SECARB Phase III – Early Test, Cranfield, MS

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EARLY TEST
CRANFIELD, MS

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Overview

- Background Information
- Phase III Design
- Summary
Upper Cretaceous Tuscaloosa-Woodbine Trend – Cranfield in Mississippi Salt Basin

Source of large volumes of CO₂ via pipeline

Source: Dutton and others 1993
Gulf Coast Stacked Storage Field Test

Phase 3: $36M, 2 observation wells, multiple injectors, 1 Mt/yr
Cranfield Geometric Overview

Denbury Cranfield unit

Phase III Early study area

Phase II Study area

10,000 ft

Tuscaloosa Formation

Brine

Residual Oil

Regional seal

Residual Gas

Monitors

Injector

Producer Monitor

2x Normal

"Heterogeneity"
Phase III Design

- Two Observation Wells
  - CASSM
  - X-well tomography
  - ERT
  - Joint inversion (saturation, sweep efficiency)
  - Fluid sampling (U-tube)
  - Thermal response
  - Whole cores / core analyses

- Geomechanical Test
  - Paired Injection / Production
  - Downhole Microseismic & Tilt
  - In-zone / out-of-zone activity: pressure and fluid migration

- Far-Field Measurements
  - RST
  - BHP
  - BHT
Characterization

Cranfield Anticline

~ 1 mile

W-E

29-12

OBS

S-N

Cranfield Anticline

~ 1 mile
Horizontal time slice with amplitude (2272 ms)

Intersection of OWC with top of injection interval
Deep water table
<table>
<thead>
<tr>
<th>Objective</th>
<th>Anticipated Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Sweep efficiency brine system</td>
<td>• Well-quantified measure of how CO₂ occupies pore volumes</td>
</tr>
<tr>
<td>(2) Novel effort to account for volume and energy input</td>
<td>• Add rigor to pressure measurement for storage prediction</td>
</tr>
<tr>
<td>(3) Leakage though 1945 wells? Assess effectiveness of surface monitoring in a deep water table</td>
<td>• Challenge these technologies - Reliable leakage detection?</td>
</tr>
</tbody>
</table>
Planned Phase III Observation
“Smart Well” Construction

- Cross well array in two wells
- High injection volumes
- Far-field monitoring – tilt, microseismic, P&T, chemistry, surface seismic
- BHP+ T
- Seismic sources/receivers
- U-tube sampler 1/4 “SS
- 2 7/8” tubing
- ERT – 20 electrodes
- Distributed temperature
- Fiberglass non-conductive casing
- Tuscaloosa DE
- BEG, LBNL, LLNL, USGS, ORNL, Pinnacle, QEA, Sandia Technologies
Planned Subsurface Measurements

CFU28-F1

Obs 1

Obs 2

180 m

70 m

30 m
Phase III Summary

Currently Mid-May / Observation Well #1
- Down-Dip Brine Injection
- Intensive Monitoring Campaign
  - Cross well
  - Geomechanical
  - Far Field
Site selection

- 2006: First cored well, brine samples
- 2007: NEPA CX, Received seismic data

Characterization

- 2008: Instrumentation, Soil gas baseline, Start workover

Site development

- 2009: Phase III Wells May, End phase II

Injection and monitoring

- Phase II EOR
- Phase III Brine

Increasing number of injectors and rate per well

Start Phase III injection
Cranfield Mississippi
INJECTION ZONE

**CFU 29-12: New Injector**

**Permeability to air (md)**

- **Average H:** 283 md
- **Average V:** 47 md

**Porosity (%)**

- **Average H:** 20.5%
- **Average V:** 20.7%

Data provided by DRJ
Core Box 1

- **Top**
- **Chert Pebble Conglomerate**
- **Braided Stream**
- **Sharp Basal Contact**
- **Marine Mudstone**
- **Lower Shoreface**
- **Shell fragments (oyster, gastropod) and Trace fossils**
- **Bottom**
Gakona – Copper River Junction, Alaska
Modern Analog – Braided Stream

http://www.uwsp.edu/geo/faculty/ritter/glossary/a_d/braided_streams.html

USGS Digital Data Series DDS-21
CFU 29-12: New Injector

INJECTION ZONE

Permeability to air (md)

Porosity (%)

Average
H: 283 md
V: 47 md

Average
H: 20.5 %
V: 20.7 %

Data provided by DRI
Fluvial Depositional Environment

Stratal slicing seismic interpretation

Channel erosion
Point bar

Channel erosion
Point bar

Channel erosion

Channel erosion

Galloway 1983

Meander fluvial model

Hongliu Zeng
Role of Dissolution in Plume and Pressure Evolution

No dissolution: volume displaced = Volume injected

Volume displaced = Volume injected – volume dissolved + fluid expansion

In miscible CO₂ EOR, a large amount of CO₂ is dissolved in oil – CO₂ migration is retarded compared to brine, where dissolution is much less.
Test adequacy of Mississippi well completions for CO$_2$ sequestration

Monitoring Zone

- 13-Chrome Isolation packer w/ feed through
- 13-Chrome Selective seat nipple
- Pressure transducer Side Pocket Mandrel w/dummy gas valve
- 1/4" tubing installed between packers to provide a conduit between isolation packers

CO$_2$ Injection Zone

- 13-Chrome Production packer w/ feed thrus
- Pressure transducer Side Pocket Mandrel w/dummy gas valve
Preparation of the Observation Wells (and outreach)
Real-time monitoring via Satellite Uplink

Well head tubing and barometric pressure at surface
### Phase III: Theoretical Approaches Through Commercialization

<table>
<thead>
<tr>
<th>Theory and lab</th>
<th>Hypotheses tested</th>
<th>Field experiments</th>
<th>Subsurface perturbation predicted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity of tools; saturated-vadose modeling of flux and tracers</td>
<td>CO₂ retained in-zone-document no leakage to air-no damage to water</td>
<td>Surface monitoring: instrument verification Groundwater program CO₂ variation over time Above-zone acoustic monitoring (CASSM) &amp; pressure monitoring</td>
<td>Pressure (flow plus deformation) correctly predicted by model</td>
</tr>
<tr>
<td>Lab-based core response to EM and acoustic under various saturations, tracer behavior</td>
<td>CO₂ saturation correctly predicted by flow modeling</td>
<td>CO₂ saturation measured through time – acoustic impedance + conductivity Tomography and change through time 3- D time lapse surface/ VSP seismic Dissolution and saturation measured via tracer breakthrough and chromatography</td>
<td>Tilt, microcosmic, pressure mapping Acoustic response to pressure change over time</td>
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<td>Advanced simulation of reservoir pressure field</td>
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</table>
Modeled December Distribution of CO$_2$

Global Mole Fraction(CO$_2$) 7050-03-19

Observation well

Middle lower Tuscaloosa (model layer 11)
GEM compositional simulator

Jong-wan Choi and JP Nicot, BEG
Regional Stratigraphy of the Tuscaloosa Formation

- Secondary seals
- Above-zone Monitoring interval
- Injection interval

- Tuscaloosa Formation
- Austin Chalk
- Eagle Ford Shale
- Upper Tuscaloosa
- Middle Tuscaloosa
- Lower Tuscaloosa
- Transgressive Unconformity
- Washita-Fredericksburgh Groups
- Cretaceous Shelf Margin
Southeast Regional Carbon Sequestration partnership
“SECARB” test

Cranfield Unit operated by Denbury Resources Inc

Mississippi River
Natchez
Mississippi

3,000 m depth Tuscaloosa Fm
Gas cap, oil ring, downdip water leg
Shut in since 1965
Strong water drive
Returned to near initial pressure