Mature Fields and Marginal Oil Wells: Key Resources for CO₂–EOR and CO₂ Storage

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The great bulk of the domestic conventional oil resource exists in mature fields and their marginal wells. These fields and wells are steadily approaching the end of their economically viable lives, particularly in a lower oil price world.

Traditional primary and secondary oil recovery methods have recovered only about a third of the oil in-place in these mature fields, leaving behind a major resource target.

A variety of enhanced oil recovery technologies can be applied to recover more of this left behind ("stranded") oil, including injection of miscible CO₂. However, these mature oil fields and their marginal wells need to remain available for effective application of CO₂-EOR.
Large Volumes of Oil Remain “Stranded” in Discovered Conventional U.S. Oil Fields

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

Traditional primary recovery and waterflooding have recovered only about a third of the oil in-place in discovered conventional U.S. oil fields, leaving behind a target of over 400 billion barrels.

A most promising enhanced oil recovery technology that can be used to recover this “stranded” oil is miscible/immiscible CO₂ injection.

*Does not include “tight” oil production or reserves.
Source: Advanced Resources International analyses, 2015.
The Regional CO$_2$-EOR Targets

Of the 414 B barrels of remaining oil in-place, 284 B barrels is technically favorable for CO$_2$-EOR. Much of oil resource is in the Permian Basin, Gulf Coast, the Mid-Continent and East/Central Texas.
Helping maintain the life of these mature conventional oil fields is a massive population of marginal wells, defined as producing 10 barrels of oil per day or less.

The latest Interstate Oil and Gas Compact Commission report “Marginal Wells: Fuel for Economic Growth”, tabulated that:

- There were 410,000 marginal oil wells (as of 2012).
- These marginal oil wells produced 740,000 barrels of oil per day, averaging about 2 barrels per day per well.
- The oil production from these marginal wells provided $25 billion of revenues (in 2012), admittedly under a more favorable oil price regime.
Importance of Maintaining the Marginal Well Population

Maintaining the economic viability and availability of these marginal wells should be a state and national priority:

- At the state and local levels, marginal wells provide jobs and drive economic activity.
- At the national level, the significant volume of oil production from marginal wells contributes to energy security and reduced oil imports.
- Looking to the future, the availability of marginal wells will be an important factor for the success of CO$_2$ enhanced oil recovery technology (and the storage of CO$_2$) in these mature domestic oil fields.
In the remainder of my presentation, I will expand on the potential size of the CO₂-EOR oil recovery and CO₂ storage opportunity in mature domestic oil fields by addressing four questions:

- What is the Status of the CO₂-EOR Industry?
- How Large is the “Size of the Prize”?
- Can CO₂-EOR Be Economically Viable in a Lower Oil Price World?
- Will There Be Sufficient Supplies of CO₂?
1. Status of the CO$_2$-EOR Industry
CO₂ Enhanced Oil Recovery: A Look at Today

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 will help drive its growth.

Current CO₂-EOR Operations and CO₂ Sources (2014)

- The 136 significant CO₂-EOR projects currently produce 300,000 barrels per day from injecting 3.5 Bcf/d of CO₂, with 0.7 Bcf/d from industrial sources.
- Lack of reliable, affordable supplies of CO₂, along with lower oil prices, are the major constraints to greater use of CO₂-EOR technology.

Source: Advanced Resources International based on Oil & Gas Journal and other industry data, 2014.
The Business Side of CO₂-EOR

The CO₂-EOR business is dominated by three “big” players - - Occidental Petroleum, Kinder Morgan and Denbury Resources.

A handful of other companies - - such as Apache, Breiburn Energy, Chaparral Energy, Chevron, Core Energy, Fasken, and Hess among others - - round out the mix.

Top Three Operators of CO₂-EOR Account for Two-Thirds of CO₂-EOR Production

<table>
<thead>
<tr>
<th>Operator</th>
<th>Total Projects</th>
<th>2015 Production (MBbl/d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxy</td>
<td>33</td>
<td>145,000</td>
</tr>
<tr>
<td>Kinder Morgan</td>
<td>4</td>
<td>80,000</td>
</tr>
<tr>
<td>Denbury</td>
<td>25</td>
<td>42,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>62</strong></td>
<td><strong>267,000</strong></td>
</tr>
</tbody>
</table>

Source: Company presentations (includes NGLs).

A number of the majors and large independents - - Anadarko, ConocoPhillips, ExxonMobil/XTO - - still operate legacy CO₂-EOR projects, but are currently much less active.
Occidental Petroleum - World Leader in Enhanced Oil Recovery

U.S. CO₂ EOR Projects

Size of bubble = CO₂ EOR Production Volume

- Inject 1.9 billion cubic feet a day
- Operate 31 CO₂ EOR projects

Source: Oil & Gas Journal 2012 Biennial EOR Survey

Occidental Petroleum operates its CO₂-EOR business as OxyPermian, located in Midland, Texas.

- Entered the CO₂-EOR business with purchase of BP’s (Amoco/Arco) and Shell’s oil fields, CO₂ sources and their ownership share of CO₂ pipelines.
- Investing $500 million in CO₂-EOR (in 2016) out of a capital budget of $2.9 billion.
- Producing 255,000 B/D in Permian Basin, with CO₂-EOR providing 145,000 B/D (including NGLs).
- Current strategy is to establish major growth programs in EOR with “game changing” technologies.
Mature Fields and Marginal Oil Wells: Key Resources for CO2–EOR and CO2 Storage

OxyPermian’s CO2-EOR Operations

CO2-EOR is a major contribution to OxyPermian’s performance:
- 60% of Oxy’s Permian production
- Oxy’s most profitable business unit
- Provides significant free cash flow

Oxy’s strategy is vertically integrated CO2-EOR:
- Ownership of CO2 supply plus long-term purchase agreements
- 1,900 miles of CO2 pipelines with 2.4 Bcf of capacity
- 33 major CO2-EOR projects

Oxy expects large future potential from use of CO2-EOR:
- Expansion/new CO2-EOR projects
- ROZ (at Wasson, Hobbs, etc.)

Source: OxyPermian, 2014
Hobbs: CO₂ Flood and Expansion Areas

North Hobbs:
- Phase 1 added 35 MMBOE
- Phase 2A will develop 13.7 MMBOE at $13.82 per BOE (Injection in 6/2016)

South Hobbs:
- Started CO₂ injection into Phase 1 in September, 2015
- Phases 1 & 2 will develop 28 MMBOE at $10.60 per BOE

Source: OxyPermian, 2016
KinderMorgan Energy

KinderMorgan, a major pipeline and energy production company located in Houston, Texas, entered the CO\textsubscript{2}-EOR supply business with the purchase of Shell’s CO\textsubscript{2} pipelines and supplies. It subsequently entered the E&P business with the acquisition of SACROC from Devon in mid-2000.

- Owns 8.5 billion barrels of OOIP resources in four key Permian Basin oil fields, plus ROZ resources.
- Current CO\textsubscript{2}-EOR oil production of 80,000 B/D (including NGLs):
  - 34,000 B/D SACROC oil
  - 21,000 B/D SACROC NGLs
  - 19,000 B/D Yates
  - 6,000 B/D Katz/GLSAU/Tall Cotton
- Capital investment (in 2016) of $880 million:
  - $320 MM for CO\textsubscript{2} S&T
  - $560 MM for E&P/CO\textsubscript{2}-EOR

Source: KinderMorgan, 2014
KinderMorgan has set forth an ambitious 10 year program for its CO₂ E&P and S&T business units:

- Expectations for annual DCF of about $1 billion/year for next 10 years.
- Investing $4.1 billion in CAPEX in next 10 years.
- Looking to the ROZ and Goldsmith Field to replace declines in SACROC oil production.

Oil prices in 2016 at $38/Bbl, 2017 at $45/Bbl, 2018 at $55/Bbl, 2019+ at $65/Bbl.

Source: KinderMorgan, 2016
Denbury Resources, a recently launched medium-size independent oil and gas company, is headquartered in Plano, Texas.

"Our primary focus is on enhanced oil recovery utilizing carbon dioxide (CO₂ EOR). Our goal is to increase the value of acquired properties through a combination of exploitation, drilling and proven engineering extraction practices, with the most significant emphasis relating to tertiary recovery operations."

Source: Denbury Resources, 2014
Denbury’s Gulf Coast CO\textsubscript{2}-EOR Activities and Assets

Denbury is the leading CO\textsubscript{2}-EOR operator in the Gulf Coast:

- 1,100 miles of CO\textsubscript{2} pipelines, including the recently completed Green Pipeline.
- About 0.7 Bcfd of natural CO\textsubscript{2} production plus notable anthropogenic sources:
  - Air Products Hydrogen: 50 MMcfd
  - PCS Nitrogen: 20 MMcfd
  - MS Power (Kemper): 115 MMcfd (2016)
  - Future (280 MMcfd)
- About 42,000 B/D of production from 14 CO\textsubscript{2}-EOR projects.
- Expects 70,000 B/D of additional production (peak) from new CO\textsubscript{2}-EOR projects (Conroe, Webster, etc.)
Denbury recently entered the Rockies CO₂–EOR business with purchase of Encore and swap of Bakken Shale assets for Exxon’s oil fields and CO₂ supply.

- Purchased of Cedar Creek Anticline from ConocoPhillips
- Constructed Greencore CO₂ pipeline with CO₂ supplies from Lost Cabin gas processing plant and Riley Ridge.
- Operating three CO₂ floods:
  - Bell Creek (Montana)
  - Hartzog (Wyoming)
  - Grieve (Wyoming)

(1) Potential, proved and produced-to-date tertiary reserves estimated as of 12/31/13 based on a range of recovery factors. Proved reserves based on year-end 12/31/13 SEC reporting.

Source: Denbury Resources, 2014
2. Size of the Prize
The first IPCC report set in-place a perspective that the CO₂ storage potential offered in mature oil fields by CO₂-EOR was a small, niche opportunity.

Two reports by Advanced Resources Int’l and Melzer Consulting for U.S. DOE/NETL, helped change the perception that CO₂ demand and associated storage by CO₂-EOR is a limited, niche opportunity.
The Size of the “Main Pay” CCUS “Prize”

- 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 $40/mt and 20% ROR (before tax).
**Less than 0.5 Bmt.
Advances in CO$_2$-EOR Recovery Technologies

Recovering more of the oil “left behind” after industry’s and nature’s waterfloods rests on successful development and integrated application of four “next generation” CO$_2$–EOR technologies:

1. Improved reservoir conformance to reduce unproductive channeling of CO$_2$ through high permeability flow paths.

2. Advanced CO$_2$ flood designs to target the high remaining oil saturation reservoir segments bypassed, or poorly swept, by the waterflood.

3. Enhanced mobility control to reduce viscous fingering and to improve the mobility ratio.

4. Development and use of fluids and chemicals that reduce the CO$_2$/oil minimum miscibility pressure (MMP).

Application of these technologies would benefit greatly from the design of “smart wells” and real-time feedback of information from the reservoir.
“Next Generation” CO$_2$-EOR and Storage Technology
3. Economics of CO$_2$-EOR
Can CO₂-EOR Be Economically Viable in a Lower Oil Price World?

Information from the “Big Three” CO₂-EOR operators - - OxyPermian, Kinder Morgan and Denbury - - shows that:

- Oxy’s “main pay” Permian Basin CO₂-EOR can operate profitably at $22 to $30/B (not including investment and return).
- Oxy’s ROZ Permian Basin CO₂-EOR has front-end development costs of $3 to $7/B.
- Kinder Morgan can profitably operate its Permian Basin CO₂-EOR projects at $20/B (not including investment and return).
- Denbury’s CO₂-EOR operating costs plus G&A (not including capital or return on capital) have declined from about $30/B in prior years to $25/B in 2015 and further to about $21/B in 1Q 2016.
Permian EOR can operate at cash costs as low as $22 per BOE.

2015 Permian EOR Cost Structure
$55 WTI, $3.00 NYMEX

- Well, Surf Maint: $14.1
- Injectant: $4.7
- Energy: $4.0
- Taxes: $2.7
- SG&A: $0

2015 Permian EOR Cost Structure
$35 WTI, $2.00 NYMEX

- Well, Surf Maint: $10.8
- Injectant: $4.0
- Energy: $2.2
- Taxes: $3.2
- SG&A: $1.8

**Occidental Petroleum – Economics of CO₂-EOR for ROZ**

**ROZ Projects development cost ranges from $3 - $7 per BOE**

**South Hobbs Residual Oil Zone (“ROZ”) Potential:**


KinderMorgan: The Business Side of CO$_2$-EOR

KinderMorgan’s CO$_2$-EOR Business Unit shows attractive economics:

- Operating costs, including CO$_2$, power, workover/labor and production taxes of about $20/B.
- Net cash margin of $20/B (at WTI).
- Three year IRR of nearly 22%.

**Oil and Gas Cash Cost Structure** ($/Net Boe)

*Costs and Revenue per net Boe, including hedges where applicable
Source: KinderMorgan, 2016
KinderMorgan: Returns on Invested Capital

Kinder Morgan’s CO₂ Business Unit Provides Company Leading Returns

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas Pipes</td>
<td>10.9%</td>
<td>10.9%</td>
<td>10.3%</td>
<td>10.7%</td>
</tr>
<tr>
<td>Products Pipelines</td>
<td>12.4</td>
<td>12.3</td>
<td>12.6</td>
<td>12.4%</td>
</tr>
<tr>
<td>Terminals</td>
<td>12.1</td>
<td>11.2</td>
<td>10.2</td>
<td>11.2%</td>
</tr>
<tr>
<td>CO2</td>
<td>25.9</td>
<td>22.8</td>
<td>16.2</td>
<td>21.6%</td>
</tr>
<tr>
<td>KM Canada</td>
<td>14.8</td>
<td>11.5</td>
<td>9.7</td>
<td>17.0%</td>
</tr>
<tr>
<td>Total Company</td>
<td>11.9%</td>
<td>11.4%</td>
<td>10.3%</td>
<td>11.2%</td>
</tr>
</tbody>
</table>

Source: KinderMorgan, 2016
KinderMorgan: Return on Investment By CO₂ Project

### IRR % vs Oil Price

<table>
<thead>
<tr>
<th></th>
<th>$30 flat</th>
<th>$40 flat</th>
<th>$50 flat</th>
</tr>
</thead>
<tbody>
<tr>
<td>SACROC Infill</td>
<td>0%</td>
<td>9%</td>
<td>53%</td>
</tr>
<tr>
<td>SACROC-Bypass</td>
<td>11%</td>
<td>30%</td>
<td>54%</td>
</tr>
<tr>
<td>SACROC P5</td>
<td>0%</td>
<td>2%</td>
<td>19%</td>
</tr>
<tr>
<td>Yates HDH</td>
<td>34%</td>
<td>66%</td>
<td>100%</td>
</tr>
<tr>
<td>GLSAU 4a</td>
<td>0%</td>
<td>0%</td>
<td>7%</td>
</tr>
<tr>
<td>Tall Cotton Ph 2</td>
<td>0%</td>
<td>8%</td>
<td>21%</td>
</tr>
</tbody>
</table>

- Forecasted operating costs do not incorporate further cost savings expected in a $40/Bbl or lower price environment
- Budgeted 2016 operating costs:
  - SACROC = $18.24 /Bbl
  - Yates = $13.43 /Bbl

Source: KinderMorgan, 2016
Economics of CO$_2$-EOR: Denbury’s CO$_2$-EOR Operating Costs

Denbury’s view is that CO$_2$-EOR provides a better NPV than the Bakken Shale. Denbury’s CO$_2$-EOR CO$_2$ operating costs plus G&A range have declined to $25 per barrel.

### Projected Production Profile with Same Capital Spending

![Projected Production Profile with Same Capital Spending](image)

**Note:** Assumes 700 BOEPD initial 30 day rate for Bakken wells.

**Source:** Denbury Resources, 2014

### Economics of CO$_2$-EOR:

#### Denbury’s CO$_2$-EOR Operating Costs

<table>
<thead>
<tr>
<th>Year</th>
<th>SMM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>83</td>
</tr>
<tr>
<td>2</td>
<td>83</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
</tr>
<tr>
<td>5</td>
<td>60</td>
</tr>
<tr>
<td>6</td>
<td>60</td>
</tr>
<tr>
<td>7</td>
<td>52</td>
</tr>
<tr>
<td>8</td>
<td>52</td>
</tr>
<tr>
<td>9</td>
<td>45</td>
</tr>
<tr>
<td>Total</td>
<td>$955</td>
</tr>
</tbody>
</table>

#### Capital Spending per Year Based on EOR Spending Pattern

<table>
<thead>
<tr>
<th>Year</th>
<th>$/BOE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td></td>
</tr>
</tbody>
</table>

#### A. Oil Prices

<table>
<thead>
<tr>
<th></th>
<th>2014 ($/B)</th>
<th>2015 ($/B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NYMEX ($/B)</td>
<td>$99</td>
<td>$49</td>
</tr>
<tr>
<td>Realized ($/B)</td>
<td>$102</td>
<td>$49</td>
</tr>
</tbody>
</table>

#### B. CO$_2$ Expenses

<table>
<thead>
<tr>
<th>Item</th>
<th>2014 ($/BOE)</th>
<th>2015 ($/BOE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. CO$_2$ Costs</td>
<td>$7</td>
<td>$5</td>
</tr>
<tr>
<td>2. Power/Fuel</td>
<td>$7</td>
<td>$7</td>
</tr>
<tr>
<td>3. Repairs/Worker Maintenance*</td>
<td>$8</td>
<td>$3</td>
</tr>
<tr>
<td>4. Labor/Chemicals/Overhead/G&amp;A</td>
<td>$8</td>
<td>$10</td>
</tr>
<tr>
<td>5. Total Expenses</td>
<td>$30</td>
<td>$25</td>
</tr>
</tbody>
</table>

*Excludes costs for Delhi field remediation.

**Source:** Denbury Resources, 2014
4. Sources of CO$_2$ for EOR
Will There Be Sufficient Supplies of CO₂?

Increased volumes of natural, industrial and anthropogenic CO₂ are available for the Permian Basin, the Mid-Continental, the Rockies and the Gulf Coast.

Significant efforts are underway to lower the costs of CO₂ capture from power plants and other industrial facilities, including:

- ExxonMobil’s Fuel Cell based CO₂ capture technology
- Advanced solid sorbents and amines
- Membranes and other methods

In addition, a series of CO₂ capture (and storage) incentives are under discussion that would “buy-down” the costs of CO₂ capture by $20 to $40 per metric ton.
KinderMorgan has expanded its 1.3 Bcfd of CO₂ production by 200 MMcfd by investing $590 million at McElmo Dome. Future CO₂ supply opportunities include:

- Investing $1 billion for St. Johns, including the 216 mile Lobos CO₂ Pipeline
- Expanding the Cortez Pipeline ($327 MM)

*KinderMorgan has expanded its 1.3 Bcfd of CO₂ production by 200 MMcfd by investing $590 million at McElmo Dome. Future CO₂ supply opportunities include:

<table>
<thead>
<tr>
<th>New Sources</th>
<th>(MMcfd)</th>
<th>(SMM)</th>
<th>(SMM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow Jacket Boosters</td>
<td>90</td>
<td>$214</td>
<td>$214</td>
</tr>
<tr>
<td>Cow Canyon</td>
<td>200</td>
<td>$380</td>
<td>$56</td>
</tr>
<tr>
<td>St. Johns</td>
<td>300</td>
<td>$982</td>
<td>$73</td>
</tr>
<tr>
<td>Additional 4 Corners Area Expansions</td>
<td>60</td>
<td>$184</td>
<td>$11</td>
</tr>
<tr>
<td>Recapture Projects</td>
<td>78</td>
<td>$96</td>
<td>$16</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>728</strong></td>
<td><strong>$1,856</strong></td>
<td><strong>$370</strong></td>
</tr>
</tbody>
</table>

*Completion of Doe Canyon expansion added 90 MMcfd and eliminated curtailments in 4Q 2013
Denbury Resources: Jackson Dome holds 5.5 Tcf of proved CO₂ reserves and an additional 2.5 Tcf of probable and possible CO₂ reserves. Denbury will purchase and use about 0.2 Bcfd of industrial CO₂ once the Kemper IGCC plant comes on stream.

Source: Denbury Resources, 2014
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