Industry Opportunities for Carbon Capture, Utilization and Storage (CCUS)

Presented at:
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Presented by:
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The development of large natural sources of CO₂ (e.g., McElmo Dome, Jackson Dome, etc.) established the foundation for the CO₂-EOR industry. Capture of industrial sources of CO₂ is helping drive its growth.

Based on the 2014 O&GJ Survey, 136 significant CO₂-EOR projects currently produce 300,000 barrels per day in the U.S. by injecting 3.5 Bcfd of CO₂, with 0.7 Bcfd from industrial sources.

In spite of limitations in supplies of CO₂ and lower oil prices, existing CO₂-EOR projects are being expanded and new CO₂-EOR projects started.

We note increased CO₂-EOR activity even though the O&GJ has terminated its CO₂-EOR Survey.

Source: Advanced Resources International based on Oil & Gas Journal and other industry data, 2014.
**CO₂-EOR: A Niche or a Robust Carbon Management Strategy?**

**U.S. Conventional Oil Endowment.** The U.S. conventional oil in-place endowment is 624 billion barrels. Primary recovery and water flooding have 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.

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**Original Oil In-Place: 624 B Barrels**  
**Remaining Oil In-Place: 414 B Barrels**

- **Target for EOR**  
  - 414 Billion Barrels
- **Proved Reserves**  
  - 20 Billion Barrels
- **Cumulative Production**  
  - 190 Billion Barrels

*Does not include “tight” oil production or reserves.  
Source: Advanced Resources International, 2015.

**Conventional Domestic Oil Resources**  
**Favorable for CO₂-EOR**

Source: Advanced Resources International internal analysis, 2016.
Potential CO\textsubscript{2} Sources

Potential Electric Generation CO\textsubscript{2} Sources
Above 1 Million Tonnes/Year

The Low-Hanging Fruit:
High Purity Stream Potential CO\textsubscript{2} Sources


Legend

\textbf{Source}
- Electricity Generation

\textbf{CO\textsubscript{2} Emissions (Metric Tons CO\textsubscript{2})}
- 1,000,000 – 5,000,000
- 5,000,000 – 10,000,000
- 10,000,000 – 15,000,000
- 15,000,000 – 20,000,000+

Legend

\textbf{High Purity Source}
- Ammonia
- Ethanol
- Ethylene Oxide
- Hydrogen
- Natural Gas Processing

\textbf{CO\textsubscript{2} Emissions (Metric Tons CO\textsubscript{2})}
- 100,000 – 500,000
- 500,000 – 1,000,000
- 1,000,000 – 1,500,000
- 1,500,000 – 5,000,000+
Capturing CO$_2$ from Industrial Facilities for EOR

Over 20 million metric tons of industrial/power plant CO$_2$ emissions are captured and used annually for enhanced oil recovery.

<table>
<thead>
<tr>
<th></th>
<th>MMcfd</th>
<th>MMmt/Yr.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Plants</td>
<td>205*</td>
<td>4</td>
</tr>
<tr>
<td>Fertilizer Plants</td>
<td>100</td>
<td>2</td>
</tr>
<tr>
<td>Hydrogen Plants</td>
<td>40</td>
<td>1</td>
</tr>
<tr>
<td>Ethanol Plants</td>
<td>15</td>
<td>*</td>
</tr>
<tr>
<td>Gas Processing Plants</td>
<td>850</td>
<td>16</td>
</tr>
</tbody>
</table>

Total: 1,210 23

Three high visibility projects - - Weyburn, Boundary Dam and Petra Nova - - utilize CO$_2$-EOR for carbon management.

*Includes NGP Coal Gasification plant.
## U. S. Oil Recovery and CO₂ Storage 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>

*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.
“Next Generation” CO$_2$ Enhanced Oil Recovery

Use of more efficient CO$_2$-EOR technologies and extension of these technologies to new oil resource settings constitutes “next generation” CO$_2$-EOR:

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.

Use of “next generation” CO$_2$-EOR will expand oil production and CO$_2$ storage capacity in the U.S.
## Oil Recovery and CO₂ Storage Potential in World’s Oil Basins*

The world’s oil basins* could produce nearly 1,300 billion barrels of oil from “next generation” CO₂-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 CO₂-EOR Oil Recovery (Billion Barrels)</th>
<th>Associated CO₂ 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><strong>TOTAL</strong></td>
<td><strong>1,297</strong></td>
<td><strong>370</strong></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)
## Distribution of Benefits of CO₂-EOR

CO₂-EOR provides a wide distribution of benefits:

- Federal and state treasuries receive $16.60/Bbl, equal to $37/mt.
- The power industry receives $13.50/Bbl, equal to $30/mt.
- The U.S. economy receives $30/Bbl, supporting well paying jobs and manufacturing.

<table>
<thead>
<tr>
<th>Notes</th>
<th>CO₂-EOR</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 NYMEX Oil Price</td>
<td>$80.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Transportation/Quality Differential</td>
<td>($3.00)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Realized Oil Price</td>
<td>$77.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Less: Royalties</td>
<td>($13.10)</td>
<td>$10.90</td>
<td>$2.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Production Taxes</td>
<td>($3.20)</td>
<td>($0.50)</td>
<td>$3.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 CO₂ Purchase Costs</td>
<td>($13.50)</td>
<td></td>
<td></td>
<td></td>
<td>$13.50</td>
</tr>
<tr>
<td>7 CO₂ Recycle Costs</td>
<td>($5.00)</td>
<td></td>
<td></td>
<td>$5.00</td>
<td></td>
</tr>
<tr>
<td>8 O&amp;M/G&amp;A Costs</td>
<td>($15.00)</td>
<td></td>
<td></td>
<td></td>
<td>$15.00</td>
</tr>
<tr>
<td>9 CAPEX</td>
<td>($7.00)</td>
<td></td>
<td></td>
<td></td>
<td>$7.00</td>
</tr>
<tr>
<td>Total Costs</td>
<td>($56.80)</td>
<td>$10.40</td>
<td>$5.90</td>
<td>$13.50</td>
<td>$30.00</td>
</tr>
<tr>
<td>Net Cash Margin</td>
<td>$20.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Income Taxes</td>
<td>($7.10)</td>
<td>($3.60)</td>
<td>$10.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Income ($/B)</td>
<td>$13.10</td>
<td>$6.80</td>
<td>$16.60</td>
<td>$13.50</td>
<td>$30.00</td>
</tr>
</tbody>
</table>

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.
Historical Business Models

- **Natural sources.** The earliest projects leveraged their proximity to large, natural sources of CO$_2$.
- **Industrial capture.** Commoditization of products at industrialized centers have recognized the value of CO$_2$.
- **Government subsidized.** Some projects were government subsidized in order to achieve commercial viability.
- **Infrastructure development.** Field operators can link to major pipeline sources of CO$_2$.

**New business models likely to evolve as incentives spur new deployment.**
U.S. Efforts to Incentivize CCS May Lead to Evolving Business Models

- Bipartisan Budget Act of 2018 (BBA)
  - Enhancements to IRC Section 45Q
- California Low Carbon Fuel Standards (LCFS)
- Regional Incentives/Regulatory Frameworks
- State Incentives/Regulatory Frameworks
## BBA Enhancements to IRC Section 45Q -- Highlights

<table>
<thead>
<tr>
<th>Previous 45Q</th>
<th>Bipartisan Budget Act of 2018</th>
</tr>
</thead>
<tbody>
<tr>
<td>▪ 75 million metric ton cap</td>
<td>▪ Eliminates 75 million metric ton cap; applies to new facilities that “break ground” by EOY 2023.</td>
</tr>
<tr>
<td>▪ Credit based on “captured qualified CO₂”</td>
<td>▪ After enactment, credit based on captured “qualified carbon oxide” (CO₂ and other carbon oxides).</td>
</tr>
<tr>
<td>▪ $20/metric ton for CO₂ stored and not used for EOR</td>
<td>▪ Allows for the transfer of qualified credits</td>
</tr>
<tr>
<td>▪ $10/metric ton for CO₂ stored and used for EOR</td>
<td>▪ $50/mt for geologic storage and $35/mt for EOR (each rate phases up over 10-year period from 2017 to 2026).</td>
</tr>
<tr>
<td>▪ Available to facility with capture equipment capturing at least 500,000 metric tons CO₂/year.</td>
<td>▪ Existing qualified facilities would continue to receive the original inflation adjusted $20 and $10 credit rates.</td>
</tr>
<tr>
<td>▪ Credit available until the 75-million-ton cap is reached.</td>
<td>▪ Capture &gt; 500,000 metric tons CO₂/year for electric generating units; &gt; 100,000 metric tons CO₂/year for other.</td>
</tr>
<tr>
<td></td>
<td>▪ Credit goes to the owner of the capture equipment.</td>
</tr>
<tr>
<td></td>
<td>▪ Available to “direct air capture” and “beneficial use (with 25,000 metric ton threshold)”</td>
</tr>
<tr>
<td></td>
<td>▪ Credit available for 12 years from the date the carbon capture equipment is placed in service.</td>
</tr>
</tbody>
</table>
CCUS Economics 101 – 45Q Example

**CO₂-EOR Storage**

- Total of: 45Q Tax Credit $35/ton
- Plus: EOR Sales Revenues
- Minus: Transport Cost to EOR field

**Saline Storage**

- Total of: 45Q Tax Credit $50/ton
- Minus: Storage Charges by Saline Operator
- Minus: Transport Cost to Saline Reservoir

**Cost of Capture**
- Equipment x Financing % Rate
- O&M
- Energy penalties

Less than:
On 5/20, IRS issued Request for Comments on 45Q enhancements.

Areas of comment included:

- Establishing “secure geologic storage”
- Leakage after credit award – “recapture”
- Defining “qualifying facilities”
- Defining “commence construction”
- Credit transferability, timing, flexibility
- Allowable structures/partnerships

90+ comments received

Guidance - late 2019/early 2020
Other Issues of Concern with 45Q

- Is 12 years of credits enough for commercial viability?
- What types of business models will involve?
- What will be the role and appetite for financial institutions and tax equity players?
- Is the 12/31/2023 deadline achievable for large, complex (e.g., power generation or direct air capture) projects?
- What impact will CCS have on electricity dispatch?
Are the 45Q Enhancements Enough?

- **Continued RD&D**
  - Reduce costs of CO$_2$ capture
  - Pursue “next generation” CO$_2$-EOR; especially targeting “carbon negative oil”

- **Further incentives beyond 45Q?**
  - Tax-exempt private activity bonds
  - Master limited partnerships
  - Incentives for CO$_2$ pipelines/pipeline expansions/buildout
  - Ensuring Parity for CCS in the power markets
    - Feed-in tariffs, CCS in “Clean Energy” Portfolio Standards
  - State incentives
Assessing Integrated Business Models

Identifying the most advantageous integrated CCUS business model requires information on four key topics.

- **Operational Change for the Capture Facility.** For example, CO₂ capture and 45Q tax credits, electricity generation will likely have a significantly higher annual capacity utilization factor (due to reduced net incremental cost) compared to other units in the system.

- **Cost of CO₂ Capture.** Assessing potential cost reductions from 2ⁿᵈ, 3ʳᵈ, 4ᵗʰ of-a-kind projects.

- **Cost of CO₂ Storage.** Recognizing that a high-quality storage complex located close to a power plant provides considerable value.

- **Value of CO₂ for EOR.** Incorporating key variables (e.g., price of oil, costs of transport, quality of EOR project, etc.) into the value proposition.
## Capital Costs for Retrofitting Coal-Fueled Power Plant with CO₂ Capture

### Engineering study post BD3 readding post-combustion CO₂ capture to SaskPower’s Shand Power Station.

Capital costs can be significantly reduced capital costs per MWh:

- Construction at larger-scale using extensive modularization
- Improved integration of the capture facility with the power unit
- Incorporating lessons learned from building and operating BD3.

### Cost Comparison of BD3 and Shand CCS Facilities

Petra Nova Carbon Capture Project: Closer Look at a New Business Model

- $1 billion project 50-50 joint venture between NRG Energy’s Carbon 360 unit and JX Nippon Oil & Gas Exploration.

- Financing Petra Nova required creative combination of partners:
  - US DOE awarded a $167 million grant as part of a competitive solicitation under the DOE’s Clean Coal Power Initiative.
  - NRG decided to build/own the CO₂ delivery pipeline and take a 50% equity stake in the West Ranch oil field.
  - JX Nippon eventually matched NRG’s $300 million equity stake.
  - $250 million in loans from Japanese banks.
In a carbon constrained emissions world, associated storage with CO₂-EOR may not achieve emissions reduction targets. In association with the EOR project, “pure” storage may be conducted in a high permeability saline formation above or below the oil reservoir.

This could require regulation mandates or steep incentives to push forward.
**Project ECO₂S Storage Zone Properties**

- **Goal:** Demonstrate the subsurface at Kemper can safely/permanently store commercial volumes of CO₂
- Abundant stacked saline sandstone bodies in Paluxy, Wash-Fred, and lower Tuscaloosa.
- 350 meters of net sand. Logs and core show sandstone average porosity of 30%(!)
- Core analysis indicates all sandstones water-saturated
- Darcy-class permeability common (up to 16 Darcies)

**High-porosity sandstone in Paluxy Formation**

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**Elemental Log Analysis (ELAN*) interpretation**

*ELAN is a mark of Schlumberger*
Storage Complex Capacity

- Each of the three potential storage zones have commercial capacity
- Together the three storage zones result in a gigatonne capacity storage complex that has the potential to act as a regional hub

<table>
<thead>
<tr>
<th>CO₂ Storage Reservoir</th>
<th>$P_{10}$ Capacity (MMmt)</th>
<th>$P_{50}$ Capacity (MMmt)</th>
<th>$P_{90}$ Capacity (MMmt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massive/Dantzler</td>
<td>60</td>
<td>120</td>
<td>200</td>
</tr>
<tr>
<td>Wash.-Fred.</td>
<td>280</td>
<td>540</td>
<td>920</td>
</tr>
<tr>
<td>Paluxy</td>
<td>160</td>
<td>310</td>
<td>530</td>
</tr>
</tbody>
</table>

DOE methodology for site-specific saline storage efficiency calculation based on fluid displacement factors for clastic reservoirs where net pay, net thickness and net porosity are known of 7.4% ($P_{10}$), 14% ($P_{50}$) and 24% ($P_{90}$) (Goodman et al., 2011)

- Low-cost storage options occur beneath the energy facility -- $2.00 - $4.00 USD per metric ton depending on volume of CO₂ captured (after DOE investment)
- Drives the value proposition where existing infrastructure could be utilized for CO₂ capture, compression, transportation and storage
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. **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.”

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

4. **Both CCUS and CO₂-EOR Still Need Supportive Policies and Actions.** R&D investment, supportive policies and expedited CO₂ pipelines can accelerate integration of CO₂-EOR and CCUS.

5. **Business Models Likely to Evolve Given New Market and Policy Realities.**
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