Developing Reserve Estimates for CO2 EOR Residual Oil Zone Projects

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Presented to SPEE
October 5th, 2011
Houston, Texas
What is a Residual Oil Zone

“Previously highly oil saturated zone from which the oil is displaced by water through tectonic tilting and/or hydro-dynamic flooding.”

Typical ROZ Traits

• Lower “Swept” Part of productive interval
• Same Rock
• Good stain, oil shows on cores
• “Wet” tests on initial completion (1-5% Oil Cut)
• Oil saturations similar to end of life waterflood 25-45%
Model for ROZ Formation

Original Oil Accumulation Under Static Aquifer Conditions

Change in Hydrodynamic Conditions, Sweep of the Lower Oil Column, Oil/Water Contact Tilt, and Development of the Residual Oil Zone
Why are ROZs Important?

ARI estimates 30 BBOIP are sitting in ROZ zones in the Permian Basin alone.

- Large opportunity for EOR
- Big impact on West Texas Oil Industry
- Huge Potential Energy Resource for America

Active ROZ Projects
- Seminole - Hess
- Wasson - Oxy
- Hanford - Fasken
- Vacuum – Chevron
- Means – Exxon
- East Seminole – Tabula Rasa
- Goldsmith – Legado

Fields with Active ROZ EOR Projects
Determining The Reserve Base

**Tools**

Analogy
- Project Placement
- Known Formation
- Historical Results

**Reservoir Characterization**
- Log Density
- Extensive Coring Program
- ROZ Saturations
- Petrophysics
- Mapping (Continuity)

**Pilot – Response**

**Answers**

Size of Resource
- OOIP

Test Mechanism of Recovery
- CO2 Flood Response
- Oil Cut

Classify Reserves
- PDP, PUD, PRB, POSS
Analogy: Project Placement & Reservoir Type

Fraction of Worldwide CO₂ EOR Production

- Permian Basin – San Andres
- Permian Basin – Non SA
- Other Basins

United States CO₂ Pipeline Infrastructure
Project Placement – GLSAU Location

- Permian Basin Location
- San Andres Reservoir
Analogous Fields and Log Section

- **Formation**: San Andres, San Andres, San Andres
- **Discovery** (Yr): 1935, 1936, 1936
- **Depth** (Ft): 4,200, 4,900, 5,200
- **Pinit** (psi): 1,712, 1,850, 2,020
- **Temperature** (Deg): 95, 107, 108
- **API Gravity** (Deg): 34, 33, 35
- **MMP** (psi): 1,150, 1,280, 1,300
- **Porosity** (Frac): 0.11, 0.11, 0.12
ROZ Field Saturation Progression

So > 100%

Waterflood Operations

ROZ Formed (Hydrodynamics)

Pre ROZ
Discovery
Today

Main Pay

ROZ

Water

Depth

Depth
Technical Data Density

105 wells through ROZ
47 Producers
58 Injectors

Logging Program
- 237 Total OH Logs used
- All redrills have Triple Combo
- Most Deepenings GR/Neutron

Wellwork
- Deepened 86 Wells Through ROZ
- Redrilled 19 Wells Through ROZ
Technical Evaluation – Legado Coring Program

- Spaced to Investigate Distribution Across Unit
- Gas Cap, Main Pay, ROZ
- Obtain Oil/Fluid Sample
- Fluorescence Photos and Saturation Measurements
GLSAU Reservoir Model

- **Greyburg Formation**
- **San Andres Low Porosity Cap**
- **Gas Cap**
- **Main Pay**
- **ROZ**
- **Transition Zone**
- **Free Water Zone**
- **San Andres (limestone)**
- **Holt Formation**

Legend:
- **Top San Andres**
- **Top San Andres Porosity**
- **Gas Oil Contact (~975')**
- **Oil Water Contact (~1080')**
- **Base ROZ (~1230')**
- **Top Limy San Andres**
- **Boso (~1300')**
- **Top Holt**

Special Notes:
- *San Cap liquid filled; partially re-saturated with oil during waterflood
- *Discovered in 1934; waterflood began in 1963
- *Residual Oil Zone CO2 pilot injected in 2009; Phase 2 main pay/ROZ co-development to begin in 2010
- *Limy San Andres not considered "flowable" in ROZ due to lower permeability
GLSAU Cored Intervals

- **Top San Andres**: Porosity
- **Gas Oil Contact (-975')**
- **San Andres Low Porosity Cap**
- **Gas Cap**
- **Main Pay**: 99, 190
- **ROZ**: 126R, 222W
- **Greyburg Formation**
- **Oil Water Contact (-1080')**
- **Base ROZ (-1230')**
- **Top Limy San Andres**
- **Transition Zone**
- **Free Water Zone**
- **San Andres (limestone)**
- **Top Holt**
- **Holt Formation**

*San Cap liquid filled partially re-saturated with oil during waterflood
*Discovered in 1934; water flood began in 1963
*Residual Oil Zone completed in 2009; Phase 2 main pay/ROZ completion to begin in 2010
*Limy San Andres considered "floody" in ROZ due to lower permeability
Technical Evaluation – Core Fluorescence

- **Gas Cap (Resaturated)**
- **Main Pay Oil Zone (MPZ)**
- **Residual Oil Zone (ROZ)**
- **Below ROZ**
Technical Evaluation – Core Saturation

Core Analysis Shows Similar Saturation Values Between the Main Pay and the ROZ
Reservoir Continuity Good Even at 3000’ Spacing (320 Acres)
Determining The Reserve Base: OOIP

Main Pay OOIP

*Detailed OOIP Knowledge from 1930s*
  - So = 80%, Swc = 20%

*At Sorw*
  - Over 400 wells drilled
  - Produced over 85 years total
  - Waterflooded 45 years
  - Oil cut 0.5-2%

*Volumetrics and Matl Bal*
  - MP OOIP ~ 250 MMBO

ROZ OOIP

*Extensive work to determine ROZ fluid contacts*
*Floodable ROZ Excludes Much of TZ*

*OOIP Convention*
  - At 1934 Field Discovery So = 38% (Current)
  - Before ROZ was created it was “Main Pay”

*Taking back to pre ROZ formation*
  - So = 80% (Same as Main pay, same Swc = 20)

*ROZ OOIP ~ 300 MMBO*

OOIP ~ 550 MMBO
Determining The Reserve Base: Recovery

**CO2 Reserves – Bulk of Reserve Value**

- ✔ Characterization of Reservoir
- ✔ Continuity of Interval
- ✔ So in the MP and ROZ
- ✔ Good analogs at Wasson and Seminole
  - • Prove Mechanism of Recovery (Pilot)
Recovery Mechanism: Pilot Design

- **Well Utility ($3.8 MM)**
  - 15 Deepen and Equip
  - 7 Re-entry and Deepen
  - 3 Drill Wells

- **Facilities ($4.5 MM)**
  - 3.5 Mile 8” CO₂ Service Pipeline
  - 700 HP Recycle Compressor (~3.2 MMCFD)
  - Separation and Test Satellite

105 wells through ROZ
47 Producers
58 Injectors
Pilot Operations – Performance

- 500 BOPD Production
- 10 Fold Increase in Oil Cut
- Oil Rate ~2 x Peak from Water Flood
- Fluid Rate ~2 x Peak from Water Flood
- Response Continuing to Increase

Full Pilot Area
Pilot Operations – #190 Producer Pattern

Surveillance Activities
- Material Balance & Performance
- Injection Tests and Profiles
- Production Logs
- Pressure Observation

Start CO₂ Injection
Total CO2 Flood Area (Pilot - Phase 1)

- Currently 950 BOPD (up from 40 BOPD prior to startup)
- Response in ~30% of wells
- Total fluid rate double the peak from water flood
Residual Oil Zone Fields Reserves Estimation – Summary

- **OOIP confidence**
  - Robust Geo Model
  - Extensive Core Density and Analysis
  - Good Log Coverage
  - Must calculate OOIP properly from pre ROZ formation oil sats

- **Recovery Projection Confidence**
  - Analogy
  - Large Number of San Andres CO2 flood Recovery Curves

- **Response to CO2 Injection**
  - Miscible
  - Strong Oil Response
  - GOR under Control
  - Dramatically Increasing Oil Cut
Questions?