Carbon Dioxide Enhanced Oil Recovery

Presented at Governor Tomblin’s 2012 Energy Summit
West Virginia: Partnerships for Energy Development
Presented by Phil DiPietro, National Energy Technology Laboratory
December 10, 2012
Summary

• In 2012 CO\textsubscript{2} EOR will provide 5% of domestic crude oil production (100 million barrels per year). It is growing, but slowly.

• The potential for CO\textsubscript{2} EOR to be much larger than current deployments, 24 to 137 billion barrels of resource (NETL estimate).

• The CO\textsubscript{2} EOR resource in West Virginia is small compared to the United States total (Original-Oil-in-Place OOIP is 0.6% of the total).

• . . . but the technically recoverable CO\textsubscript{2} EOR resource in West Virginia is 183 million barrels of crude oil production, instate revenues of ~ $16 B over 30 – 50 years ($85/bbl * 183 MMbbls = 15.6 B\$).
Two-page primer on CO₂ EOR

Source: Advanced Resources International
CO$_2$-EOR results from the Denver Unit of the Wasson Oil Field (Occidental Petroleum)


<table>
<thead>
<tr>
<th>Recovery Method</th>
<th>Oil Recovery Efficiency (% OOIP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>17.2%</td>
</tr>
<tr>
<td>Waterflood</td>
<td>30.1%</td>
</tr>
<tr>
<td>CO2 Flood</td>
<td>19.5%</td>
</tr>
<tr>
<td>Total</td>
<td>66.8%</td>
</tr>
</tbody>
</table>
Snapshot of CO$_2$ EOR in the United States
Crude Oil Production from CO$_2$ EOR in the United States

Reference point: between 2010 and 2012, total U.S. crude oil production increase by ~ 900,000 bpd

Source: Advanced Resources Intl. and Oil and Gas Journal, 2012.
Sources of CO₂ Supply for Enhanced Oil Recovery Operations in the United States

CO₂ EOR Resource Assessment
Potential Crude Oil Supply and CO₂ Demand from CO₂ EOR in the United States

Add fields in Alaska, the gulf of Mexico, and residual oil zones that are technically possible for CO₂ EOR (+12)

Add fields in the lower 48 states that are technically possible for CO₂ EOR but do not screen as economic (+16)

Next Generation CO₂ EOR Technology, fields in the lower 48 states onshore that screen as economic for CO₂ EOR (+8)

Current CO₂ EOR Technology, fields in the lower 48 states onshore that screen as economic for CO₂ EOR

Source: DOE/NETL Report 2011/1504

Next Generation CO₂ EOR Technology Scenario

20 Billion metric tons of CO₂ demand, 60 billion barrels of crude oil production

CO$_2$ EOR in West Virginia
Oil-bearing Geologic Formations in West Virginia

- The Big Oil Fields Database contains 51 oil-bearing reservoirs in West Virginia, total OOIP 2.4 Bbbls OOIP
- The reservoirs in the database represent 74% of oil production in the state
- 32 reservoirs in the database screen as amenable to miscible CO2 EOR (OOIP 2.0 Bbbls)
- Technically recoverable resource based on current best practices CO2 EOR technology is 183 million barrels of crude oil (9% OOIP)
- More study required to estimate how much may be economic to produce

Primary data sources: ARI's Big Fields Database, EIA's Appalachian Basin Oilfield map, EPA's Greenhouse Gas Reporting Program and Ventyx's Energy Velocity data
Production Potential from CO₂ EOR in West Virginia Relative to Current Production

West Virginia Field Production of Crude Oil (Thousand Barrels per Month)

Cushing, OK WTI Spot Price FOB (Dollars per Barrel)

183 MMbbls / 40 years * 12 months/yr = 380 Mbbbls/month
Oil-bearing Formations and Sources of CO₂ in West Virginia

Source Data: Advanced Resources International Big Fields Database, EIA's Appalachian Basin Oilfield map, EPA's Greenhouse Gas Reporting Program and Ventyx's Energy Velocity data
Getting to Market with Produced Crude Oil

- Ergon refinery
  - Newel West Virginia
  - Capacity: 20,000 barrels per day
  - 100% Appalachian grade paraffinic crude oils
- Marathon Oil
  - Cattletsburgh, KY
  - Capacity: 233,000 barrels per day
  - Variety of crudes, topping
- Refineries responding to recent increase in regional crude oil supply
- 183 MMbbls over 40 yrs – 12,000 barrels per day
Challenges to Overcome for Economic CO₂ EOR in West Virginia

<table>
<thead>
<tr>
<th></th>
<th>Average Net Pay (feet)</th>
<th>Average Permeability (milliDarcy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Virginia</td>
<td>17</td>
<td>21</td>
</tr>
<tr>
<td>Rest of United States</td>
<td>123</td>
<td>377</td>
</tr>
</tbody>
</table>

Source: Advanced Resources International, Big Oil Fields Database. Numbers are OOIP weighted average from all fields that have positive technically recoverable resource.
Challenges to Overcome for Economic CO₂ EOR in West Virginia

Other challenges:
- Heterogeneous rock makes uniform sweep difficult to achieve
- Mountainous terrain increases the cost of drilling
- Existing wells likely not usable
- Scant data from P/S recovery increase uncertainty of oil response
- State unitization laws
- No big, cheap source of CO₂ (a la McElmo/Jackson Dome) to get things started

Positives:
- Heterogeneity, low perm, and undocumented P/S operations are double-edged swords: there may be a lot of un-swept oil!
- Nearby refineries represent market for produced crude oil
Case Study: Oil Fields Prospective for CO$_2$ EOR in Southwest West Virginia

- Six oil fields within 100 miles of Mingo County are prospective for miscible CO$_2$-EOR
- Four of the oil fields fall along a straight line. In concept, they could be developed sequentially along a single CO$_2$ pipeline
- The key insight was that four marginal reservoirs could be combined to form one good target

Source: Kuuskraa and Petrusak. 2012. CO2 Storage and Utilization Options Near Mingo County West Virginia. Draft NETL report
## Case Study: Four fields in the Mingo County CO₂ EOR Concept

<table>
<thead>
<tr>
<th>Field</th>
<th>Depth (ft)</th>
<th>Pay (ft)</th>
<th>Acreage</th>
<th>Temp (°F)</th>
<th>API °</th>
<th>OOIP (Million Bbls)</th>
<th>CO₂ demand (Million mtCO₂)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walton*</td>
<td>2000</td>
<td>29</td>
<td>6,740</td>
<td>75</td>
<td>43</td>
<td>&gt;100</td>
<td>14.1</td>
</tr>
<tr>
<td>Granny Creek*</td>
<td>1940</td>
<td>40</td>
<td>3,840</td>
<td>73</td>
<td>45</td>
<td>20-100</td>
<td>6.5</td>
</tr>
<tr>
<td>Blue Creek</td>
<td>1700</td>
<td>10-30</td>
<td>16,000</td>
<td>85</td>
<td>43</td>
<td>&gt;100</td>
<td>20.6</td>
</tr>
<tr>
<td>Cabin Creek</td>
<td>3000</td>
<td>20</td>
<td>4,600</td>
<td>84</td>
<td>44</td>
<td>10-20</td>
<td>5.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>47</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Kuuskraa and Petrusak. 2012. CO₂ Storage and Utilization Options Near Mingo County West Virginia. Draft NETL report
Summary

• There are challenges to developing CO₂ EOR in West Virginia, but the prize is big, ~ 16 B$ in revenue from crude oil sales over 30-50 years

• CO₂ EOR is established and growing in other parts of the United States, needed capability exists

• Many of the technologies being developed at the National Energy Technology Laboratory can enable CO₂ EOR in more complex settings like exist in West Virginia
Thank you!

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joseph.dipietro@netl.doe.gov
412.386.5853
### Crude Oil Production from CO₂ EOR Compared to Total U.S. Production

<table>
<thead>
<tr>
<th>year</th>
<th>U.S. Crude Oil Production* (Mbbls/day)</th>
<th>U.S. Crude Oil from CO₂ EOR** (Mbbls/day)</th>
<th>CO₂ EOR as a percent of total U.S. production</th>
<th>Annual increase/decrease in total U.S. crude oil production (Mbbls/day)</th>
<th>Annual increase/decrease in U.S. crude oil production from CO₂ EOR (Mbbls/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>5089</td>
<td>240</td>
<td>4.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>5077</td>
<td>245</td>
<td>4.8%</td>
<td>-12</td>
<td>5</td>
</tr>
<tr>
<td>2008</td>
<td>5000</td>
<td>250</td>
<td>5.0%</td>
<td>-77</td>
<td>5</td>
</tr>
<tr>
<td>2009</td>
<td>5353</td>
<td>261</td>
<td>4.9%</td>
<td>353</td>
<td>11</td>
</tr>
<tr>
<td>2010</td>
<td>5479</td>
<td>272</td>
<td>5.0%</td>
<td>126</td>
<td>11</td>
</tr>
<tr>
<td>2011</td>
<td>5658</td>
<td>278</td>
<td>4.9%</td>
<td>179</td>
<td>6</td>
</tr>
<tr>
<td>2012***</td>
<td>6365</td>
<td>284</td>
<td>4.5%</td>
<td>707</td>
<td>6</td>
</tr>
</tbody>
</table>

* Energy Information Administration  
** Kuuskraa OGJ 2012  
*** Total U.S. crude oil production estimated to be 12.5% higher than 2011 based on monthly data through July
<table>
<thead>
<tr>
<th>Company</th>
<th>2012 Crude Oil Production from CO₂ EOR (Mbbl/d)</th>
<th># of Active Projects in 2012</th>
<th>Cumulative percent of total production from CO₂ EOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occidental</td>
<td>88.0</td>
<td>31</td>
<td>31%</td>
</tr>
<tr>
<td>Denbury Resources</td>
<td>39.7</td>
<td>22</td>
<td>45%</td>
</tr>
<tr>
<td>Kinder Morgan</td>
<td>31.6</td>
<td>3</td>
<td>56%</td>
</tr>
<tr>
<td>Chevron</td>
<td>24.2</td>
<td>7</td>
<td>65%</td>
</tr>
<tr>
<td>Hess</td>
<td>20.5</td>
<td>4</td>
<td>72%</td>
</tr>
<tr>
<td>Whiting Petroleum</td>
<td>20.0</td>
<td>4</td>
<td>79%</td>
</tr>
<tr>
<td>Anadarko</td>
<td>13.8</td>
<td>7</td>
<td>84%</td>
</tr>
<tr>
<td>Merit Energy</td>
<td>13.6</td>
<td>7</td>
<td>88%</td>
</tr>
<tr>
<td>Other</td>
<td>32.8</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>284.2</strong></td>
<td><strong>124</strong></td>
<td></td>
</tr>
</tbody>
</table>

Other includes: ExxonMobil, ConocoPhilips, Apache, Chaparral Energy, XTO Energy, Devon, Energen Resources, Legado, Fasken, Resolute Natural Resources, Core Energy, Great Western Drilling, Orla Petco, Stanberry Oil, and George R. Brown.

Source: Kuuskraa, V.A. July 2012. QC updates carbon dioxide projects in OGJ's enhanced oil recovery survey. Oil&Gas Journal.
## Different Approaches to CO₂ Supply

Amount Sold, Purchased, and Produced in 2010

<table>
<thead>
<tr>
<th>Company</th>
<th>Sold to 3rd Parties</th>
<th>Purchased from 3rd Parties</th>
<th>Produced &amp; Utilized Internally</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denbury Resources</td>
<td>111</td>
<td>0</td>
<td>852</td>
</tr>
<tr>
<td>Kinder Morgan</td>
<td>1,000</td>
<td>0</td>
<td>300</td>
</tr>
<tr>
<td>Occidental Petroleum</td>
<td>0</td>
<td>0</td>
<td>1,700</td>
</tr>
<tr>
<td>Chaparral Energy</td>
<td>0</td>
<td>41</td>
<td>0</td>
</tr>
<tr>
<td>Whiting Petroleum</td>
<td>0</td>
<td>380</td>
<td>0</td>
</tr>
<tr>
<td>Hess Corporation</td>
<td>0</td>
<td>195</td>
<td>80</td>
</tr>
<tr>
<td>Chevron Corp.</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Anadarko Petroleum</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Total Amount of CO₂ (MMcf/d)

Information compiled from SEC filings

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**Chart:**
- **Y-axis:** Total Amount of CO₂ (MMcf/d)
- **X-axis:** Companies
- **Legend:**
  - Sold to 3rd Parties
  - Purchased from 3rd Parties
  - Produced & Utilized Internally

**Notes:**

- No Info Provided
Components of Next Generation CO$_2$ EOR

• Improved conformance and mobility control
  – Increase viscosity of CO$_2$
  – Plug up high permeability channels.

• Locate and contact unswept pay
  – Better “see” CO$_2$ plume
  – Precisely locate CO$_2$ injection

• Increase CO$_2$ injection
  – Primarily a function of inexpensive CO$_2$
  – Also need ability to CO2 plume to have confidence to inject at higher rate

• Achieve near miscible behavior
  – Model and predict oil production response.
Figure 3. Sources of CO₂ for Domestic EOR Floods

Crude Oil Production from CO₂ EOR, Potential

Current Best Practices CO\textsubscript{2} EOR Technology Scenario,
9 Billion metric tons of CO\textsubscript{2} demand, 24 billion barrels of crude oil production

Source: DiPietro and Nichols. 2012. “Scenarios for CO\textsubscript{2} EOR in the United States through 2100” draft NETL report
Typical Permian Basin CO$_2$ EOR Project Cost Structure (Occidental Petroleum)