CO2 EOR and Carbon Storage

With Case Example from Weyburn Field

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IEAGHG Summer School
Perth, December 2015
Oil recovery classification

- **Primary Recovery**
  - Natural Flow
  - Artificial Lift (Gas Lift, Pump Jack, etc.)

- **Secondary Recovery**
  - Waterflood

- **Tertiary Recovery**
  - Pressure Maintenance (dry hydrocarbon gas injection)

**Conventional Oil Recovery**
- Thermal
  - Steamflooding
  - Steam-Assisted Gravity Drainage (SAGD)
  - Combustion

**Enhanced Oil Recovery**
- Gas Miscible/Immiscible
  - Hydrocarbon
  - CO₂
  - Nitrogen
  - Flue Gas

- Chemical and Other
  - Alkaline Polymer
  - Microbial/Foam
CO\textsubscript{2} EOR and associated storage
Fundamentals of CO$_2$ EOR

- CO$_2$ and oil are not miscible on 1$^{st}$ contact - that is the formation of a single phase with no observable interface
- Multiple contacts are needed in which various oil components and CO$_2$ transfer back and forth until oil-enriched CO$_2$ cannot be distinguished from CO$_2$-enriched oil
- For an isothermal reservoir the minimum pressure needed to attain miscibility is the minimum miscibility pressure (MMP)
- Mixing causes swelling of oil and viscosity reduction of oil – more mobile oil.
Reservoir Injection and Production

- Increasing reservoir heterogeneity result in more complex well geometries and production methods.
Key CO₂ – Oil properties for EOR

• CO₂ Density (liquid or dense phase) is close to, but lighter than oil and water.
  ✓ Efficient sweep of new portion of reservoir.
  ✗ Must be in liquid or dense phase region.

• CO₂ is miscible with oil at high pressures and immiscible at lower P.
  ✗ MMP is higher with heavier oil.
  ✗ Reservoir heterogeneity means that P must be significantly above MMP
  ✓ Miscibility and lower CO₂ density results in oil swelling.
  ? Lower MMP through *new technologies*.
  ? *New technologies* to recover at partially miscible conditions.

? Asphaltenes, waxes, mineral scales, etc, can precipitate due to CO₂ presence. Lab work is needed to evaluate.
Key reservoir characteristics for CO$_2$ EOR

- Minimum reservoir pressure of 7.5 Mpa (1100 PSI) is desirable for miscibility (miscibility is also oil property-dependent).
- Reservoir temperature between 30° and 100°C.
- Oil gravity between ~25° and 48° API.
- Water-flood residual oil saturation greater than 25%.
- Nature of porosity and permeability for lateral fluid communication.

- Not all reservoirs suitable for CO$_2$ EOR
## Making the Business case for CCS

<table>
<thead>
<tr>
<th>CCS related project features</th>
<th>Clear business case</th>
<th>Clear business case due to climate policies</th>
<th>Business cases that requires government support and other revenue</th>
</tr>
</thead>
</table>
| • Industrial separation already takes place  
• Storage site known–oil field | • Industrial separation already takes place  
• Some previous knowledge of storage site | • CO₂ separation at relatively high cost (power) and storage site known–oil field  
or  
• Development of a greenfield storage site with industrial separation |
| Business case drivers | • EOR revenues | • Reduction in future/current carbon cost liabilities  
• Potential carbon credit markets | • Government funding  
• Reduction in future/current carbon cost liabilities  
• EOR revenues  
• Risk sharing |
Sources of CO₂ and CO₂ EOR projects counted as CCS Projects


CO₂ EOR CCS Projects
Natural CO₂ Sources
Anthropogenic CO₂ Sources

CO₂ Storage Resource Estimates for Oil and Gas Reservoirs in (Gigatonnes):
Canada 16 | United States 120
Weyburn-Midale Area

6500 tonnes/day new CO2
6500 tonnes/day recycled CO2
2.4 MT/year
~ 24 MT Stored

1250 tonnes/day new CO2
400 tonnes/day recycled CO2
0.46 MT/year
~ 4 MT Stored
Weyburn Storage Site Operations

Map ca 2004 and operations have expanded into “future” area

- Weyburn Unit 55,000 acres (220 km\(^2\))
- 1.4 Billion bbls OOIP
  - Sour crude 25-43 API
  - 160 million bbls incremental
  - 30 years of life
- ~300 injector wells
  - 160 water only
  - 110 WAG
  - 17 CO\(_2\) only
- 700 producers
- ~50% wells are Hz and 50% vertical
Geological Model Important to Predict Performance

Weyburn Flow Unit Model

- Poplar/Ratcliffe
- Midale Evaporite
- M1
- M2
- M3
- M3A
- M3B
- M3C
- M Ch
- V1
- V2 lower
- V2 upper
- V3
- V4
- V5
- V6
- Frobisher Evaporite
- Frobisher Marly
- Frobisher Vuggy

Legend:
- Dolostone
- Limestone
- Evaporite

Reservoir Zone: Marly
- Depth: 1450m
- Average Pay: 3m
- Porosity %: 26
- Permeability mD: 10

Reservoir Zone: Vuggy
- Depth: 1460m
- Average Pay: 5m
- Porosity %: 15
- Permeability mD: 30

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PATTERN & WELL LAYOUT

Courtesy Cenovus Energy
EXAMPLE OF WELL RESPONSE

101/14-11-006-14W2/00

- Oil Rate (CD): 38.08 m³/d
- Water Rate (CD): 120.29 m³/d
- Gas Rate (CD): 51.26 Mscm/d
- Water Cut: 75.95 % None

- Cumulative Oil Prod: 195046.40 m³
- Cumulative Water Prod: 1220964.70 m³
- Cumulative Gas Prod: 18.26 MMscm

Production Rates - May 2003

Oil Rate (CD) (m³/d)
Water Cut (% None)
Gas / Oil Ratio (Mscm/m³)

Courtesy Cenovus Energy
Oil production volumes

Weyburn Unit Oil Production

Production through YE 2010

Date

BOPD (gross)

Primary & Waterflood

Vertical Infills

Pre CO2 Hz Infills

CO2 EOR

Courtesy Cenovus Energy
Source CO₂ Characteristics

250 mmscfd CO₂ by-product of coal (lignite) gasification by Dakota Gasification

- approx. 8000 tonnes/day suitable for EOR

CO₂ purity 95% (less than 2% H₂S)

- trace mercaptans (provide basis for leak detection at surface facilities)

320 km pipeline (14 in & 12 in) built & operated by Great Plains

Compressed CO₂ delivered to Weyburn and Midale at the field gate
Recycle gas compression

Courtesy Cenovus Energy
Relation between oil production, purchased CO$_2$ and recycled CO$_2$

Source: Jakobsen, Hauge, Holm and Kristiansen 2005
CO$_2$ injection

Weyburn Unit CO2 Injection

- MMscf/day
- Jan-00 to Jan-10
- Recycle Gas
- DGC CO2

Courtesy Cenovus

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Time Lapse 3D Seismic

Slide courtesy PTRC
### Weyburn and Midale CO₂-EOR Operating Statistics

<table>
<thead>
<tr>
<th></th>
<th>Weyburn (EnCana)</th>
<th>Midale (Apache)</th>
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<tbody>
<tr>
<td><strong>Start of CO₂ injection / duration</strong></td>
<td>2000 / 30 years</td>
<td>2005 / 30 years</td>
</tr>
<tr>
<td><strong>Injection pressure</strong></td>
<td>10 - 11 MPa (1450 - 1600 psi)</td>
<td></td>
</tr>
<tr>
<td><strong>Daily injection rate of fresh CO₂</strong></td>
<td>6,500 t/d (125 MMscf/d)</td>
<td>1,250 t/d (25 MMscf/d)</td>
</tr>
<tr>
<td>Recycle rate of CO₂ &amp; produced gas &amp; produced gas</td>
<td>6,500 t/d (125 MMscf/d)</td>
<td>400 t/d (8 MMscf/d)</td>
</tr>
<tr>
<td><strong>Total daily CO₂ injection rate</strong></td>
<td>13,000 t/d (250 MMscf/d)</td>
<td>1,650 t/d (33 MMscf/d)</td>
</tr>
<tr>
<td><strong>Annual amount of fresh CO₂ injected</strong></td>
<td>2.4 million tonnes</td>
<td>0.46 million tonnes</td>
</tr>
<tr>
<td><strong>Total amount of fresh CO₂ injected to date</strong></td>
<td>16.1 million tonnes (June 2010)</td>
<td>2.11 million tonnes (June 2010)</td>
</tr>
<tr>
<td><strong>Incremental / total oil production</strong></td>
<td>18,000 / 28,000 b/d</td>
<td>2,600 / 5,700 b/d</td>
</tr>
<tr>
<td><strong>Projected total incremental oil recovery due to CO₂</strong></td>
<td>155 million barrels</td>
<td>60 million barrels (17% OOIP)</td>
</tr>
<tr>
<td><strong>CO₂ utilization factor</strong></td>
<td>3 - 4 Mcf/b</td>
<td>2.3 Mcf/b</td>
</tr>
<tr>
<td><strong>Projected amount of CO₂ stored at project completion</strong></td>
<td>30+ million tonnes* (gross)</td>
<td>10+ million tonnes* (gross)</td>
</tr>
<tr>
<td><strong>Total capital cost of EOR project</strong></td>
<td>CAD$1.3 billion</td>
<td>CAD$475 million</td>
</tr>
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*June 2010*
Weyburn CO₂ Storage Capacity

IEA Estimated CO₂ Storage = ~55 MT

- IEA Potential Storage Capacity
- Latest Forecast

Weyburn & Midale will store CO₂ equivalent to removing about 9 million cars off the road for a year

Latest Estimate > 30 MT

~22 Million Tonnes Stored to Date

EOR Operations

CO₂ Storage (million tonnes)
# Storage Scenarios
(based on reservoir simulation of 75 pattern model)

**Base Case:** Business as usual. Shut in wells at end of field life.

**Case II:** Shut-in producers and continue to inject CO₂ at end of production

**Case III:** Continue to produce and reinject until GOR reaches 1,500

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<th>EOR Base Case (2000 – 2033)</th>
<th>Alternative Storage Case II</th>
<th>Alternative Storage Case III</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ Stored, million tonnes</td>
<td>23.2</td>
<td>29.01 (5.9 oil)</td>
<td>54.9 (31.6 oil)</td>
</tr>
<tr>
<td>Oil recovery after EOR, % OOIP</td>
<td>47.2%</td>
<td>----</td>
<td>54.3% (7.1%)</td>
</tr>
<tr>
<td>Net CO₂ Utilization Ratio*, m³/m³</td>
<td>416 (3-4 Mcf/b)</td>
<td>----</td>
<td>1,462</td>
</tr>
</tbody>
</table>

* m³ of CO₂ stored / m³ of oil recovery
Volumes of CO$_2$ potentially stored through CO$_2$ EOR

Source: Global CCS Institute 2012
Source of CO$_2$ for EOR in the U.S.

Source: Annual Energy Outlook 2011, U.S. Energy Information Administration, Issues in Focus
Barriers to CO$_2$-EOR

- Lack of readily available, high quality CO$_2$
- Requires a long-term commitment
  - Strategic versus opportunistic outlook
- Economies of scale required
  - Need an “anchor” reservoir with material oil in-place
  - Ownership fragmentation must be addressed (e.g. Unitization)
- Difficult to get multiple partners to agree to upfront capital investment
- Limited technical expertise
- Certain corporate structures less suited to take on CO2-EOR risks
Wellbore & legacy issues
Does CO2-EOR = emissions abatement?

Maybe, if...
- Anthropogenic CO$_2$
- Recycled
- Monitored
- Transition to dedicated storage site possible or likely

CO$_2$ Life Cycle Analyses
- What extent is CO$_2$ generated in associated activities included in accounting
Summary

- CO₂ EOR has been in practice 40+ years and has demonstrated safe, large-scale injection and geologic storage of CO₂
- CO₂ EOR can provide a business case for injection and associated storage of CO₂
- CO₂ EOR sites can transition to dedicated storage but may need to meet obligations
  - MMV
- Does provide avenue for mitigating GHG emissions to atmosphere
CO$_2$ EOR and Carbon Storage

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