National Enhanced Oil Recovery Initiative

Meeting One

Hyatt Regency Washington

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U.S. EOR Industry: An Overview

Current State of Play and Future Potential

Steve Melzer, Chief Geek

Melzer Consulting
U.S. EOR Industry: An Overview

Current State of Play and Future Potential

1) CO₂ Enhanced Oil Recovery – A Quick Look at the Technology

2) Where, How Much Oil and CO₂, Who are the Key Players?

3) The Growing Demand for CO₂
   A) Oil Pricing
   B) New Targets (ROZs)

4) Market Issues and Barriers to Greater Deployment
Primary, **Secondary** and **Tertiary** Recovery

**Primary:** New Wells Are Drilled, Pressures within the Fluids in the Reservoir Cause Them to Flow to Surface

**Secondary:** Comes after the Reservoir Pressures are Depleted, Some Wells are Recompleted to Become Injection Wells and a Fluid is Injected to Repressure and Sweep Additional Oil; Generally the Injected Fluid is Water and we call it waterflooding (water and oil do not mix)

**Tertiary:** The Injectant used causes the oil properties to change hence allowing more of the bypassed oil in the secondary phase to be produced; heat (steam), CO$_2$, and surfactant like chemicals are the most common types; At depths greater than 2500 feet, the CO$_2$ is not a gas – has the density of a liquid
SYNONYMS

• CO₂ Enhanced Oil Recovery and CO₂ Flooding will be used interchangeably herein.

• Tertiary Flooding is sometimes used as a substitute term for CO₂ EOR but does imply that the CO₂ flood follows a waterflood.
JUST A REMINDER: THE OIL IS IN PORES, NOT IN UNDERGROUND POOLS

Pore Geometries
Courtesy of Mark Knackstedt
Australian National University
PRIMARILY, WF AND TERTIARY RECOVERY FROM THE W. TX SAN ANDRES FORMATION EXPERIENCE

NEARLY HALF THE OIL IS STILL THERE, EVEN AFTER TERTIARY (CO$_2$) PHASE!

BUT BEWARE OF AVERAGES!!
Primary, Secondary and Tertiary Oil (an example)
CO₂ EOR

How It Works

• CO₂ dissolves in oil, lowers oil viscosity, reduces interfacial tension, and swells the oil, thereby allowing oil affixed to the rock and trapped in pore spaces to flow more freely.

• The early phase of oil production (called primary production) decreases the fluid pressures in a reservoir. CO₂ injection repressures the reservoir, thereby reestablishing a drive mechanism. CO₂ EOR can follow primary production or follow a water injection (waterflooding) phase. Historically, since CO₂ is more expensive than water, it has followed waterflooding but if CO₂ storage has value, secondary CO₂ floods could become commonplace.

• A portion of the injected CO₂ will be produced with the oil and water, separated at the surface, and recycled to be used again in the reservoir. The recycle volumes, as a percentage of total* injection volumes, will vary from 0% early in the flood to as much as 60% in a very mature flood.

• Typically 90-100% of the purchased CO₂ volume is retained in reservoir (dead end pores and channels).*

  CO₂ EOR technology has been around at a commercial scale since the early 1970’s

* The percentage of stored volumes will be 90%+ of the Purchased Volumes
Section 2

CO$_2$ EOR:
Where, How Much and Who are the Key Players
CO$_2$ EOR: Coming of Age

Decade by Decade Growth in U.S. EOR

100 million barrels per year

Ref: Oil & Gas Journal Biennial EOR Reports: Apr of Even Numbered Years
U.S. & Permian Basin CO₂ EOR Production Growth (1972-2010) 
*Plus a Case History (PB) of a CO₂ Supply Constrained Market*

Perm Basin & U.S. CO2 EOR History

- PB CO2 EOR OIL (KBOPD)
- U.S. CO2 EOR OIL (KBOPD)

Supply Limited ‘Decline’
So How Much CO$_2$ is Used in EOR?
Volumes and Sources of CO$_2$ for EOR*

The CO₂ Injection and Transportation Companies

### Significant CO₂ Suppliers/Transporters

<table>
<thead>
<tr>
<th>Supplier/Transporter</th>
<th>Location/State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denbury Resources (Jackson***)</td>
<td></td>
</tr>
<tr>
<td>Kinder Morgan (McElmo*, Doe Canyon*, Bravo*)</td>
<td></td>
</tr>
<tr>
<td>ExxonMobil (McElmo*, Sheep Mtn*, LaBarge**)</td>
<td></td>
</tr>
<tr>
<td>Occidental (Bravo*, Sheep Mtn*)</td>
<td></td>
</tr>
<tr>
<td>Dakota Gasification (N. Dak)</td>
<td></td>
</tr>
<tr>
<td>SandRidge/Oxy (Val Verde*)</td>
<td></td>
</tr>
<tr>
<td>CVR Partners: Coffeyville (under construction)</td>
<td></td>
</tr>
<tr>
<td>Chaparral Energy (Ok)</td>
<td></td>
</tr>
<tr>
<td>Chevron (McElmo*)</td>
<td></td>
</tr>
<tr>
<td>Core Energy (MI)</td>
<td></td>
</tr>
</tbody>
</table>

* Permian Basin, ** Wyoming, *** Mississippi, Gulf Coast (Tx, La), Wy/Mt (coming)

### CO₂ Flood Operators

As of Jan ‘10

<table>
<thead>
<tr>
<th>Operator</th>
<th>Count</th>
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<tr>
<td>Anadarko</td>
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<td>Apache Corp.</td>
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<tr>
<td>Chaparral Energy</td>
<td>7</td>
</tr>
<tr>
<td>Chevron</td>
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<tr>
<td>ConocoPhillips</td>
<td>2</td>
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<tr>
<td>Core Energy</td>
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<td>Denbury Resources</td>
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<td>Devon</td>
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<tr>
<td>Energen</td>
<td>1</td>
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<tr>
<td>ExxionMobil</td>
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<tr>
<td>Fasken</td>
<td>5</td>
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<tr>
<td>Great Western</td>
<td>1</td>
</tr>
<tr>
<td>George R. Brown Partnership</td>
<td>1</td>
</tr>
<tr>
<td>Hess Corporation</td>
<td>4</td>
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<tr>
<td>Kinder Morgan</td>
<td>2</td>
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<td>Merit Energy</td>
<td>7</td>
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<td>Orla Petco</td>
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<tr>
<td>Oxy Permian</td>
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<tr>
<td>Resolute Nat’l Resources</td>
<td>2</td>
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<tr>
<td>SandRidge Tertiary</td>
<td>1</td>
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<tr>
<td>Whiting Petroleum</td>
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<td>XTO Energy</td>
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Section 3
THE GROWING DEMAND FOR CO$_2$
BACKGROUND

(OF CO₂ EOR PROJECT GROWTH*)

GROWTH OF WW and PERMIAN BASIN CO₂ EOR PROJECTS
1984 - 2010

Ref: Biennial OGJ EOR Surveys and UTPB/PIA
.....and Growth Even with Languishing Oil Pricing

GROWTH OF PERMIAN BASIN & WORLDWIDE CO2 PROJECTS
1984 - 2004

YEAR
NO. OF PROJECTS
0 20 40 60 80
WW Projects
PB Projects

Average Growth > 2 Projects/Yr

WTI Posted Oil Prices - 1988-2000

YEAR
OIL PRICES IN $/bbl
$0 $10 $20 $30 $40
Average Price = $18.80 (U.S.)

Average
Price = $18.80 (U.S.)
There is Pent Up Growth
Just from Conventional EOR Targets
but....

A Huge New Set of Targets are
Coming of Age
The Science

• Many Basins in the U.S. have had more than one stage of tectonics affect them
• Any Post Subsidence/Oil Entrapment Stage can move oil around
• The oil industry is expert at looking at where the oil went
• We are just now realizing where it came from is also valuable (let’s call those zones ‘naturally waterflooded’ intervals)
The Engineering

• The oil industry goes after the residual oil targets left behind in our own waterfloods

• Why can’t the industry go after those zones that have been naturally waterflooded?

• Let’s call those residual oil zones (ROZs)

• Industry is (quietly) doing just this today in the Permian Basin
MIDDLE SAN ANDRES PALEOGEOGRAPHY
with Location of Industry Documented ROZ Zones/Fields*

* Adapted from Sagnak (2006), Chevron Presentation at the 12/06 CO₂ Flooding Conference
The List of On-going ROZ Projects

<table>
<thead>
<tr>
<th>Type and operator</th>
<th>Field</th>
<th>State</th>
<th>County</th>
<th>Top MPZ Depth, ft</th>
<th>Pay zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active CO₂ miscible</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Chevron</td>
<td>Vacuum San Andres Grayburg Unit</td>
<td>NM</td>
<td>Lea Co.</td>
<td>4,550</td>
<td>San Andres/Grayburg</td>
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<tr>
<td>Fasken</td>
<td>Hanford</td>
<td>Tex.</td>
<td>Gaines</td>
<td>5,500</td>
<td>San Andres</td>
</tr>
<tr>
<td>Hess</td>
<td>Seminole Unit-ROZ Phase 1</td>
<td>Tex.</td>
<td>Gaines</td>
<td>5,500</td>
<td>San Andres</td>
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<tr>
<td>Hess</td>
<td>Seminole Unit-ROZ Phase 2</td>
<td>Tex.</td>
<td>Gaines</td>
<td>5,500</td>
<td>San Andres</td>
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<tr>
<td>Hess</td>
<td>Seminole Unit-ROZ Stage 1 Full Field Dev</td>
<td>Tex.</td>
<td>Gaines</td>
<td>5,500</td>
<td>San Andres</td>
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<tr>
<td>Legado</td>
<td>Goldsmith-Landreth Unit</td>
<td>Tex.</td>
<td>Ector</td>
<td>4,200</td>
<td>San Andres</td>
</tr>
<tr>
<td>Occidental</td>
<td>Wasson Bennett Ranch Unit</td>
<td>Tex.</td>
<td>Yoakum</td>
<td>5,250</td>
<td>San Andres</td>
</tr>
<tr>
<td>Occidental</td>
<td>Wasson Denver Unit</td>
<td>Tex.</td>
<td>Yoakum</td>
<td>5,200</td>
<td>San Andres</td>
</tr>
<tr>
<td>Occidental</td>
<td>Wasson ODC</td>
<td>Tex.</td>
<td>&amp; Gaines</td>
<td>5,200</td>
<td>San Andres</td>
</tr>
</tbody>
</table>
SSAU MPZ & ROZ Crossection and Zonal Attributes*

<table>
<thead>
<tr>
<th></th>
<th>Gross Thickness</th>
<th>Net Thickness</th>
<th>Porosity</th>
<th>Permeability Range</th>
<th>OOIP</th>
<th>Initial Oil Saturation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Pay Zone (MPZ):</td>
<td>160’</td>
<td>126’</td>
<td>12%</td>
<td>0.8-120 md</td>
<td>1 billion stbo</td>
<td>0.84</td>
</tr>
<tr>
<td>Residual Oil Zone (ROZ):</td>
<td>246’</td>
<td>197’</td>
<td>12.6%</td>
<td>0.5-270 md</td>
<td>960 million stbo</td>
<td>0.32</td>
</tr>
</tbody>
</table>

* Source: Hess Corporation References from the 2001 and 2008 CO₂ Flooding Conferences
Remember this Chart?

Seminole Field Production History

Primary Phase
Secondary
Tertiary

Oil Production - BOPD

Date

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‘Quaternary’ Oil at the Seminole Field  
(Given Access to Needed CO₂ Supplies)

Total, Primary, Waterflood, Main Pay and ROZ CO₂ Performance  
(the Concept of "Brownfield" Quaternary Oil)

Annualized Oil Production in bopd

Year

TOTAL OIL - bopd
Proj Primary-bopd
Proj Waterflood-bopd
Main Pay EOR Baseline
Quat 2.0 Oil - bopd
Quat 3.0 Oil - bopd

Primary Production Peak
Secondary Production Peak
Tertiary CO₂ Production Peak
Quaternary CO₂ ROZ Production Peak

Primary Cum = 125 mm bbls
Secondary Cum = 325 mm bbls
Tertiary Cum = 200 mm bbls
Quaternary Cum = 300 or 200 mm bbls

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HOW BIG IS THIS ROZ BUSINESS?

• Type II ROZs are Ubiquitous in the Permian Basin, We are Finding Them on the West and East Sides of the Central Basin Platform, on the North and Northwest Shelves; They Seem to lie in ‘Fairways’

• It is Extremely Common to see the ROZs 200 feet in thickness, They are *not* Restricted to Existing Fields

• Porosities of 10-14% are common with Permeabilities of >10 millidarcies.

• ROZs are Commonly Better Developed than the the CO₂ data base, i.e., the Main Pay Zones

• Residual oil saturations (\(S_{orw}\)) are Generally 20-40% for most of the ROZ thickness – very analogous to water swept zones in Main Payzones

• Now that we have begun to look, we are finding these ROZs to be very common in other U.S. Basins
Section 4
Market Issues and Barriers to Greater Deployment
HISTORICAL BARRIERS TO WIDER CO$_2$ EOR DEPLOYMENT

- The Oil/Gas Industry Is Increasingly Exploration Focused
- Until the mid-90’s, Technology has been Tightly Held
- CO$_2$ EOR is Very Capital Intensive, Most of Which Comes Up Front Leading to Low Rates of Returns
- Availability of CO$_2$
- Widely Held Bias that EOR Targets Were Small
CO₂ SUPPLY CONSTRAINTS ARE NOW HOLDING BACK DEPLOYMENT OF CO₂ EOR

This has been a Huge Problem in the Permian Basin, Also True in Rockies although Shute Creek Expansion is helping in the Short Term

In Mississippi where Denbury Worked Hard to Avoid the CO₂ Supply Problem....

Next Year, CO₂ EOR could be half the State’s Production
Thank you

Time for Questions?

...and our industry partners
Backup Slides
The Model Forecasts
Just With EOR State-of-the-Art
What are the Needs for CO₂?*

Exhibit 6. U.S. CO₂ Demand and Supply Situation Through 2050

- Potential CO₂ Demand for EOR in need of Industrial Processes and Power Plants with CO₂ Capture (4.1 Bmt)
- Level production through 2050 from current and planned industrial facilities with CO₂ capture (1.1 Bmt)
- Level production through 2050 from existing natural gas processing facilities with CO₂ capture (0.7 Bmt)
- Depletion of all known unmixed underground accumulations (2.3 Bmt)

2011 State-of-the-Art EOR Technology, Lower 48 onshore, no ROZ, no tight shale (8.2 Bmt)

Demand Supply

EIA 2011 (Just Released)

CO₂ injection volumes in the Reference case, 2005-2035

Energy Information Administration | Annual Energy Outlook 2011
AEO 2011 Total Injection Volumes
And Then There are All These New Targets

*ARI Calls ‘Next Gen’*

![Bar chart showing technically and economically recoverable oil recovery and CO₂ demand.]

- **Technically Recoverable**
  - Oil Recovery: 135 billion barrels
  - CO₂ Demand: 45 billion tons

- **Economically Recoverable**
  - Oil Recovery: 66 billion barrels
  - CO₂ Demand: 19.5 billion tons

*At an oil price of $85/B, a CO₂ market price of $40/mt and a 20% ROR, before tax.*

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

Source: Advanced Resources Intl (2011).
The NRDC Look at CO$_2$ EOR & Demand for CO$_2$