Global Opportunities for CO₂-EOR with CCUS

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Presented by:
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Advanced Resources International, Inc.

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Introduction

- Utilizing and storing anthropogenic (industrial) CO$_2$-EOR with EOR is gaining traction.
- CO$_2$-EOR is overcoming the “niche opportunity” mindset.
- CO$_2$-EOR represents large oil production potential.
- And leads to potential large demand for industrial CO$_2$ for CO$_2$-EOR.
- However, this potential cannot be realized without plentiful, affordable CO$_2$ (along with sufficient oil prices).
Main Questions Addressed

- What is the potential for CO₂-EOR?
  - U.S.
  - Global
- How much CO₂ storage could result from CO₂-EOR?
- Is CO₂ effectively stored during CO₂-EOR operations?
- Who will benefit from pursuing CCUS with CO₂-EOR?
- What will it take to realize these benefits?
Global Opportunities for CO₂-EOR with CCUS

Near-Term Potential for Oil Production from U.S. CO₂-EOR

Increased CO₂ supplies are enabling new CO₂-EOR projects and expansion of existing CO₂ floods:

- Bell Creek, Montana
- Burbank and NE Hardesty, Oklahoma
- Seminole ROZ Stages 1-3, Goldsmith, West TX
- Webster, Conroe, Thompson, East TX

These and other announced new/expanded CO₂ floods could drive significant growth in near-term CO₂-EOR-based oil production:

- 430,000 B/D by 2015
- 650,000 B/D by 2020

CO₂–EOR Production by Region (MB/D)

Source: Advanced Resources International (2013)
Rapidly Increasing Utilization and Storage of Anthropogenic CO₂ with EOR

In a study for U.S. DOE/NETL, Advanced Resources tabulated the announced new sources of CO₂ supply scheduled to come on-line by 2020.

These could result in significant growth in CO₂ supplies for EOR (most of it from anthropogenic sources):  
- 4.4 Bcfd (~ 85 million metric tons per year) by 2015  
- 6.8 Bcfd (>130 million metric tons per year) by 2020
Announced CO₂-EOR Operations and CO₂ Sources (2020)

<table>
<thead>
<tr>
<th>Oil Production (2020)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂-EOR Projects</td>
<td>147</td>
</tr>
<tr>
<td>Oil Production (MBbl/d)</td>
<td>638</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CO₂ Supplies (2020)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Sources</td>
<td>30</td>
</tr>
<tr>
<td>Natural</td>
<td>6</td>
</tr>
<tr>
<td>Industrial</td>
<td>24</td>
</tr>
<tr>
<td>CO₂ Supply (Bcf/d)</td>
<td>6.5</td>
</tr>
<tr>
<td>Natural</td>
<td>3.4</td>
</tr>
<tr>
<td>Industrial</td>
<td>3.1</td>
</tr>
</tbody>
</table>

No. of U.S. CO₂-EOR Projects: 147
- Natural CO₂ Source: 6
- Industrial CO₂ Source: 24

Source: Advanced Resources International, Inc., based on Oil and Gas Journal, 2014 and other sources.
**U.S. Conventional Oil Endowment.** The U.S. conventional oil in-place endowment is 624 billion barrels. Primary recovery and water flooding will recovered about a third of this oil endowment, leaving behind 414 billion barrels.

Much of this “left behind oil” (284 billion barrels) is technically favorable for CO₂-EOR and is widely distributed across the U.S.
“Next Generation” CO$_2$-EOR Technologies and New Resource Targets can Further Expand this Potential

1. Scientifically-based advances in CO$_2$-EOR technology
2. Integrating CO$_2$ capture with CO$_2$ utilization by CO$_2$-EOR
3. Application of CO$_2$-EOR to residual oil zones (ROZs)
4. Deployment of CO$_2$-EOR in offshore oil fields.
5. Deployment of CO$_2$-EOR in tight (shale) oil formations.
The volume of oil in-place in the twelve county San Andres ROZ “fairway” of the Permian Basin, West Texas (excluding areas under existing oil fields) is 196 billion barrels, with 137 billion barrels classified as “higher quality”*.

The ROZ oil in-place below existing oil fields in the Permian Basin represents an additional 42 billion barrels of oil in-place, with much of this resource “higher quality”.

* Higher quality ROZ resources have porosity greater than 8% and oil saturation greater than 25%.
**Global Opportunities for CO₂-EOR with CCUS**

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**U. S. Oil Recovery and CO₂ Storage Potential From "Next Generation" CO₂-EOR Technology***

<table>
<thead>
<tr>
<th>Reservoir Setting</th>
<th>Oil Recovery*** (Billion Barrels)</th>
<th>CO₂ Demand/Storage*** (Billion Metric Tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Technical</td>
<td>Economic**</td>
</tr>
<tr>
<td>L-48 Onshore</td>
<td>104</td>
<td>60</td>
</tr>
<tr>
<td>L-48 Offshore/Alaska</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>Near-Miscible CO₂-EOR</td>
<td>1</td>
<td>*</td>
</tr>
<tr>
<td>ROZ (below fields)****</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td><strong>Sub-Total</strong></td>
<td>136</td>
<td>80</td>
</tr>
<tr>
<td>Additional From ROZ “Fairways”</td>
<td>40</td>
<td>20</td>
</tr>
</tbody>
</table>

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*The values for economically recoverable oil and economic CO₂ demand (storage) represent an update to the numbers in the NETL/ARI report “Improving Domestic Energy Security and Lowering CO₂ Emissions with “Next Generation" CO₂-Enhanced Oil Recovery (CO₂-EOR) (June 1, 2011).

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

***Includes 2.6 billion barrels already being produced or being developed with miscible CO₂-EOR and 2,300 million metric tons of CO₂ from natural sources and gas processing plants.

**** ROZ resources below existing oilfields in three basins; economics of ROZ resources are preliminary.
U.S. Demand for CO$_2$: Number of 1 GW Size Coal-Fired Power Plants

**Technical Demand/Storage Capacity**

<table>
<thead>
<tr>
<th>Total CO$_2$</th>
<th>Anthropogenic CO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>240</td>
<td>228</td>
</tr>
</tbody>
</table>

**Economic Demand/Storage Capacity**

<table>
<thead>
<tr>
<th>Total CO$_2$</th>
<th>Anthropogenic CO$_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>133</td>
<td>121</td>
</tr>
</tbody>
</table>

**Reservoir Setting**

<table>
<thead>
<tr>
<th>Reservoir Setting</th>
<th>Number of 1GW Size Coal-Fired Power Plants***</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-48 Onshore</td>
<td>Technical: 170, Economic: 90</td>
</tr>
<tr>
<td>Near-Miscible CO$_2$-EOR</td>
<td>Technical: 5, Economic: 1</td>
</tr>
<tr>
<td>ROZ**</td>
<td>Technical: 34, Economic: 28</td>
</tr>
<tr>
<td>Sub-Total</td>
<td>Technical: 240, Economic: 133</td>
</tr>
<tr>
<td>Additional From ROZ “Fairways”</td>
<td>Technical: 86, Economic: 43</td>
</tr>
</tbody>
</table>

*Assuming 7 MMmt/yr of CO$_2$ emissions, 90% capture and 30 years of operations per 1 GW of generating capacity.

**At an oil price of $85/B, a CO$_2$ market price of $40/mt and a 20% ROR, before.

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

***Assuming 7 MMmt/yr of CO$_2$ 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.

Source: Advanced Resources Int’l (2011).
Oil Recovery and CO\textsubscript{2} Storage Potential in World’s Oil Basins*

The world’s oil basins* could produce nearly 1,300 billion barrels of oil from “next generation” CO\textsubscript{2}-EOR technology and store 35 years worth of nearly 1,800 GW of coal-fired power plant emissions.

<table>
<thead>
<tr>
<th>Region</th>
<th>Technical CO\textsubscript{2}-EOR Oil Recovery (Billion Barrels)</th>
<th>Associated CO\textsubscript{2} Demand/Storage Capacity (Billion Metric Tons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Asia Pacific</td>
<td>47</td>
<td>13</td>
</tr>
<tr>
<td>2. C. &amp; S. America</td>
<td>93</td>
<td>27</td>
</tr>
<tr>
<td>3. Europe</td>
<td>41</td>
<td>12</td>
</tr>
<tr>
<td>4. FSU</td>
<td>232</td>
<td>66</td>
</tr>
<tr>
<td>5. M. East/N. Africa</td>
<td>595</td>
<td>170</td>
</tr>
<tr>
<td>6. NA/Other</td>
<td>38</td>
<td>11</td>
</tr>
<tr>
<td>7. NA/U.S.</td>
<td>177</td>
<td>51</td>
</tr>
<tr>
<td>8. S. Africa/Antarctica</td>
<td>74</td>
<td>21</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,297</td>
<td>370</td>
</tr>
</tbody>
</table>

* Includes potential from discovered and undiscovered fields, but not future growth of discovered fields.

Source: IEA GHG Programme/Advanced Resources International (2009)
## CO₂-EOR/CCUS Potential in Selected APEC Economies

<table>
<thead>
<tr>
<th>Economy</th>
<th>CO₂-EOR Potential</th>
<th>Potential CO₂ Storage Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Billion barrels)</td>
<td>(Billion tonnes)</td>
</tr>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Brunei Darussalam</td>
<td>0.8</td>
<td>1.9</td>
</tr>
<tr>
<td>People’s Republic of China</td>
<td>0.5</td>
<td>43.3</td>
</tr>
<tr>
<td>Indonesia</td>
<td>0.3</td>
<td>4.3</td>
</tr>
<tr>
<td>Malaysia-Thailand (Malay Basin)*</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Vietnam</td>
<td>0.6</td>
<td>0.7</td>
</tr>
<tr>
<td>Mexico</td>
<td>14.1</td>
<td>23.9</td>
</tr>
<tr>
<td>Peru</td>
<td>1.1</td>
<td>2.6</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>18.4</strong></td>
<td><strong>77.7</strong></td>
</tr>
</tbody>
</table>

* Also includes resources from the Baram Delta/Brunei Sabah Basin reported for Brunei Darussalam
**CO₂-EOR Technology: A Closed-Loop System**

- **Purchased CO₂**
  - Anthropogenic and/or Natural Sources

- **Injected CO₂**

- **Recycled CO₂**
  - from Production Well

- **Zone of Efficient Sweep**

- **Immobile Oil**

- **CO₂ Dissolved (Sequestered) in the Immobile Oil and Gas Phases**

- **CO₂ Stored in Pore Space**

- **Driver**
  - Water

- **Water**

- **CO₂**

- **Miscible Zone**

- **Oil Bank**

- **Additional Oil Recovery**
Today, because of high costs of CO₂ capture, CO₂ emissions from power plants are released to the atmosphere, while oil produced by conventional means is imported and consumed based on demand.

**Current Situation (No CCUS) - - Years 2021-2060**

- **U.S. electric power sector (without CCUS)** emits 1.6 Gt of CO₂/yr, 64 Gt in 40 years.
- U.S. imports 5+ million barrels per day (net) of crude oil and petroleum products, 80 billion barrels in 40 years.
- U.S. spends $160 billion per year on oil imports, $6.4 trillion in 40 years.

**Electric Power Plants**

- CO₂ Emissions 1.6 Gt/yr.
- 64 Gt in 40 yrs.

**Oil Imports (Net)**

- To U.S.
  - 5 Million Bbls/day
  - 2 Billion Bbls/yr.
  - 80 Billion Bbls in 40 yrs.
- $160 Billion/yr.
- $6.4 Trillion in 40 yrs.

- From U.S.
Alternative Case – Thought Experiment

Alternative Case (Use of CCUS) - - - Years 2021 to 2060

- Revenues from sale of CO₂ to the EOR industry plus financial incentives* support installation of CO₂ capture on 60% of current U.S. coal and natural gas power plant capacity.

- Approximately 0.9 Gt/yr of CO₂ is captured and sold to the EOR industry for $30/m ton, providing $27 billion/yr ($1.08 trillion in 40 years) to the power industry.

- CO₂ purchased from the power industry enables production of 5+ million barrels/day of additional domestic oil (80 billion barrels in 40 years).
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Whose Oil Will Be “Left In The Ground?”

• Given this potential, along with expectations for “peak oil demand”, a significant portion of the oil resource and its carbon content will ultimately be “left in the ground.”

• The question is - - will the oil “left in the ground” be oil that is conventionally produced and currently imported into the U.S. or oil produced in the U.S. by the injection and storage of CO₂ captured from power/industrial plants?

• With CCUS and CO₂-EOR, a potential 80 billion barrels of conventionally produced oil will not be imported into the U.S., displacing oil that may eventually be “left in the ground”.

• Moreover, studies by ARI/University of Wyoming and IEA show that the potential exists for CO₂-EOR to result in “carbon negative oil.”
**Distribution of Benefits of CO₂-EOR**

<table>
<thead>
<tr>
<th>Notes</th>
<th>CO₂-EOR Industry</th>
<th>Mineral Owners</th>
<th>Federal/State Treasuries</th>
<th>Power Plant/Other Capturers of CO₂</th>
<th>General Economy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>NYMEX Oil Price</td>
<td>$80.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Transportation/Quality Differential</td>
<td>$(3.00)</td>
<td>$10.90</td>
<td>$2.20</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Less: Royalties</td>
<td>$(13.10)</td>
<td>$(10.50)</td>
<td>$(3.70)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Production Taxes</td>
<td>$(3.20)</td>
<td>$(0.50)</td>
<td>$(3.70)</td>
<td>$5.00</td>
</tr>
<tr>
<td>5</td>
<td>CO₂ Purchase Costs</td>
<td>$(13.50)</td>
<td>$(13.50)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>CO₂ Recycle Costs</td>
<td>$(5.00)</td>
<td>$(0.50)</td>
<td>$(3.70)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>O&amp;M/G&amp;A Costs</td>
<td>$(15.00)</td>
<td>$(15.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>CAPEX</td>
<td>$(7.00)</td>
<td>$(7.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Total Costs</td>
<td>$(56.80)</td>
<td>$(10.40)</td>
<td>$(5.90)</td>
<td>$(13.50)</td>
</tr>
</tbody>
</table>

**Net Cash Margin** $20.20

| Income Taxes | $13.10 | $6.80 | $16.60 | $13.50 | $30.00 |

**Net Income ($/B)** $13.10

CO₂-EOR provides a wide distribution of benefits:

- **Federal and state treasuries** receive $16.60/B, equal to $37/mt.
- **The power industry receives** $13.50/B, equal to $30/mt.
- **The U.S. economy** receives $30/B, supporting well-paying jobs and manufacturing, a topic we are examining for a CURC*/ClearPath Foundation supported study.

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1 Assumes an oil price of $80 per barrel (WTI) based on EIA AEO 2017 oil price for year 2022.
2 Assumes $3 per barrel for transportation.
3 Royalties are 17%; 1 of 6 barrels produced are from Federal and state lands.
4 Production and ad valorem taxes of 5% from FRS data.
5 CO₂ sales price of $30/metric ton including transport; 0.45 metric tons of purchased CO₂ per barrel of oil.
6 CO₂ recycle cost of $10/metric ton; 0.5 metric tons of recycled CO₂ per barrel of oil.
7 O&M/G&A costs from ARI CO₂-EOR cost models.
8 CAPEX from ARI CO₂-EOR cost models.
9 Combined Federal and state income taxes of 35%, from FRS data.
Source: Advanced Resources International internal study, 2017.

*Carbon Utilization Research Council,*
Steps to Achieving Lower Cost, Publicly-Acceptable CO\(_2\) Supply for CO\(_2\)-EOR

- Sell more CO\(_2\) to CO\(_2\)-EOR projects
  - Through better utilization and better economics with “next generation” CO\(_2\)-EOR technologies

- Pursue economies of scale for CO\(_2\) transport; using existing infrastructure to the extent possible

- Gain public acceptance
  - Requires rigorous site selection, monitoring, and public outreach
  - But without imposing regulatory requirements that inhibit CO\(_2\)-EOR deployment

- Reduce the costs of CO\(_2\) capture!!!
  - Requires doing projects, which cannot happen today w/o CO\(_2\)-EOR
Concluding Thoughts and Observations

1. **CO₂-EOR Offers Large CO₂ Storage Capacity Potential.** CO₂-EOR in oil fields can accommodate a major portion of the CO₂ captured from industrial facilities for the next 30 years.

2. **CO₂ is Stored with CO₂-EOR.** The amount stored depends on the priority placed on maximizing/optimizing storage.

3. **CCS Benefits from CO₂-EOR.** The revenues (or cost reduction) from sale of CO₂ to EOR helps CCS economics, overcomes some barriers, while producing oil with a lower CO₂ emissions “footprint.”

4. **CO₂-EOR Needs CCUS.** Large-scale implementation of CO₂-EOR is dependent on CO₂ supplies from industrial sources.

5. **Both CCUS and CO₂-EOR Still Need Supportive Policies and Actions.** Focused R&D investment, supportive policies and expedited CO₂ pipelines can accelerate the integrated use of CO₂-EOR and CCUS.
Global Opportunities for CO₂-EOR with CCUS

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