnes/year
- Of these 22 projects, 16 are injecting CO₂ for EOR
- In the near term, majority (73%) of all global CCS projects will be pursued by injecting CO₂ for EOR

Source: Global CCS Institute
Size of the “Main Pay” CCUS “Prize” with CO₂-EOR

- With “Current Technology,” the economically viable* oil recovery and demand for CO₂ from the main pay of domestic oil fields (lower-48) is:
  - 22 billion barrels of crude oil
  - 9 billion metric tons of CO₂

- Use of “Next Generation” technologies increases these values to:
  - 78 billion barrels of crude oil
  - 26 billion metric tons of CO₂

- This demand for CO₂ is equal to CO₂ capture from 45 to 130 GWs of coal-fired power.

<table>
<thead>
<tr>
<th>Resource Area</th>
<th>Economic Oil Recovery (BBbls)*</th>
<th>Demand for Purchased CO₂ (Billion Metric Tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower-48, Onshore</td>
<td>21</td>
<td>63</td>
</tr>
<tr>
<td>Lower-48, Offshore</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>78</td>
</tr>
</tbody>
</table>

*At oil prices of $80 to $90/B, CO₂ costs of $36 to $40/mt and 20% ROR (before tax).
**Less than 0.5 Bmt.
“Next Generation” CO₂ Enhanced Oil Recovery

Use of more efficient CO₂-EOR technologies and extension of these technologies to new oil resource settings constitutes “next generation” CO₂-EOR:

1. Scientifically-based advances in CO₂-EOR technology
2. Integrating CO₂ capture with CO₂ utilization by CO₂-EOR
3. Application of CO₂-EOR to residual oil zones (ROZs)
5. Deployment of CO₂-EOR in tight (shale) oil formations.

Use of “next generation” CO₂-EOR will expand oil production and CO₂ storage capacity in the U.S.
Permian Basin ROZ Below Existing Oil Fields

Oil Saturation Profile in the TZ/ROZ (Wasson Denver Unit Well Log)

Main Pay Zone (MPZ)
Transition Zone (TZ)
Residual Oil Zone (ROZ)

Base of Producing OWC
Base of Ultimate OWC

Wasson Denver Unit Oil Resources (Billion Barrels)

<table>
<thead>
<tr>
<th></th>
<th>Main Pay Zone</th>
<th>TZ/ROZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>OOIP</td>
<td>2.4</td>
<td>3.0</td>
</tr>
<tr>
<td>P/S Recovery</td>
<td>1.1</td>
<td>1.5*</td>
</tr>
<tr>
<td>“Stranded”</td>
<td>1.3</td>
<td>1.5</td>
</tr>
<tr>
<td>EOR Potential</td>
<td>0.5**</td>
<td>0.5***</td>
</tr>
</tbody>
</table>

*Produced by nature. **Approximately 0.3 billion barrels already produced/proven to date. ***Numerous ROZ projects underway.

Seminole Unit (San Andres) ROZ Project
(Three Hess Oil operated miscible CO₂ floods in the ROZ interval show successful oil response.)

<table>
<thead>
<tr>
<th>Project</th>
<th>Acres</th>
<th>CO₂ Injection Patterns</th>
<th>Oil Production (B/D)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2010</td>
</tr>
<tr>
<td>Phase 1</td>
<td>500</td>
<td>10</td>
<td>1,200</td>
</tr>
<tr>
<td>Phase 2</td>
<td>480</td>
<td>9</td>
<td>1,700</td>
</tr>
<tr>
<td>Stage 1</td>
<td>2,320</td>
<td>29</td>
<td>1,000</td>
</tr>
</tbody>
</table>
Residual Oil Zone “Fairways” of the Permian Basin

- These ROZ “fairways” were first defined by Melzer and Trentham (2010).

- These “fairways” represent where it is believed the ROZ exists beyond the structural boundary of existing oil fields.

- An initial study assessed the potential of the San Andres ROZ “fairway” resource in four counties in West Texas.

- We recently extended this assessment to eight additional counties.

- Other basins are also believed to contain potential ROZ resources.
### U.S. Demand for CO₂:
Number of 1 GW Size Coal-Fired Power Plants

#### Technical Demand/Storage Capacity
- **Total CO₂**
  - 240
- **Anthropogenic CO₂**
  - 228

#### Economic Demand/Storage Capacity**
- **Total CO₂**
  - 133
- **Anthropogenic CO₂**
  - 121

<table>
<thead>
<tr>
<th>Reservoir Setting</th>
<th>Number of 1GW Size Coal-Fired Power Plants***</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Technical</td>
</tr>
<tr>
<td>L-48 Onshore</td>
<td>170</td>
</tr>
<tr>
<td>L-48 Offshore/Alaska</td>
<td>31</td>
</tr>
<tr>
<td>Near-Miscible CO₂-EOR</td>
<td>5</td>
</tr>
<tr>
<td>ROZ**</td>
<td>34</td>
</tr>
<tr>
<td>Sub-Total</td>
<td>240</td>
</tr>
<tr>
<td>Additional From ROZ “Fairways”</td>
<td>86</td>
</tr>
</tbody>
</table>

*Assuming 7 MMmt/yr of CO₂ emissions, 90% capture and 30 years of operations per 1 GW of generating capacity.

**At an oil price of $85/B, a CO₂ market price of $40/mt and a 20% ROR, before.

Source: Advanced Resources Int’l (2011).

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*At $85 per barrel oil price and $40 per metric ton CO₂ market price with ROR of 20% (before tax).

** ROZ resources below existing oilfields in three basins; economics of ROZ resources are preliminary.

***Assuming 7 MMmt/yr of CO₂ emissions, 90% capture and 30 years of operation per 1 GW of generating capacity; the U.S. currently has approximately 309 GW of coal-fired power plant capacity.
Flow Chart of CO₂-EOR Operations

Source: Advanced Resources Int'l (2011).
Profiles for CO₂ Injection and Oil Production in CO₂-EOR

Source: Bellona, 2005
CO$_2$ RETENTION

Industry’s Historical Definition

CO$_2$ Retention: amount of CO$_2$ injected in a reservoir that remains:

\[
\frac{(CO_2 \text{ Injected} - CO_2 \text{ Produced} - CO_2 \text{ Leakage})}{CO_2 \text{ Acquired}^*}
\]

To determine CO$_2$ storage, the denominator should represent CO$_2$ purchased or acquired?

In general, the CO$_2$ volume stored for EOR is approximately the volume initially purchased.

* Note that it is ‘Total Injected Volumes’ which Includes Recycled Volumes
**CO₂-EOR: Traditional Operations vs. Designing for Storage**

- Traditional life cycle emissions studies use assumptions of CO₂ utilization for CO₂-EOR based on historical CO₂ operations designed to minimize the amount of CO₂ injected.
  - 0.2 - 0.25 tonnes stored/incremental barrel of oil produced
- Current EOR operations in the Permian Basin are approaching utilization values of 0.4 tonnes/barrel.
- Next generation EOR can result in CO₂ utilization 30% to 50% higher, or more.
- An NETL showed that the ROZ “fairway” in 4 counties could provide space for 18 billion tonnes of CO₂ storage, while producing 27 billion barrels of oil.
  - A utilization of 0.66 tonnes/barrel
  - In this case, the volume of CO₂ stored exceeds the CO₂ content of the produced oil, i.e., a negative carbon balance.
Alternative Approaches to Increase CO$_2$ Storage with CO$_2$-EOR

- Inject CO$_2$ earlier in project life
- Inject CO$_2$ longer
- Continuously inject CO$_2$ instead of alternating with water via WAG
- Inject CO$_2$ into the residual oil/transition zone
- Inject CO$_2$ into other geologic horizons accessible from same surface infrastructure used for CO$_2$-EOR
- Produce residual water to “make more room” for CO$_2$. 
Integrating CO$_2$-EOR and CO$_2$ Storage Could Further Increase Storage Potential

- **CO$_2$ Source**: Injection of CO$_2$ from a power plant or industrial source.
- **Oil to Market**: Production well extracting oil.
- **Saline Reservoir**: Underground layer where CO$_2$ is stored.
- **Current Water Oil Contact** & **Original Water Oil Contact**: Boundaries of different oil and water contacts.
- **TZ/ROZ**: Transition Zone/Remaining Oil Zone.
- **Swept Area & Unswept Area**: Areas where CO$_2$ has or has not swept through.
- **Stage #1, #2, #3**: Different stages or layers of the reservoir.

Integrating CO$_2$-EOR and CO$_2$ Storage: CO$_2$ injection enhances oil recovery, while its storage increases overall storage capacity.
Transitioning CO\textsubscript{2}-EOR to CO\textsubscript{2} Storage

- May need to “prepare” CO\textsubscript{2}-EOR reservoir for storage, prior to end of CO\textsubscript{2}-EOR operations, to “re-optimize” for storage.

- May be particularly important for reservoirs that have undergone WAG processes
  - Reduce reservoir pressure and improve CO\textsubscript{2} injectivity.

- Could be facilitated by converting from a WAG to continuous CO\textsubscript{2} injection
  - Producing the water (and incremental oil), but not reinjecting the water.

- Would allow for pressure in the reservoir to decline, the injection rate for CO\textsubscript{2} to increase, and free up pore space in the reservoir for additional CO\textsubscript{2} storage.
Transitioning CO₂-EOR to CO₂ Storage

ROZ BASE
1_run.irf

- Oil Rate SC (bbl/day)
- Gas Rate SC (ft³/day)
- Ave Pres POVO SCTR FIELD

Time (Date)

2020 2025 2030 2035 2040 2045

0 50 100 150 200

0.00e+0 2.00e+5 4.00e+5 6.00e+5 8.00e+5 1.00e+6 1.20e+6

2,000 2,100 2,200 2,300 2,400 2,500 2,600 2,700 2,800

Oil Rate SC PROD
Water Rate SC PROD
Gas Rate SC INJ-CO₂
Ave Pres POVO SCTR FIELD
In addition, the oil would displace oil that would otherwise be imported and produced with no associated storage of CO₂, further improving the carbon balance.

If one thinks of CO₂-EOR’s oil as additive, and does not take into account the displacement of more carbon-intensive electric power by CCS, then CO₂-EOR could release more CO₂ than it eliminates.

However, if one believes that oil produced by CO₂-EOR will mostly displace other sources of oil to meet this demand, and/or result in lower carbon intensity power, then CO₂-EOR results in negative CO₂ emissions.
CO₂-EOR/Class II Activities That Also Apply to Class VI/CO₂ Storage

- Most site characterization
  - Maps and cross sections
  - Geochemistry
  - Assess storage reservoir(s)/confining zone(s)
  - Risk assessment/mitigation
- Most or all well drilled (?)
- Abandonment of unused existing wells (?)
- Most surface infrastructure
- Existing computational model(s) (reservoir simulation); as appropriately modified
- Substantial monitoring activities
  - Pressure, temperature, composition, fluid sampling, surface leakage/emissions, etc.
Monitoring Data Cost/Benefit Analysis

Source: Ringrose, Philip, “The In Salah CO₂ Storage Project: Lessons Learned, presentation at the IEAGHG Network Meeting, Trondheim, Norway, 10-13 June 2013
CO₂-EOR and Reservoir Integrity Concerns

- Reservoir integrity issues, concerns, and approaches for mitigation well covered in previous CARB Workshops.
- CO₂-EOR fields offer demonstrated confinement and seal integrity, with established reservoir geologic understanding and many years of operational experience to draw on.
- CO₂-EOR projects have extensive data on capacity, injectivity, and fluid retention from operations.
- Appropriate monitoring and quantification approaches for CO₂-EOR differ (possibly significantly) than those for saline storage – and should be specific to the site.
  - Imposing saline storage monitoring and quantification approaches for CO₂-EOR likely unnecessary, inefficient, not cost effective, and possibly counterproductive.
- Largest risk for CO₂-EOR pertains to legacy wells.
CO₂ Leakage from CO₂-EOR Operations

- Review of very large CO₂-EOR project by Occidental resulted in the following:
  - Total CO₂ Purchased = 115 million tonnes (2.2 Tcf)
  - Total CO₂ Injected = 252 million tonnes
  - Total CO₂ Recycled = 137 million tonnes
  - Operating & Fugitive Losses = 0.3%
  - Sequestered = 99.7%

- Accounting for the CO₂ emissions as part of CO₂-EOR operations in the SACROC field resulted in the following:
  - Purchased -- 260.0 million tonnes
  - Direct/Indirect Emissions - 18.5 million tonnes
  - Capital Emissions - 2.0 million tonnes
  - Total Sequestered -- 239.5 million tonnes (>92% sequestered)
CO₂-EOR and Well Integrity Concerns

- Well integrity issues, concerns, and approaches for mitigation were also well covered in the CARB Well Integrity Workshop.

- Legacy wells are perhaps the most significant risk factor associated with CO₂ storage in association with CO₂-EOR.
  - Failure rates in CO₂-EOR operations are small, but concerns remain.
  - Existing Class II well requirements are designed to address – but may not always effectively do so.

- Field experience has shown that reactions in the field are much slower than that seen in the lab, but do occur.
Conclusions

- Vast storage volume potential available from CO\textsubscript{2} storage in association with CO\textsubscript{2}-EOR.
- Operating to optimize for CO\textsubscript{2} storage, or co-optimize for CO\textsubscript{2} storage with CO\textsubscript{2}-EOR, rather than just for oil production, can further increase storage potential.
- Without CO\textsubscript{2}-EOR, substantial volumes of CO\textsubscript{2} storage in the near term unlikely (need to take advantage of the commercial drivers).
- Risks for CO\textsubscript{2} storage with CO\textsubscript{2}-EOR different than for saline storage – different approaches for monitoring and quantification likely warranted.
- Nonetheless, CO\textsubscript{2} storage with CO\textsubscript{2}-EOR can be effectively monitored, verified, and quantified.