Southeast Regional Carbon Sequestration Partnership (SECARB)  
Phase III Anthropogenic Test and Plant Barry Carbon Dioxide Capture and Storage Demonstration

Presented to:  
CSLF Projects Interaction & Review Team  
Washington, D.C., USA  
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Presented by:  
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Senior Technical Advisor  
Southern States Energy Board
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- Anthropogenic Test CO\textsubscript{2} Capture Unit funded separately by Southern Company and partners.
Presentation Outline

- Regional Carbon Sequestration Partnerships
  - Seven Regional Entities
  - SECARB Phase III Projects

- SECARB Anthropogenic Test
  - Plant Barry Capture Unit
  - Dedicated CO2 Pipeline
  - Injection & Monitoring Systems

- Project Integration & Risk Management
  - Key Integration Questions
  - Risk Management & Assessment
  - Public Outreach and Education
RCSP Phase III: Development Phase

Large-Scale Geologic Tests

- Large-volume tests
- Four Partnerships currently injecting CO₂
- Remaining injections scheduled 2013-2015

<table>
<thead>
<tr>
<th>Partnership</th>
<th>Geologic Province</th>
<th>Target Injection Volume (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Big Sky Nugget Sandstone</td>
<td>1,000,000</td>
</tr>
<tr>
<td>2</td>
<td>MGSC Illinois Basin-Mt. Simon Sandstone</td>
<td>1,000,000</td>
</tr>
<tr>
<td>3</td>
<td>MRCSP Michigan Basin-Niagaran Reef</td>
<td>1,000,000</td>
</tr>
<tr>
<td>4</td>
<td>PCOR Powder River Basin-Bell Creek Field</td>
<td>1,500,000</td>
</tr>
<tr>
<td>5</td>
<td>Horn River Basin-Carbonates</td>
<td>2,000,000</td>
</tr>
<tr>
<td>6</td>
<td>SECARB Gulf Coast – Cranfield Field- Tuscaloosa Formation</td>
<td>3,400,000</td>
</tr>
<tr>
<td>7</td>
<td>Gulf Coast – Paluxy Formation</td>
<td>250,000</td>
</tr>
<tr>
<td>8</td>
<td>SWP Regional CCUS Opportunity</td>
<td>1,000,000</td>
</tr>
<tr>
<td>9</td>
<td>WESTCARB Regional Characterization</td>
<td></td>
</tr>
</tbody>
</table>

Note: Some locations presented on map may differ from final injection location
**SECARB Phase III**

**Early Test**

- Denbury Resources’ Cranfield Field
  - Near Natchez, Mississippi
  - CO₂ Source: Denbury
  - CO₂ Transportation: Denbury
  - Saline MVA: GCCC

**Anthropogenic Test**

- Capture: Alabama Power’s Plant Barry, Bucks, Alabama
- Transportation: Denbury
- Geo Storage: Denbury’s Citronelle Field, Citronelle, Alabama
SECARB’s Anthropogenic Test
Citronelle, Alabama
CSLF Gaps Analysis: SECARB Anthropogenic Test

### GENERAL

<table>
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<th>Project Scale</th>
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<td>Demonstration</td>
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### CAPTURE TECHNOLOGIES

<table>
<thead>
<tr>
<th>Capture Type</th>
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<tbody>
<tr>
<td>Post-combustion capture</td>
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<table>
<thead>
<tr>
<th>Technology</th>
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<tbody>
<tr>
<td>Advance the capture technology</td>
<td></td>
</tr>
<tr>
<td>Advance purification and compression technology</td>
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### TRANSPORT

<table>
<thead>
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<tr>
<td>Pipeline Transport</td>
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### STORAGE AND MONITORING

<table>
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<th>Storage Complex Type</th>
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<tbody>
<tr>
<td>Saline formations</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Storage complex characterization</th>
<th>✓</th>
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<tbody>
<tr>
<td>CO₂-water-rock (or coal) interactions</td>
<td></td>
</tr>
<tr>
<td>Impact of the quality of CO₂ on storage</td>
<td></td>
</tr>
<tr>
<td>Improved modelling of complex</td>
<td></td>
</tr>
<tr>
<td>Effects of CO₂ rock/water interactions and induced changes in temperature, pressure and stress on permeability, injectivity, migration, trapping and capacity</td>
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</table>

<table>
<thead>
<tr>
<th>Monitoring the storage complex including risk assessment</th>
<th>✓</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development of new or improved CO₂ monitoring technologies</td>
<td></td>
</tr>
<tr>
<td>Improve baseline monitoring and distinguish between natural and anthropogenic CO₂</td>
<td></td>
</tr>
<tr>
<td>Development of risk minimization/mitigation methods and strategies, including leakage</td>
<td></td>
</tr>
<tr>
<td>Improve well integrity, well abandonment practices, and/or remediation of existing wells</td>
<td></td>
</tr>
</tbody>
</table>
SECARB Phase III Anthropogenic Test

- Carbon capture from Plant Barry equivalent to 25MW.
- 12 mile CO$_2$ pipeline constructed by Denbury Resources.
- CO$_2$ injection into ~9,400 ft. deep saline formation (Paluxy)
- 100,000 metric tons injected (29 October 2013)
- Monitoring CO$_2$ during injection and 3 years post-injection.
CO₂ Capture Demo

- Southern Company’s CCS Commercialization Program Goals
  - Deploy integrated CCS demo to understand the integration of capture plant and injection field
  - Advance capture technology performance to preserve the new and retrofit PC coal option
  - “Learn by doing” to create competitive advantage and maintain leadership position in technology development

- The Plant Barry (Alabama Power) 25MW Demo
  - Southern Company Services & Mitsubishi Heavy Industries collaboration with partners
  - KM-CDR capture technology (500 TPD)
Plant Barry Capture Unit: 25MW, 500 TPD
Plant Performance

- Flue gas CO₂ concentration is dependent on boiler load
- KM-CDR process can be adjusted to achieve the desired CO₂ capture rate and production rate with varying boiler conditions

<table>
<thead>
<tr>
<th>Flue Gas Condition</th>
<th>Base Case</th>
<th>High Energy Efficiency Case</th>
<th>High Loading Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flue Gas Flow Rate [Nm³/hr]</td>
<td>109,000</td>
<td>112,000</td>
<td>116,000</td>
</tr>
<tr>
<td>CO₂ Concentration at the Quencher Inlet [vol.% (w)]</td>
<td>10.8</td>
<td>10.5</td>
<td>10.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operation Results</th>
<th>Base Case</th>
<th>High Energy Efficiency Case</th>
<th>High Loading Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ Capture Rate [TPD]</td>
<td>505</td>
<td>509</td>
<td>543</td>
</tr>
<tr>
<td>CO₂ Removed Efficiency [%]</td>
<td>91</td>
<td>91</td>
<td>91</td>
</tr>
<tr>
<td>Steam Consumption [tonne-steam/tonne-CO₂]</td>
<td>0.98</td>
<td>0.95</td>
<td>1.02</td>
</tr>
</tbody>
</table>
Actual load following data in 2 modes

**CO₂ Production Scheme**
- Demand dictated by additional CO₂ product requirement
- Ramp of ~5%/minute
- Very stable removal rate
  - Capture Rate
  - CO₂ Flow
  - Flue Gas flow

**CO₂ compliance scheme**
- Demand dictated by additional boiler load (leads to more flue gas flow)
- Ramp of ~5%/minute
- Small dip in removal (5%), but recovery to 90% within 10 minutes
NEPA/Permitting at SECARB’s Integrated Project

- UIC Class V permit application
  - Submitted to Alabama Dept. of Env. Quality December 2010
  - Updated March 2011
  - Revise for EPA August 2011
- Environmental Assessment (EA)
  - Mitigation
    - 3 mi of wetlands (wetland mitigation planned)
    - 23 gopher tortoise burrows
  - Consultation
    - Fish & Wildlife Service for the gopher tortoise
    - Corp of Engineers for wetlands
    - SHPO (State cultural/archeological assets)
    - Storm-water construction (BMPs)

NEPA Finding of No Significant Impact (FONSI)
Directional drilling required to avoid disturbing Gopher Tortoise habitat

Images Courtesy Southern Company
**CO₂ Pipeline and Measurement Design**


- 4-inch (10 cm) pipe diameter carbon steel pipe

- Normal operating pressure: 1,500 psig (10.3 MPa) maximum

- Buried average of 5 ft (1.5 m) with surface re-vegetation and erosion control
CO₂ Pipeline Overview

- Typical Pipeline/Injection Operations
  - 1,448 psi and 90°F at the transfer station
  - Rate: 9.64MMcfd (~480 tonnes/day) at 1,314 psi (wellhead) 63°F.

- Typical CO₂ Purity

<table>
<thead>
<tr>
<th>Component</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>N₂</td>
<td>0.011</td>
</tr>
<tr>
<td>O₂</td>
<td>0.010</td>
</tr>
<tr>
<td>CO₂</td>
<td>99.979</td>
</tr>
</tbody>
</table>
Detailed Characterization of the Injection Site

### Selecting a Good Storage Formation

- Proven four-way closure at Citronelle Dome
- Injection site located within Citronelle oilfield where existing well logs are available
- Deep injection interval (Paluxy Form. at 9,400 feet)
- Numerous confining units
- Base of USDWs ~1,400 feet
- Existing wells cemented through primary confining unit
- No evidence of faulting or fracturing (2D)

<table>
<thead>
<tr>
<th>System</th>
<th>Stratigraphic Unit</th>
<th>Major Sub Units</th>
<th>Potential Reservoirs and Confining Zones</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tertiary</td>
<td>Citronelle Formation</td>
<td>Freshwater Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Undifferentiated</td>
<td>Freshwater Aquifer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vicksburg Group</td>
<td>Base of USDW Local Confining Unit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jackson Group</td>
<td>Minor Saline Reservoir</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Claiborne Group</td>
<td>Saline Reservoir</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wilcox Group</td>
<td>Saline Reservoir</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Midway Group</td>
<td>Confining Unit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Selma Group</td>
<td>Confining Unit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eutaw Formation</td>
<td>Minor Saline Reservoir</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tuscaloosa Group</td>
<td>Minor Saline Reservoir</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Washita-Fredericksburg</td>
<td>Confining Unit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Paluxy Formation</td>
<td>Injection Zone</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mooringsport Formation</td>
<td>Confining Unit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ferry Lake Anhydrite</td>
<td>Confining Unit</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Donovan Sand</td>
<td>Oil Reservoir</td>
<td></td>
</tr>
</tbody>
</table>

- Chloride, sodium, and magnesium are high, which may indicate potential salinity issues.
- The formation is considered suitable for CO2 storage due to its permeability and capacity.
Extrapolated Continuity of Upper Paluxy Sandstones At Citronelle Southeast Unit Northwest - Southeast
SECARB Citronelle: MVA Sample Locations

- One (1) Injector (D-9-7 #2)
- Two (2) deep Observation wells (D-9-8 #2 & D-9-9 #2)
- Two (2) in-zone Monitoring wells (D-4-13 & D-4-14)
- One (1) PNC logging well (D-9-11)
- Twelve (12) soil flux monitoring stations
## Whole Core Analyses & Confining Unit Characterization

<table>
<thead>
<tr>
<th>Core Analysis</th>
<th>D 9-7 #2</th>
<th>D 9-8 #2</th>
<th>D 9-9 #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral Gamma Ray</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Routine Porosity, Permeability, Grain Density</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Vertical and Orthogonal Permeability</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Relative Permeability</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>X-ray Diffraction Mineralogy</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Fluid Sensitivity – Permeability vs. Throughput</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Thin-Section Petrography</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Mercury Injection Capillary Pressure</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Source Rock Analysis</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Shale Rock Properties</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Methane Adsorption Isotherm</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
Geology Summary for Simulation

- Proven four-way closure at Citronelle Dome with existing logs
- Injecting into Paluxy @ 9,400 feet
- >260 net feet of “clean” sand
- Average porosity of 19% (ranges from 14% to 24%)
- Average permeability of 300 md (ranges from 30md to 1,000 md)
- No evidence of faulting/fracturing (2D)
SECARB’s Anthropogenic Test
Project Integration & Risk Management
Business Integration

Key business integration questions:

- What business relationships must be established?
- How can CO$_2$ transportation and injection impact the capture unit?
- How can plant shutdown impact CO$_2$ transportation and injection?
- What types of communications and control systems are needed?
Monitoring & Compliance

- Key monitoring & compliance questions:
  - How are risk-based monitoring programs developed and implemented?
  - What safeguards and mitigating strategies can be employed to reduce risk?
  - How can risk management tools assist in project compliance?
## Project Risk Assessment Matrix: DNV KEMA Approach

<table>
<thead>
<tr>
<th>CONSEQUENCE</th>
<th>LIKELIHOOD</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>A: Remote</td>
</tr>
<tr>
<td>A: Remote</td>
<td>Schedule to start-up of operations</td>
</tr>
<tr>
<td>B: Unlikely</td>
<td>Unlikely to occur during life of project</td>
</tr>
<tr>
<td>C: Possible</td>
<td>50/50 chance of occurring during life of project</td>
</tr>
<tr>
<td>D: Probable</td>
<td>Likely to occur during life of project</td>
</tr>
<tr>
<td>A: Certain</td>
<td>Very likely (P&gt;0.95) to occur during life of project</td>
</tr>
</tbody>
</table>

### CONSEQUENCE SEVERITY

#### E: Persistent Severe
- Health and safety (HS): On site & off site exposures/injuries.
- Environmental protection (E): Persistent severe damage, Extensive remediation required.
- Schedule to start-up of operations: More than 12 months
- Cost: More than $10 million
- Reputation: National or International media attention. Regulators shut down operations.
- Likelihood: M
- Impact: H

#### D: Severe
- Health and safety (HS): On site injuries/exposures leading to absence from work more than 5 days or long term negative health effects.
- Environmental protection (E): Severe environmental damage. Remediation measures required. Environment restored < 5 years.
- Schedule to start-up of operations: 6-12 months
- Cost: $1 to $10 million
- Reputation: Regional media attention. Regulatory or legal action taken
- Likelihood: L
- Impact: M

#### C: Moderate
- Health and safety (HS): Lost time event/on site injury leading to absence from work up to 5 days, or affecting daily life activities more than five days.
- Environmental protection (E): Damage managed by Company response teams, env. restored < 2 years.
- Schedule to start-up of operations: 3-6 months
- Cost: $100 to $1000 k
- Reputation: Local media attention. Regulatory or legal action likely
- Likelihood: L
- Impact: M

#### B: Minor
- Health and safety (HS): Minor injury or health effect - affecting work performance, such as restricting work activities, or affecting daily life activities for up to 5 days.
- Environmental protection (E): Damage, but no lasting effect.
- Schedule to start-up of operations: 1-3 months
- Cost: $10 to $100 k
- Reputation: Public awareness may exist, but there is no public concern
- Likelihood: L
- Impact: M

#### A: Slight
- Health and safety (HS): Slight injury or health effect - not affecting work performance or daily life activities.
- Environmental protection (E): Damage contained within premises.
- Schedule to start-up of operations: Less than 1 month
- Cost: Less than $10 k
- Reputation: On-site communications
- Likelihood: L
- Impact: M
Evolution of risk profile

- Risk scenarios (by reference no.)
- Risks in yellow “tolerable” band gradually reduced through implementation of risk treatment: 15 (June 2011) -> 8 (Jan. 2012) -> 6 (May 2013).
- Open risks reduced from 47 (June 2011) to 38 (Jan. 2012) to 35 (May 2013).
SECARB Citronelle: Top ranked risks

- Initially **June 2011** the top ranked risks related to:
  - **Permitting** – 30, 31
  - Injectivity and containment – 8, 9, 10, 11
  - Modelling and monitoring – 14, 32
  - Reliable operations – 1, 23, 24, 38,
  - Pipeline and wells – 3, 21, 34

- In **January 2012**, Class V permit had been granted and drilling of monitoring wells and pipeline construction had been completed. Top ranked remaining risks related to:
  - **Authorization to inject** – 31
  - Containment – 8, 9, 10 (low likelihood, but high consequence)
  - Reliability of operations – 23, 38
  - Pipeline or casing leak – 21, 29

- In **May 2013** project had been operating for 9 months. Top remaining risks related to:
  - Possible loss of containment – 8, 9, 10
  - Reliability of operations – 23, 41
  - Post-injection MVA / **Authorization for closure** – 52
Public Outreach and Education

- Public Outreach Plan using DOE Best Practices Model
- Active Community Engagement through Open House Meetings and Tours
- Communicating Project Status
  - Local, Regional, International Outreach
  - Annual SECARB Stakeholders’ Briefing
  - Dedicated Website
  - Facebook Page: facebook.com/SECARB
  - Twitter Feeds: @SECARB1
  - Press Releases & E-blasts
  - RCSP Working Groups
- Knowledge Sharing
  - Lessons Learned presented in Various Workshops & Conferences
- Education: Training Center (separately funded)
  - SECARB-Ed (secarb-ed.org)
    - Classroom Training and Webinars
    - RECS-2011, 2012, and 2013 (hosted in AL)