Plant Barry - Citronelle Field Project
Southeast Regional Carbon Sequestration Partnership (SECARB)

Prepared for:
Carbon Storage R&D Project Review Meeting

Pittsburgh, PA

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13 August 2014
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Topics of Discussion

1. Citronelle Field Project Overview
2. Surface and Shallow MVA
3. Deep MVA
4. Experimental MVA
5. Questions, Answers, Discussion
1. Support the United States’ largest prototype CO$_2$ capture and transportation demonstration with injection, monitoring and storage activities;
2. Test the CO$_2$ flow, trapping and storage mechanisms of the Paluxy;
3. Demonstrate how a saline reservoir’s architecture can be used to maximize CO$_2$ storage and minimize the areal extent of the CO$_2$ plume;
4. Test the adaptation of commercially available oil field tools and techniques for monitoring CO$_2$ storage
5. Test experimental CO$_2$ monitoring activities, where such technologies hold promise for future commercialization;
6. Begin to understand the coordination required to successfully integrate all four components (capture, transport, injection and monitoring) of the project; and
7. Document the permitting process for all aspects of a CCS project.
Citronelle Storage Overview

Project Schedule and Milestones

The CO₂ capture unit at Alabama Power’s (Southern Co.) Plant Barry became operational in 3Q 2011.

A newly built 12 mile CO₂ pipeline from Plant Barry to the Citronelle Dome completed in 4Q 2011.

A characterization well was drilled in 1Q 2011 to confirm geology.

Injection wells were drilled in 4Q 2011.

100k – 150k metric tons of CO₂ will be injected into a saline formation beginning 3Q 2012.

3 years of post-injection monitoring.
Barry Carbon Capture Project Overview

- Flue gas outlet
- CO₂ Absorber
- Cooling Tower
- Regeneration Vessel
- CO₂ Compressor
- Flue gas inlet
- Solvent Storage
Geologic Overview

- Proven four-way closure at Citronelle Dome
- Injection site located within Citronelle oilfield where existing well logs are available
- Deep injection interval (9,400 ft)
- Numerous confining units
- Base of USDWs ~1,400 feet
- Existing wells cemented through primary confining unit
- No evidence of faulting or fracturing, based on oilfield experience, new geologic mapping and reinterpretation of existing 2D seismic lines.
Field Overview

- One Injector (D-9-7 #2)
- Two deep Observation wells (D-9-8 #2 & D-9-9 #2)
- Two in-zone & above zone Monitoring wells (D-4-13 & D-4-14)
- One PNC logging well (D-9-11)
- Four shallow groundwater monitoring wells
- Twelve soil flux monitoring stations
Surface and Shallow MVA

Goal #1: Operational monitoring
- Injection rate and wellhead pressure
- CO₂ stream composition

Goal #2: Identification of fast-flow pathways (nearby abandoned well)
- Perfluorocarbon tracers
- Soil CO₂ flux measurements
- Groundwater sampling
Injection Rate and CO$_2$ Composition Summary

- Average quality of the captured gas is 99.933% CO$_2$, 0.015% O$_2$ and 0.052% N$_2$.  

111,706 tonnes
Shallow MVA-CO$_2$ Flux and Tracer Sampling

Soil CO$_2$ Flux

Tracer Results

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<th>Testing</th>
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Soil CO$_2$ results appear to vary as a function of mean temperature and PFT have been non-detect
3 - Background Monitoring Events:
- January 2012 (N=1) through July 2012 (N=3)

7 - Injection Period Monitoring Events:
- November 2012 (N=4) through May 2014 (N=10)

Background anomalies of Manganese, Iron, and Chloride above UIC permit. To evaluate the potential exceedance of regulatory standard (e.g., UIC permit discharge limit), the EPA GW Unified Guidance recommends the collection of >4 data points before performing statistical comparisons (e.g. confidence limit determinations)
Deep MVA

- **Goal #1: Operational monitoring**
  - Well logging (PNC and spinner surveys)

- **Goal #2: In-zone CO₂ migration, leak detection and pressure monitoring**
  - Downhole pressure monitoring
  - Cross-well seismic surveys
  - Offset vertical seismic profile (VSP) surveys
  - Walkaway VSP

VSP source offset locations (stars), receiver locations (D9-7#2 and D9-8#2), and walk-away lines (blue and red lines)
## Deep MVA-Spinner Surveys

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A software program was used to measure the average velocity decreases (in percent of total flow) as the CO2 injection exits the well bore at the specified intervals.

**Table notes:**
- The values in the table represent measured flow percentages for different sand units and time periods.
- The measurements are taken from the chart which shows temperature, pressure, and CO2 injection velocity data.

**Diagram notes:**
- The diagram illustrates a caged fullbore flowmeter (6 arm CFBM) which is used in monitoring and measuring flow rates in the well bore.
Deep MVA - Pressure Response

![Graph showing pressure response with labels for D9-8#2, D4-14 in Zone, D4-13 above confinement, and CO2 injected.]

- D9-8#2
- D4-14 in Zone
- D4-13 above confinement
- CO2 Injected
Deep MVA – Pressure Response

Pressure Gauges off-line
Discrete MVA Activities
Seismic ops

Pre-Injection Baseline
Gauges off-line

Unreliable Gauges?
Permanent MBM vs Removable Memory Gauge

April MVA operations

June MVA operations
The system, as expected, is getting more compressible with continued injection. As a result, the response time (observed initiation of injection) at the offset observation wells continues to grow. This tells us something about the saturation between the wells, when calibrated to reservoir models.
Crosswell seismic may hold the best opportunity of visualizing the injected CO$_2$; however, time-lapse acquisition during injection operations are difficult.
Experimental MVA-Modular Borehole Monitoring (MBM) System

• Motivation: Deep monitoring wells are expensive to drill and complete and have limited space available for instrumentation
  - Monitor CO₂ plume location
  - Reservoir pressure and temperature
  - Fluid sampling
  - Leak detection
  - CO₂ saturations
• An experimental, semi-permanent geophone deployment was desired to act as a “fence-post” during time-lapse VSP acquisition

VSP source offset locations (stars), receiver locations (D9-7#2 and D9-8#2), and walk-away lines (blue and red lines)
MBM Design and Monitoring Capabilities

- 18 Level, tubing deployed, clamping geophone array (6,000-6,850 ft)
- Two in-zone quartz pressure/temperature gauges for reservoir diagnostics
- U-tube for high frequency, in-zone fluid sampling (tube-in-tube design)
- Fiber optic cable for distributed temperature and acoustic measurements
  - Heat-pulse monitoring for CO₂ leak detection
  - Acoustic array for CO₂
- 2 7/8” production tubing open for logging
Shorter MBM array has an lateral image area that is smaller, but it should be able to see changes in the gather response and images over time due to CO₂ injection.
Difference between the monitor and baseline surveys reveal subtle changes in the amplitudes at depth; however the changes may not be significant because of noise.
DAS allows seismic monitoring with fiber optics

- Sensitivity less than standard geophone, but 3000 sensors versus 18
- Spatial sampling and ease of deployment much greater
Citronelle DAS-Geophone Comparison from Walkaway

**DAS Data**

SP 2021; Combined Deconvolved stack of 152 sweeps; RMS normalized

**Geophone Data**

Processed by D. Miller, Silixa

**DAS vs. Geophone**

SP 2003; iDAS setting D30; channel at 6450 ft

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**Acquisition of stacked source sweeps improved DAS data signal to noise ratio, producing traces that match those from more sensitive geophones**
Improved DAS VSP Processing

- Downgoing Deconvolution
- Travel Time Picks
- Velocity Model
- Comparison to Well Logs (Sonic, Gamma)

- Good tie to logs
- Reflections clear
- Strong ‘ringing’ in some zones
Heat Pulse Testing and Fiber Optic Distributed Temperature Sensing (DTS)

Ambient Temperature (Blue)
Heated Temperature (Red)

Temperature Profile along Entire Cable
(0 – 9,800 ft +/-)

Temperature Profile Across Bottomhole Assembly (9,300-9,900 ft)

Packer
Flat Pack
Colder Kill Fluid
Rat Hole
Deep Groundwater Sampling

- In- and above-zone monitoring may be used as a compliance tool to detect CO₂ leakage
- Samples undergo geo-chemical transformation when collected from deep wells, e.g.,
  - Exsolution of dissolved gases
  - Changes in dissolved CO₂ concentrations that control pH and alkalinity
  - Exposure to the atmosphere causes changes in redox conditions

USGS photo: Fluid Sampling during Pumping at D9-8#2
Testing & Monitoring: In-zone Comparison
Deep Groundwater Sampling Methodologies

A. Gas-lift
- Samples had the highest pH indicating possible loss of dissolved gas
- Sampling method should be limited to major and unreactive solutes

B. Pumping
- Relatively high Fe concentrations compared to other methods, showing evidence of contamination or geochemical changes in samples
- Sampling method should be limited to major and unreactive solutes

C. Kuster sampler:
- Field measurements of initial pH had the lowest value
- Geochemical data consistent in repeated sampling

D. U-tube:
- In general, sample results are comparable to the Kuster method

USGS collecting in-zone groundwater samples using:
A. gas-lift; B. electric submersible pump; C. Kuster sampler; and D. u-tube sampler
Accomplishments

- Injected over 110,000 metric tons to date from the world’s largest CO₂ capture system using advanced amines on a coal-fired unit
- Fully integrated carbon capture, transportation and storage project
- Demonstrating monitoring technologies at a commercial-scale (i.e., oil field setting) within the regionally extensive Paluxy saline formation
- Unique opportunity to evaluate performance of different seismic survey configurations and sensors
- Research effort is focused on developing, testing and validating borehole-based monitoring technologies and methods
Thank You from the SECARB Team

- Questions
- Comments
- Discussion