Industry Opportunities for Carbon Capture, Utilization and Storage (CCUS) in the U.S.

Presented at:
GWPC Underground Injection Control Conference

Presented by:
Michael Godec, Vice President
Advanced Resources International, Inc.

February 16-19, 2020
San Antonio, Texas
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.

Status of CO₂-EOR: A Snapshot in Time

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.

Current CO₂-EOR Operations and CO₂ Sources (2014)

Source: Advanced Resources International based on Oil & Gas Journal and other industry data, 2014.
Industry Opportunities for Carbon Capture, Utilization and Storage (CCUS) in the U.S.

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.
Potential CO₂ Sources

Potential Electric Generation CO₂ Sources
Above 1 Million Tonnes/Year

The Low-Hanging Fruit:
High Purity Stream Potential CO₂ Sources

“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.
## 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><strong>80</strong></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.
**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 <strong>“break ground” by EOY 2023.</strong></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></td>
<td>▪ Allows for the transfer of qualified credits</td>
</tr>
<tr>
<td>▪ $20/metric ton for CO₂ stored and not 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>▪ $10/metric ton for CO₂ stored and used for EOR</td>
<td>▪ Existing qualified facilities would continue to receive the original inflation adjusted $20 and $10 credit rates.</td>
</tr>
<tr>
<td>▪ Available to facility with capture equipment capturing at least 500,000 metric tons CO₂/year.</td>
<td>▪ Capture &gt; <strong>500,000</strong> metric tons CO₂/year for electric generating units; &gt; <strong>100,000</strong> metric tons CO₂/year for other.</td>
</tr>
<tr>
<td></td>
<td>▪ Credit goes to the <strong>owner of the capture equipment.</strong></td>
</tr>
<tr>
<td></td>
<td>▪ Available to “<strong>direct air capture” and “beneficial use</strong> (with 25,000 metric ton threshold)”</td>
</tr>
<tr>
<td>▪ Credit available until the 75-million-ton cap is reached.</td>
<td>▪ Credit available for <strong>12 years</strong> from the date the carbon capture equipment is placed in service.</td>
</tr>
</tbody>
</table>
Request for Comments by IRS on 45Q

- 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 - ??????
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, direct air capture) projects?
- What impact will CCS have on electricity dispatch?
Are the 45Q Enhancements Enough?

- **Continued RD&D**
  - Reduce costs of CO₂ capture
  - Pursue “next generation” CO₂-EOR; especially targeting “carbon negative oil”

- **Further incentives beyond 45Q?**
  - Tax-exempt private activity bonds
  - Master limited partnerships
  - Incentives for CO₂ pipelines/pipeline expansions/buildout
  - Ensuring Parity for CCS in the power markets
    - Feed-in tariffs, CCS in “Clean Energy” Portfolio Standards
  - State incentives
Possible State Policy Approaches/Incentives

- Supportive state regulatory policies
- Clear rules for long term storage
  - CO₂ storage trust funds; rules for CO₂/pore space ownership and responsibility
- CO₂ pipelines – common carrier/eminent domain
- Financial incentives for carbon capture
  - Financial assistance, off-take priority, cost recovery, eligibility under “clean energy” standards, assumption of long-term liability
- Tax incentives/optimization
  - Additional tax credits for CO₂-EOR + storage, tax exemptions for “pollution control equipment” associated with CO₂ capture.
Support for CO₂ Pipeline Infrastructure

- Regional Initiative co-convened by Governors of Wyoming and Montana.
- Launched in 2015:
  - Officials from 15 states*
  - With industry and NGO stakeholders and experts
- Objectives:
  - Help policymakers better understand states’ potential for CCS, CO₂-EOR and utilization
  - Recommend state and federal strategies and policies
- Support implementation of policy recommendations and project deployment.
- Funding from MacArthur Foundation, Hewlett Foundation and Spitzer Charitable Trust.

*State participation varies and includes governors’ staff, cabinet secretaries, utility commissioners and agency and commission staff.
Historical Business Models

- Natural sources. The earliest projects leveraged their proximity to large, natural sources of CO₂.
- Industrial capture. Commoditization of products at industrialized centers have recognized the value of CO₂.
- Government subsidized. Some projects were government subsidized in order to achieve commercial viability.
- Infrastructure development. Field operators can link to major pipeline sources of CO₂.

New business models likely to evolve as incentives spur new deployment.
$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.
Capital Costs for Retrofitting Coal-Fueled Power Plant with CO₂ Capture

Cost Comparison of BD3 and Shand CCS Facilities


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.
“Next Generation” CO₂-EOR and Carbon Negative Oil – Is it Possible?

- Most life-cycle analyses (LCA) of CO₂-EOR are based on historical operations:
  - Where CO₂ use was minimized per incremental barrel because of the high costs for CO₂
- Such LCAs often do not represent the emerging paradigm where CO₂ storage is a co-objective.
- Such LCAs often do not represent current efficiencies in CO₂-EOR operations.
- Such LCAs often do not represent current refining operations.
  - An increasing portion of crude today is transformed into non-combustible products, like asphalt, lubricants, waxes, and chemical feedstocks.
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)

**Paluxy sandstone**

- High-porosity sandstone in Paluxy Formation

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

*ELAN is a mark of Schlumberger
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>P₁₀ Capacity (MMmt)</th>
<th>P₅₀ Capacity (MMmt)</th>
<th>P₉₀ 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% (P₁₀), 14% (P₅₀) and 24% (P₉₀) (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.
“Stacked” Storage/Combined CO₂-EOR Plus Storage

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.

https://www.arb.ca.gov/cc/sequestration/seq.htm
U.S. Regulatory Experience – Class VI

- Concerns remain that obstacles exist to allow CO₂-EOR to be viable source for CO₂ emissions reduction.
- To date, the timeline for obtaining Class VI permits approval has been too long – as much as four years or more.
- 50-year “default” for post-injection site care (PISC) hinders possible CCS project financing
- EPA’s inconsistent application of financial responsibility instruments is hindering permitting and deployment.
- The process for allowing states to acquire primacy for Class VI well permitting has been very slow.
- Greater Class VI regulatory certainty is necessary to encourage new Class VI projects.
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.**
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

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

Immobile Oil

Immobile Oil
CO₂-EOR Performance

While relatively simple in concept, successful application of CO₂-EOR entails sophisticated design, process/flow modeling, and continuous monitoring.

In the Permian Basin, CO₂ EOR can recover 15% of OOIP.

In Gulf Coast oil fields, CO₂-EOR can produce as much oil as primary or secondary recovery.


CCUS Economics 101 – 45Q Example

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

Less than:

**CO₂-EOR Storage**
- Total of: 45Q Tax Credit $35/ton
- plus EOR Sales Revenues
- minus Transport Cost to EOR field

**OR**

**Saline Storage**
- Total of: 45Q Tax Credit $50/ton
- minus Storage Charges by Saline Operator
- minus Transport Cost to Saline Reservoir
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 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>$3.00</td>
</tr>
<tr>
<td>Realized Oil Price</td>
<td>$77.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Less: Royalties</td>
<td>($13.10)</td>
<td>$10.90</td>
<td>$2.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Production Taxes</td>
<td>($3.20)</td>
<td>($0.50)</td>
<td>$3.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 CO₂ Purchase Costs</td>
<td>($13.50)</td>
<td></td>
<td></td>
<td>$13.50</td>
<td></td>
</tr>
<tr>
<td>6 CO₂ Recycle Costs</td>
<td>($5.00)</td>
<td></td>
<td></td>
<td>$5.00</td>
<td></td>
</tr>
<tr>
<td>7 O&amp;M/G&amp;A Costs</td>
<td>($15.00)</td>
<td></td>
<td></td>
<td>$15.00</td>
<td></td>
</tr>
<tr>
<td>8 CAPEX</td>
<td>($7.00)</td>
<td></td>
<td></td>
<td>$7.00</td>
<td></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>9 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>

**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.

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.