Large Scale CO$_2$ Flood Begins Along Texas Gulf Coast
(Technical Challenges in Re-Activating an Old Oil Field)

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Presented at the 17$^{th}$ Annual CO$_2$ Flooding Conference
December 8-9, 2011
Midland, Texas
CO$_2$ Supply & Oil Fields

17th Annual CO$_2$ Flooding Conference
– Dec-8-9, 2011 - Midland, Texas
323 Mile “Green” Pipeline

17th Annual CO₂ Flooding Conference
– Dec-8-9, 2011 - Midland, Texas
West Hastings Unit

Fault Block A currently shut-in and being re-pressurized with water & CO₂

INITIAL PATTERNS - CRESTAL AREA

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West Hastings Unit

- Discovered by Stanolind Oil (Amoco) in 1934
- Frio sandstone reservoir at 6000 feet
- 30-33% porosity, 500-4000 md permeability
- 582 million barrels oil produced
- 2.7 billion barrels water production
- 10 acre development during primary
- 70% displacement efficiency with water
- 99.2% watercut (900 BOPD, 115,000 BWPD)
CO₂ Injection Initiated in Crestal Area

• Highest remaining oil saturation
• Largest concentration of remaining wellbores (all wells had to be addressed)
• Small original gas cap has been saturated above residual oil saturation and is not a concern for encountering low oil saturation
• Updip bounding faults allow for improved re-pressurization (no flow boundary)
West Hastings Unit Production History

Cumulative Oil (MBO)

- 350,000 BOPD Peak Water Rate
- 75,000 BOPD Peak Oil Rate
- 450 Wells

450 Wells

BOPD, BWPD, MCFPD, Well Count

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Multiple Sands to Consider

- 37 oil productive sands
- 15 fault blocks
- Approximately 1 billion barrels original oil-in-place
- Top 6 sands (Upper Frio A sands) contain 65% OOIP
- In Fault Block A, 34 Upper Frio and 4 Lower Frio patterns used. This includes F sand future development.
- 80 Acre 5-spot patterns utilized in Upper Frio A1-A5 sands
- Upper Frio sands are split between two different patterns (A1,A2,A3 and A4,A4L,A5) to improve areal and vertical sweep
- Limited perforations are used on injectors so that CO₂ will sweep all sands uniformly (each perforation capable of ~1 MMCF/D CO₂ injection, therefore 15-20 perforations are utilized in each well)
Original Oil-Water Contact — same for all sands (-6085 ft)
• Continuous (100%) CO₂ injection in main oil column.

• Injectors placed at original oil-water contact will initially be water only and then WAG.

• Injectors are staggered between A1,A2,A3 (red) pattern and A4,A4L,A5 (purple) pattern.
Design Basis to Improve Vertical Sweep

- Upper Frio patterns alternate between sands as we move downdip
- Each injector injects 15 MMCF/D CO₂ and sweeps 80 acres
- 4 dedicated producers for each pattern

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Oil and CO₂ Production Forecasting

% CO₂ Injected which is produced back

% OOIP Oil Recovered

CO₂ Produced / CO₂ Injected

% OOIP Oil Recovery

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Hastings 550 MMCF/D CO$_2$ Facilities Site

32 well Test Site

Oil & Water Handling + Line Heaters

Separation and Recycle Compression

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Planned Start-up January, 2012
Line Heaters at Test Site
Year-end 2011 (~175 MMCF/D CO₂ Injection)

A1, A2, A3 Sands
- Original Oil-Water Contact A-1 Sand
- 4 patterns
- 4 CO₂ Injectors
- 6 Water Injectors
- 8 Producers

A4, A4L, A5 Sands
- Original Oil-Water Contact A-4 Sand
- 4 patterns
- 4 CO₂ Injectors
- 6 Water Injectors
- 8 Producers

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Reservoir Re-pressurization

Reservoir pressure increase matched by reservoir model

175 MMCF/D CO₂ + 75,000 BWPD (160,000 RB/D) injection rate by Jan-2012 to maximize pressure

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Key Learnings – Reservoir Re-pressurization

• Rock compressibility can be on the order of 30E-6 psi⁻¹ (much higher than Hall plot)
• High permeability allows for pressure to leak-off faster (increased injection rate and volume required)
• By raising reservoir pressure above aquifer pressure, downdip water injection is required to minimize losses of CO₂ into the aquifer
• Large make-up water supplies are necessary
• Portions of the field must be shut-in to allow for re-pressurization (impacts production)
Year-end 2012 (~270 MMCF/D CO₂ Injection)

A1, A2, A3 Sands

- 9 patterns
- 9 CO₂ Injectors
- 6 Water Injectors
- 12 Producers

A4, A4L, A5 Sands

- 9 patterns
- 9 CO₂ Injectors
- 7 Water Injectors
- 12 Producers
Year-end 2013 (~360 MMCF/D CO₂ Injection)

A1,A2,A3 Sands
- 15 patterns
- 15 CO₂ Injectors
- 9 Water Injectors
- 21 Producers

A4,A4L,A5 Sands
- 15 patterns
- 9 CO₂ Injectors
- 7 Water Injectors
- 19 Producers
Year-end 2014 (~480 MMCF/D CO₂ Injection)

A1, A2, A3 Sands
- 19 patterns
- 15 CO₂ Injectors
- 9 Water Injectors
- 25 Producers

A4, A4L, A5 Sands
- 15 patterns
- 9 CO₂ Injectors
- 7 Water Injectors
- 19 Producers

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Injection Profiles on CO₂ & Water Injectors

WHU-4304

Excellent Profile

19 MMCF/D CO₂ Injection

Limited perforations (18 shots)

WHU-3106

Good Profile

1623 BWPD Wtr Injection

Limited perforations (15 shots)

WHU-2101

Excellent Profile

5543 BWPD Wtr Injection

Limited perforations (20 shots)

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Perforation Shot Density for CO₂

DEPTH – 5500’
TBG – 2-7/8” CLS
FLUID – CO2
A1/A2/A3 - LAYERS

10 holes (10%) in 100 feet
20 holes (20%) in 100 feet
15 MMCFPD

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Reduced Shot Density Limits Water Injection

WATER INJECTION
10 holes (10%) in 100 feet
20 holes (20%) in 100 feet

5000 BWPD
Injection Profiles – Limited Entry Perforations

- Excellent: WHU-2101, WHU-3106 (15%)
- Good: WHU-4812, WHU-6116, WHU-6117, WHU-6206, WHU-4701, WHU-4304, WHU-2702, WHU-4805 (62%)
- Poor: WHU-1708, WHU-3401, WHU-6011 (23%)
Injection Profiles – Limited Entry Perforations

WHU 3106

**Excellent Profile**

**Sands:** A4, A4L, A5  
**Gross Interval:** 5697-5774  
**Avg. Rate @ 1300 psi ≈ 22.7 MMCFD**

Injecting 26.5 MMCFD @ 1600 psi  
21 perforations

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Injection Profiles – Limited Entry Perforations

WHU 4805

**Good Profile**

**Sands:** A4, A5  
**Gross Interval:** 5984-6074  
**Avg. Rate @ 2050 psi ≈ 4500 BWPD**

Injecting 2200 BWPD @ 1600 psi  
20 perforations

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Injection Profiles – Limited Entry Perforations

WHU 3401

Poor Profile

Sands: A4, A5
Gross Interval: 5882-5978
Avg. Rate @ 2050 psi ≈ 6500 BWPD

Injecting 6800 BWPD @ 1850 psi
18 perforations
Challenges Faced By Activating Old Oil Fields

• Well files (and history) may be difficult to obtain
• P&A records filed with RRC are critical
• Additional pre-cautionary measures (casing inspection log, bond log, pressure test, etc.) are taken when P&A’d wells are re-entered and used as injectors or producers. (30 wells in Fault Block A)
• Production records (by well) may be limited, however since CO₂ recovers the residual oil, past production performance is not critical
• Urban development may require that houses be moved, real estate purchased, etc.
## Work Scope Required to Develop Fault Block A

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<th>Well Type</th>
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| Unsuccessful                 | 3    | 1    |      |      | 4     |
Technical Challenges
Sealing & Non-Sealing Faults

Fault Block C
Start of CO2 Injection in 2014

Increased Uncertainty Due to Faulting

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Technical Challenges
Development of Multiple Stacked Sands

Water Injection at Oil-Water Contacts (Must Determine Which Sands Can Be Combined and Timing for Implementation)

Reservoir Size 147-616 acres

Crestal CO₂ Injection

700'

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Conclusions

- West Hastings Unit CO₂ flood is a significant, large scale EOR project along the Texas Gulf Coast
- Anthropogenic and natural CO₂ supplies will be used to recover incremental oil from Frio sands at 6000 feet
- Water injection is found to be a critical element in the design of the CO₂ flood due to the presence of a large aquifer and the requirement to raise reservoir pressure
- Technical challenges (multiple sands, faulting, depleted reservoir pressure) have been addressed using innovative approaches (dedicated patterns for groups of sands, limited perforations, downdip water injection, etc.)
- Success rate of re-entering plugged and abandoned wells has been high. Well histories and diagrams are critical.
Questions ?