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Southeast Regional Carbon Sequestration Partnership (SECARB)

Phase III Early and Anthropogenic CO_2 Injection Field Tests

Field Test Location and Amount/Sources of CO_2

Early Test
Cranfield Oilfield, Mississippi
- *1.5 million tonnes of CO_2 over 1.5 years*
- *Jackson Dome (Natural Source)*

Anthropogenic Test
Southern Company Electric Generating Facility
- *100,000 to 250,000 tonnes of CO_2 per year*
- *Power Plant (Commercial/Anthropogenic Source)*

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Field Test Partners

Primary Sponsors
U.S. Department of Energy
National Energy Technology Laboratory
Southern States Energy Board

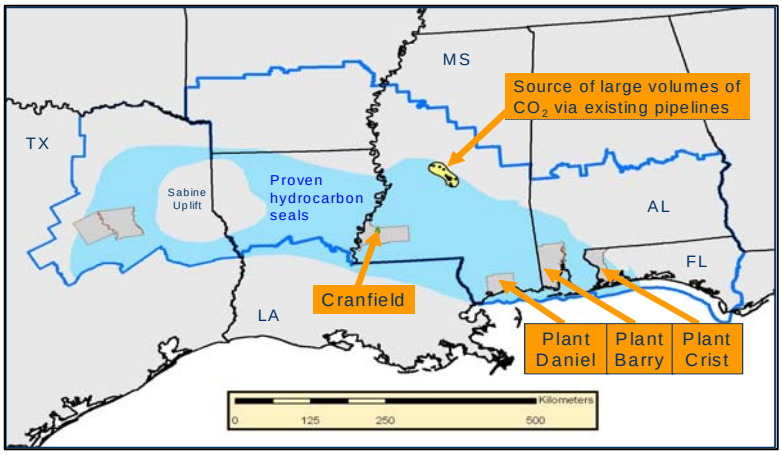
Industrial Partners *(in alphabetical order)*
Advanced Resources, International
Denbury Resources, Inc.
Electric Power Research Institute
Gulf Coast Carbon Center, Bureau of Economic Geology, University of Texas at Austin
Lawrence Berkeley National Laboratory
Lawrence Livermore National Laboratory
Mississippi State University
QEA
Schlumberger Carbon Services
Southern Company
University of Mississippi
U.S. Geological Survey

Summary of Field Test Site and Operations

The Southeast Regional Carbon Sequestration Partnership's (SECARB) Phase I and II efforts have shown that numerous thick, regionally extensive, high porosity saline formations with excellent thick shale confining zones exist within the Gulf Coastal Plain and have the potential to hold centuries of carbon dioxide (CO_2) emissions from this region. The lower Tuscaloosa Formation is a representative formation that is being studied in the SECARB Phase III program at the Cranfield Oilfield, located near Natchez, Mississippi (the Early Test). The Tuscaloosa, as well as other saline formations in the region, will be considered for a storage demonstration at a Southern Company CO_2 capture test location (the Anthropogenic Test). Following are summaries of the field tests to be conducted as SECARB's Phase III carbon sequestration program.

The Early Test will be conducted in Adams and Franklin Counties, Mississippi, about 15 miles east of Natchez and 1.5 miles north of the unincorporated city of Cranfield (Figure 1). The area selected for the Early Test is immediately east of the SECARB Phase II "Stacked Storage" study underway in the oil rim. The area is heavily wooded and hilly (elevation is 200-400 feet) with flat terrace areas near streams. Land use is rural; timber production, gravel quarrying, and oil production are important industries as well as some farming. U.S. Route 61 and U.S. Route 84 provide highway access to the area. A network of county and private gravel roads provides access to well sites. The area is hilly upland with no mapped wetlands. No significant water bodies are found in the study area. South Coles Creek provides surface drainage. Critical habitats or wildlife refuges for any of the listed species of plants or wildlife do not exist in the vicinity of the project site. The closest wildlife refuge is the St. Catherine Creek National Wildlife Refuge. St. Catherine's is located approximately 20 miles southwest of the project area on the east bank of the Mississippi River which is 10 miles south of the city of Natchez.

Figure 1. Geographic Location of the SECARB Phase III Program



For the Early Test, The Bureau of Economic Geology (BEG) will partner with Denbury Resources, Incorporated, to take advantage of ongoing CO_2-EOR efforts by the field operator. This presents SECARB with the opportunity to monitor the injection of approximately 1.5 million tonnes of CO_2, over 1.5 years, in the down-dip water leg of an oil reservoir in order to test commercial and experimental MMV protocols. This large volume injection test will provide important data in preparation for SECARB's longer duration injection efforts associated with the Anthropogenic Test, to be carried out by Southern Company, the Electric Power Research Institute and Advanced Resources International, Incorporated.

The Anthropogenic Test will be conducted on or in proximity to a Southern Company plant site on the Gulf Coast (Figure 1). Data confirms that the test sites are regionally similar to the geologic setting of the larger Gulf Coast area. Southern Company will negotiate site access agreements with appropriate contractors to perform the project on the selected Southern Company plant site. Should a storage site other than that owned and maintained by Southern Company be required, the project team will obtain appropriate access.

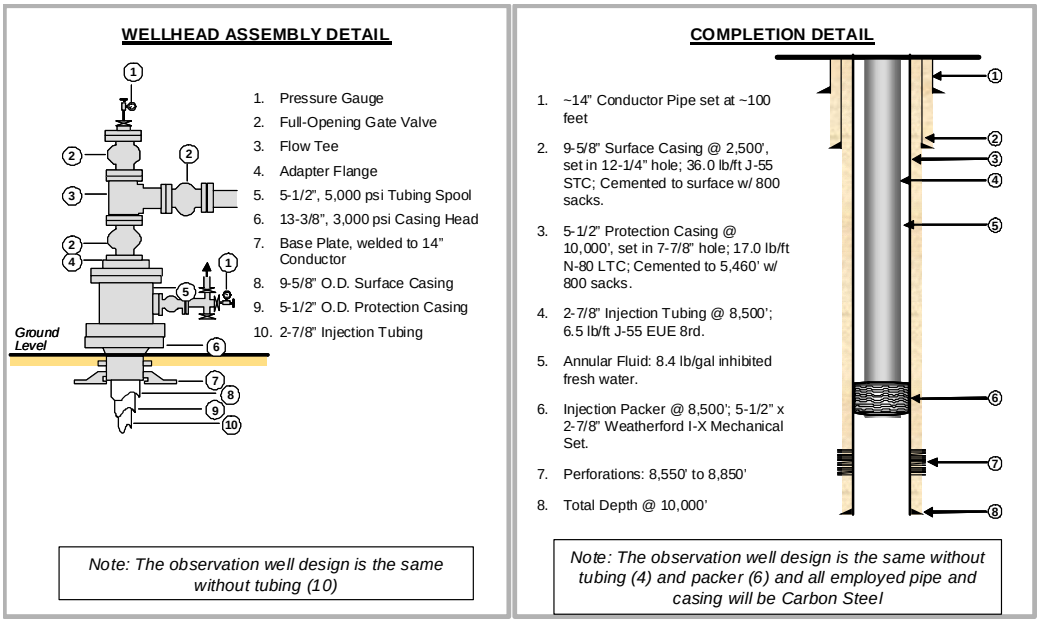


Figure 2. General Well Completion Design

The Anthropogenic Test site development design will be linked to the daily rate of delivered CO_2. Capture volumes, through a yet to be determined CO_2 capture method, are anticipated to range from 100,000 to 250,000 tonnes per year. It is anticipated that one injection well will be sufficient to handle these daily volumes.

The CO_2 from the capture facility is anticipated to be at injection pressure and will be transported through well site metering equipment to confirm the rate, pressure and temperature of the CO_2. Deep, subsurface monitoring wells will be constructed similarly to the injection wells. However, the monitoring wells will include additional in-well monitoring equipment, such as pressure, temperature and possible geochemistry probes. The wellhead and subsurface completion profiles are shown in Figure 2.

Research Objectives

The Southeast Regional Carbon Sequestration Partnership's (SECARB) Phase III activities will focus on the large scale demonstration of safe, long-term injection and storage of CO_2 in a saline reservoir that holds significant promise for future development within the region. The project will promote the building of experience necessary for the validation and deployment of carbon sequestration technologies in the region. Phase III will continue refining Phase II sequestration activities and will begin to validate sequestration technologies related to regulatory, permitting and outreach. The multi-

Figure 3. A Type Stratigraphic Column of the Gulf Coast Region

System	Series	Stratigraphic Unit	Sub-Units	Hydrology
Tertiary	Miocene	Misc. Miocene Units	Pascagoula Fm.	Freshwater Aquifers
			Hattiesburg Fm.	
			Catahoula Fm.	
	Oligo-cene	Vicksburg		Saline Reservoir
			Red Bluff Fm.	Minor confining unit
	Eocene	Jackson		Saline Reservoir
		Claiborne		Saline Reservoir
		Wilcox		Saline Reservoir
	Paleo-cene	Midway Shale		Confining unit
Cretaceous	Upper	Selma Chalk	Navarro Fm.	Confining unit
			Taylor Fm.	
		Eutaw	Austin Fm.	Confining unit
			Eagle Ford Fm.	Saline Reservoir
		Tuscaloosa Group	Upper Tusc.	Minor Reservoir
			Marine Tusc.	Confining unit
			Lower Tusc.	Saline Reservoir
	Lower	Washita-Fredricksburg	Dantzler Fm.	Saline Reservoir
			"Limestone Unit"	

partner collaborations developed during Phase I and Phase II will continue in Phase III with additional support from resources necessary to implement strong and timely field projects.

The Early Test is a saline test that will be conducted in the down dip "water leg" of the Cranfield unit, operated by Denbury Resources in Mississippi. Large volumes of CO_2 can be delivered by Denbury's Sonat Pipeline, which is supplied by natural CO_2 from Jackson Dome.

In the Early Test, the modeling and monitoring R&D objectives will be to: 1) assess reservoir contact efficiency of the large volumes of CO_2 injected to better quantify CO_2 storage capacity; 2) quantify pressure effects and brine movement though a heterogeneous rock volume to better understand the significance of these on storage capacity and ability to monitor pressure and brine migration; 3) quantify inter-well interactions as large plumes develop, focusing on interaction of pressure, heterogeneity, and gravity as controls on migration; 4) better understand the performance of pressure and capillary seals; 5) develop and assess the effectiveness of existing and novel monitoring tools; and 6) assess how monitoring tools can be used efficiently, effectively, and hierarchically in a long-term monitoring environment. The test will deploy a high resolution real- time cross well geophysics program using LBNL Continuous Active Source Seismic Monitoring (CASSM) in combination with an LLNL Electric Resistance Tomography (ERT) to observe the developed of the CO_2 plume. Pressure, distributed temperature, and fluid evolution will also be developed simultaneously, and a geochemical and tracer program will complete the measurements required to validate models at the resolution needed to move to large scale during a high volume injection test. Down-hole tilt, microseismic measurements, intermitted fluid chemistry, pressure, saturation, and temperature surveys will be collected in nearby wells. A time lapse 3-D surface seismic will assess the ultimate extent of the plume.

In the Anthropogenic Test, the R&D objectives will be to: 1) further test the lessons learned at the Early Test, with respect to CO_2 storage, flow and immobilization mechanisms; 2) evaluate injection and storage conditions at a second geographic point in the same, or a similar, regionally extensive saline reservoir to help establish ultimate CO_2 storage capacity; 3) evaluate how best to integrate and minimize the impacts of CO_2 captured from a power plant on the operation of transportation infrastructure and long-term storage formations; 4) understand how the reservoir architecture (the interplay between the reservoir flow units, seals and baffles) can be used to optimize storage and to minimize the areal extent of the plume; and 5) evaluate the impact of captured CO_2 from power plants on the geochemistry of the saline water in the Lower Tuscaloosa Formation.

Summary of Modeling and MMV Efforts

SECARB is planning an extensive monitoring, measurement and verification program for its field activities. Each site will be well instrumented with multiple sensor arrays. Standard off-the-shelf technologies will be tested in carbon sequestration applications. In addition, novel new tools and techniques will be tested and evaluated. SECARB has proposed an extensive program to monitor performance during the 10-year Phase III project. In addition, the two industry partners who are hosting the injection tests have an interest in supporting MMV activities for extended periods.

Table 1. Measurement Technologies

Measurement Technique	Measurement Parameters	Application
Introduced – noble gasses/partitioning tracers	Dissolution of CO_2 into brine	Significant uncertainties in pressure response is the amount of CO_2 dissolved. The SECARB Early Test will deploy the U-tube to reservoir depths to obtain tracer chromatography to assess dissolution via chromatography. This is a follow-on to Frio with a larger volume and longer flow-path using the same techniques. The SECARB team recognizes that laboratory measurements of fractionation into relevant fluids and rocks is key to quantifying this test.
Produced fluid composition	CO_2 via mass, DIC, DOC; Selected major and minor cations, organics	Validation of well log and cross-well CO_2 detection, index of rock-water reaction.
Bottom-hole pressure	Pressure transducers on wireline with real-time readout	Key measurement assessing relationship between pressure field and multiphase field.
Distributed down hole temperature	Measure zones of fluid movement	Additional data to constrain flow units, especially to determine flow-unit thicknesses under relevant conditions. Also indicates well integrity.
Pulsed neutron reservoir saturation; Cased hole sonic if modeling predicts sensitive	CO_2 saturation	Distribution of CO_2 at measurements points, model match, validation and quantification of CASSM and cross-well ERT. Key input to capacity calculation term "E."
Time-lapse 3-D seismic imaging (surface deployed)	Change from baseline, only if baseline assessment shows reasonable sensitivity to the expected CO_2 saturation change	Extent of CO_2 plume, especially down-dip. May substitute VSP if sensitivity is higher.
Continuous Active Source Seismic Monitoring (CASSM); Cross-well seismic tomography	Detect timing of CO_2 movement cross the plane of measurement	History match model, with high frequency temporal records with pressure signal
Passive seismic monitoring	Assess stress distribution	Development of stress in formation
Above-zone pressure and fluid monitoring	Assess leakage signal (possible through well completions- poor cement bond)	Continuation from Phase II to obtain long record (if Phase II results justify)
Cross-well electrical resistance tomography (ERT)	Improve measurement of saturation; will be used if proves feasible and economic	Tool development will extend the range of cross-well measurement of saturation and improve the rigor of history match and seismic inversion.
Subsurface deformation	Tilt; Measurements at surface to assess depth-effectiveness of tool under high injection rates	Quantify geomechanical effects on storage formation as part of pressure-field assessment.
CO_2 land surface-soil gas assessment	Measure natural CO_2 fluxes – aquifer-vadose zone-soil-land-surface and atmosphere in depth over time.	Determine sensitivity of these techniques under regional conditions. Possible follow-on-tracer test to validate hypothesis.
Aquifer monitoring	Alkalinity, DIC, DOC, isotopes, chloride selected cations and anions.	Assessment of method in compact possibly contaminated setting, directly regulated recourse. Possible follow-on-tracer test to validate hypothesis.

Accomplishments to Date

Early Test

Phase III activities at Cranfield are underway. A draft Environmental Assessment has been prepared and is ready for public review. Denbury has committed to horizontal drilling of select injector wells into the water leg in support of the SECARB research. Denbury has offered to make producer wells available for far-field monitoring during the initial months of Phase III activities. Data gathered from the SECARB Phase II (Gulf Coast Stacked Storage Field Test) injection currently underway at Cranfield provides confidence in the correctness of the static geologic model and the numerical model that will support the Phase III program. In particular, two months of injection data has been collected at the observation and associated monitoring wells, and they indicate pressure increase in the injection zone within the

predicted range. No pressure increase in the above-zone-monitoring interval, in addition to data obtained from 12 nearby wells completed in the 1940s, confirms the integrity of the seal and provides the team with confidence to proceed to a larger injection.

Three dimensional seismic data has been collected and analyzed, which led to site selection for the Phase III down-dip brine saturated areas on the east side of the field, a high sandstone thickness area where no injection has taken place. Additional characterization has been completed, including core examination and thin section analysis, advanced seismic analysis, and initial groundwater sampling. A novel combination of tools to better quantify the volumes occupied by CO_2 as dissolved and mobile phases has been selected, and a plan for well drilling followed by instrument deployment for injection in early 2009 has been developed.

Anthropogenic Test

The SECARB team is working diligently to select the Anthropogenic Test site and associated capture technology. The project's goal is to locate and assess, using large-scale demonstration projects, the suitability of regional geologic formations to receive and store large volumes of CO_2 captured from coal-fired power plants. The project will be conducted at a Southern Company power plant where suitable geologic storage will be demonstrated and a capture technology will be integrated with a large-scale geologic storage. Although Southern Company has agreed in the near future to make the site available, confidentiality must be maintained at this time. The site is not identified to ensure that public acceptance is not adversely impacted by a premature release of the site name.

Table 2. CO_2 Storage Capacity of the SECARB Gulf Coast Area Deep Saline Formations

Saline Formations	State	CO_2 Storage Capacity			
		Trillion Cubic Feet		Billion Metric Tons	
		High Estimate	Low Estimate	High Estimate	Low Estimate
Gulf Coast Basins (Pliocene)	Multiple states*	25,705	6,426	1,360	340
Gulf Coast Basins (Miocene)	Multiple states*	75,824	18,956	4,012	1,003
Gulf Coast Basins (Oligocene)	Multiple states*	24,884	6,221	1,317	329
Gulf Coast Basins (Eocene)	Multiple states*	29,588	7,397	1,565	391
Gulf Coast Basins (Tertiary Undivided)	Multiple states	3,225	806	171	43
Gulf Coast Basins (Olmos)	TX	84	21	4	1
Tuscaloosa Group	Multiple states	1,027	257	54	14
Woodbine and Paluxy Formations	TX	963	241	51	13
Pottsville Formation	MS	210	53	11	3
Mt. Simon Sandstone	TN	95	24	5	1
Potomac Group	Multiple states*	340	85	18	4
South Carolina-Georgia Basins	Multiple states*	597	149	32	8
Cedar Keys, Lawson Formations	FL	2,099	525	111	28
Offshore Atlantic (Unit 120)	Federal	6,733	2	356	89
Offshore Atlantic (Unit 90)	Federal	587	0.1	31	8
Total		**171,961**	**41,163**	**9,098**	**2,275**

* Including offshore Federal Waters

Target Sink Storage Opportunities and Benefits to the Region

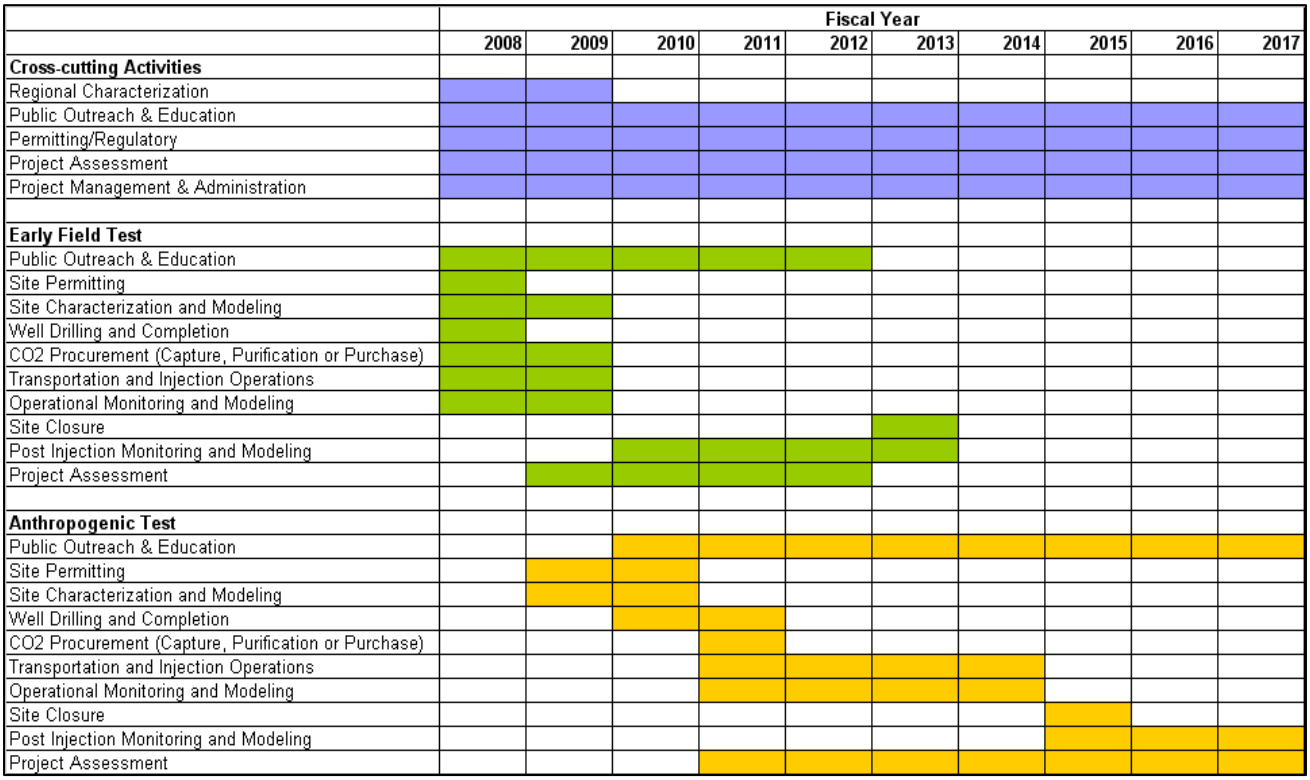
The target formation is representative of the Gulf Coast geology that could be used to store 50 percent of the CO_2 produced in the SECARB region during the next 100 years. The lower Tuscaloosa Formation is a key component of a larger, regional group of similar formations, in terms of deposition and character, called the Gulf Coast Wedge. This wedge of sediments spans the entire region (from the Gulf of Mexico, through Texas, Louisiana, Mississippi, Alabama, Florida, Georgia, South Carolina, North Carolina, and Virginia) and includes the largest saline sinks (in terms of areal extent and capacity) for the SECARB region as well as the United States. Annual stationary point-source emissions of CO_2 have been estimated to be 1,047 Mt (Massachusetts Institute of Technology 2007). Using the range of reported capacity, the Gulf Coast Wedge has the capacity to accommodate these emissions for approximately 300 to nearly 1,200 years, should 100 percent of this CO_2 be captured and stored.

Project Cost and Key Dates

PHASE III PROJECT COST		
	Dollars	Percent
DOE Share	$64,949,078	69.32%
Non-DOE Share	$28,740,163	30.68%
Total Value	$93,689,241	

KEY PROJECT DATES	
EARLY TEST	
Baseline Completed	3/09
Drilling Operations Begin	1/09
Injection Operations Begin	4/09
MMV Events	Baseline 1/09-7/10
Injection Operations End	* injection rate reduced 7/10
ANTHROPOGENIC TEST	
Injection Operations Begin	FY11
MMV Events	FY09
Injection Operations End	FY14

Field Test Schedule



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