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Southeast Regional Carbon Sequestration Partnership (SECARB)

Phase III Early CO_2 Injection Field Test at Cranfield

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 (250,830 tonnes injected as of November 2009)*
- *Jackson Dome (Natural Source)*

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Field Test Partners

Primary Sponsors
U.S. Department of Energy
National Energy Technology Laboratory
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Project Lead
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Industrial Partners
(in alphabetical order)
Anchor/QEA
BP
Center for Frontiers of Subsurface Energy Security
Denbury Onshore LLC
Lawrence Berkeley National Laboratory
Lawrence Livermore National Laboratory
Mississippi State University
National Risk Assessment Program
National Energy Technology Laboratory
Oak Ridge National Laboratory
Schlumberger Carbon Services
Sandia Technologies LLC
Scottish Carbon Centre
Alabama Power
University of Mississippi
U.S. Geological Survey Menlo Park/Jackson

Summary of Field Test Site and Operations

The Southeast Regional Carbon Sequestration Partnership's (SECARB) Phase I and II studies have shown that numerous thick, regionally extensive, high porosity saline formations with excellent thick shale confining zones exist within the passive margin sedimentary wedge the underlies the Gulf Coastal Plain and have the potential to hold centuries of carbon dioxide (CO_2) emissions from this region. A large volume injection into the lower Tuscaloosa Formation, one of the typical formations of this wedge, provides an early opportunity to assess modeling and monitoring approaches. The project is called SECARB Phase III Early Test and complements SECARB's Anthropogenic Test, a linked capture and sequestration project in Alabama.

The Early Test has completed the first year of monitoring in Adams and Franklin Counties, Mississippi, about 15 miles east of Natchez (Figure 1). The area selected for the Early Test is in the saline "water leg" east of the SECARB Phase II study recently completed in the oil rim. The rural area is heavily wooded and hilly with a thick unsaturated section. Land use includes timber production, gravel quarrying, oil production, and farming. The injection zone in the lower Tuscaloosa Formation is a fluvial conglomeritic sandstone with high vertical and lateral heterogeneity (Figures 2-3).

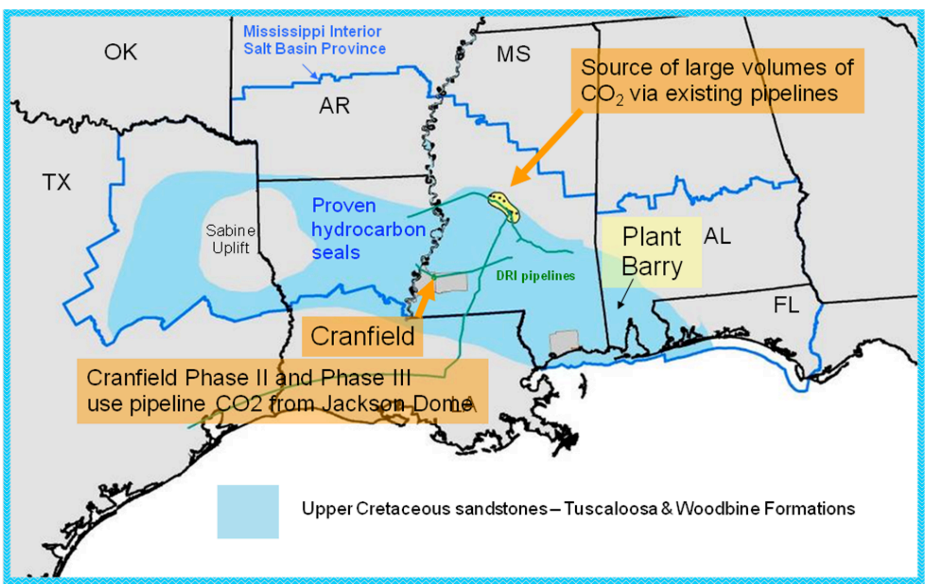


Figure 1. Geographic Location of the SECARB Phase III Program. The Early Test is underway at Cranfield in Mississippi. The location of the Anthropogenic Test carbon capture project that will occur at Alabama Power's Plant Barry in Alabama is also shown.

The Bureau of Economic Geology (BEG) has partnered with Denbury Onshore LLC to monitor 30 months the injection at a rate of one million tonnes of CO_2 per year to guide evolution from experimental to commercial monitoring protocols as well as rationale develop an improved basis for estimation of sequestration capacity. Four integrated programs are in operation. The high volume injection Test (HiVIT) program started April 1, 2009 at an initial rate of 40,000 tonnes of CO_2 per month, with monitoring via pressure and fluid sampling though far-field wells, and regional groundwater monitoring conducted by the University of Mississippi and Mississippi State. The HiVIT reached the one million tonne/year target rate in December, 2009 and the 1.5 Million tonne stored target in spring, 2011. The detailed area study (DAS) is designed to allow observation of fluid flow through the rock volume between two 10,700 ft deep instrumented wells through an innovative cross-well multi-physics monitoring program (Figure 4). The well-based program engineered by Sandia Technologies LLC includes time-lapse seismic tomography, combined with LBNL continuous active seismic source monitoring (CASSM), LLNL cross-well electrical resistance tomography, above-zone pressure monitoring provided by Promore, fiber-optic distributed temperature, time-laps wireline monitoring by Schlumberger, high-frequency sampling of fluids for natural and introduced tracers using the U-tube. The geomechanical test (Pinnacle, Weston, LBNL) attempted microseismic monitoring between two closely spaced wells on either side of the non-transmissive eastern limb of the crestal graben. The “P area” is testing surface monitoring strategies in an area where complex soil gas environments including well pads, pits from historic oil field operations and plants complicate interpretation of leakage signal. Methane is anomalously high, however no CO_2 leakage has been detected. Anchor –QEA provides modeling

Figure 2. A Typical 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 Formation	upper Tusc.	Minor Reservoir
			middle (marine) Tusc	Confining unit
			lower Tusc.	Saline Reservoir
	Lower	Washita-Fredricksburg	Dantzler Fm.	Saline Reservoir
			"Limestone Unit"	

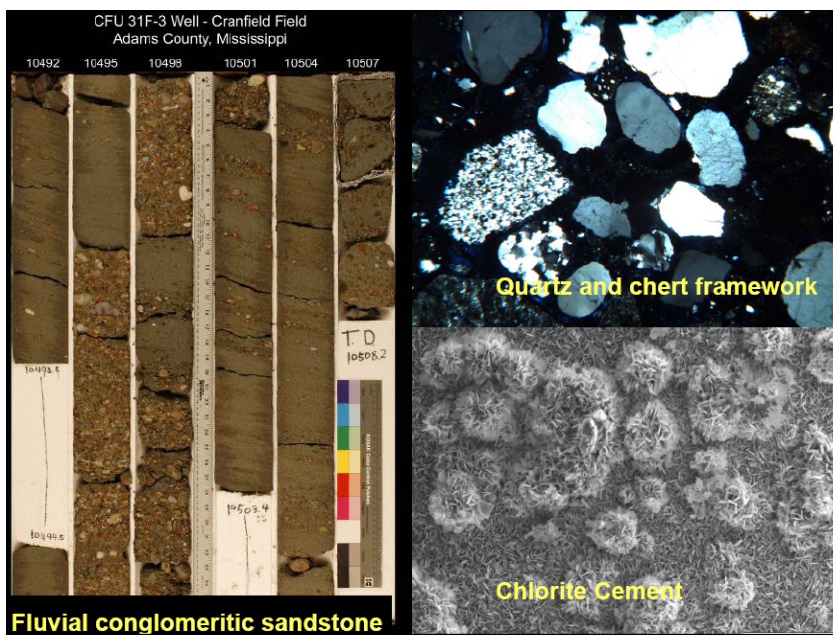


Figure 3. Characterization of the Tuscaloosa Formation injection zone for the early test has been nearly completed.

support.

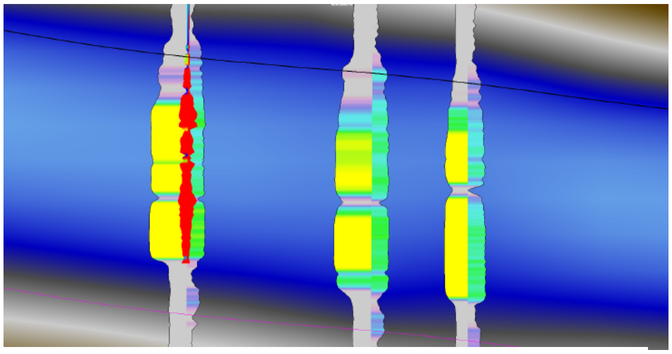


Figure 4. An injection well and two closely spaced observation wells at the Detailed Area Study (DAS) allow quantitative assessment of flow using multiple types of cross-well

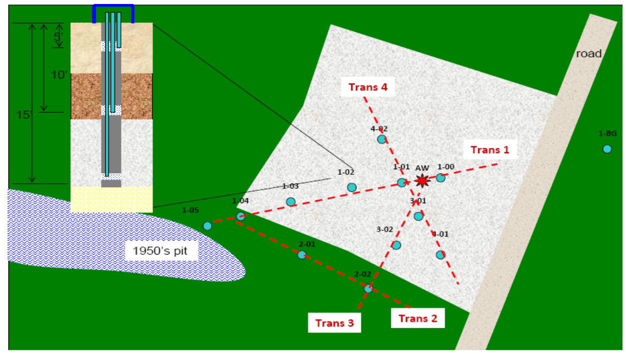


Figure 5. Study at the "P area" is developing an improved understanding of soil gas monitoring methods in an area with typical infrastructural complexities and a methane anomaly..

Characterization is recognized as the cornerstone of monitoring and modeling, and the team has invested heavily in wireline logs, core analysis of key reservoir and confining intervals, fluid sampling, hydrologic testing, and extensive and diverse laboratory follow-up. A quantitative static geocellular model has been constructed in Petrel and input into GEM-CO_2 for assessment of multiphase flow in the Phase II and the HiVIT.

A year of design discussions guided selection of the monitoring program. The monitoring approach focused on the advancing research-oriented objectives (listed above) and balanced the opportunities and uncertainties presented by this site with cost, value, and risk of research success. The team recognized that this is one of a series of tests conducted internationally and in the U.S., which allowed us to focus heavily on method development and scientific objectives, because of the relatively high security offered by this site and operator. The project team selected three focus areas: the DAS to examine multiphase fluid flow and pressure at the interwell scale: the P site to experiment with effective near surface monitoring strategies at a P&A well site, and the GMT to look at sub-fracture stress near a non-trans missive fault.

Injection rate was measured as primary signal. At the DAS, two observation wells, arrayed as a transect toward the down-dip plume edge, sampled a segment through the evolving pressure field and plume. Injection rates were stepped during the 18 month monitoring period to provide an opportunity to measure pressure response, this was linked to other metrics especially introduced tracers. Time-lapse difference from baseline was used as a primary tool. Bottom-hole pressure on wireline is the major signal. Redundancy proved valuable, as tool durability was variable. Real-time output for the array controlled the timing of monitoring. U-tube sampling was used for high frequency tracer chromatography (PFT, SF_6, noble gasses and natural tracers). Cross-well tools include repeat cross-well tomography, continuous active source seismic monitoring (CASSM) and real-time cross-well electrical resistance tomography (ERT). Walk away and 3-D VSP was conducted in time lapse coordinated with repeat 3-D survey over the HiVIT. Fiber-optic distributed temperature was installed on the casing in one observation well and the tubing of the other.

A surface monitoring experiment is using nested soil gas and groundwater sample wells to test natural flux from one near-surface CO_2 reservoir (aquifer-vadose-zone-soil-atmosphere) to another. This will determine natural variability and assess the leakage signal that could be detected above background variability at a site with the types of complexities that are expected at a commercial site.

A suite of subsurface modeling tools are in use, including analytical assessment of pressure from gas storage literature, one-dimensional (1-D) seal flux assessment, MODFLOW for the pressure modeling in the single phase region, and GEM-CO_2 for the two phase fields are in use. For geochemical assessments PHREEQC and Geochemists workbench are the major modeling tools in use for single phase regions; CORE2D and TOUGHREACT are used to multiphase reactive volume transport and multiphase flow.

Table 1 Measurement Technologies Employed at Phase III Early Test site

Measurement Technique	Measurement Parameters	Application
Introduced – noble gasses/partitioning tracers (DAS)	Dissolution of CO_2 into brine	Significant uncertainties in mass balance and pressure response is the amount of CO_2 dissolved. The U-tube sampler was used to obtain high quality- high frequency fluids with intact tracers to assess dissolution and flow processes
Produced fluid composition (DAS, HiVIT)	Gasses and tracers via mass spectrometer, Selected major and minor cations, organics via GC, stable isotopes, noble gases.	Validation of well log and cross-well CO_2 detection, index of rock-water reaction.
Bottom-hole pressure injection (DAS)	Pressure transducers on wireline with real-time readout	Assess relationship between pressure field and multiphase field.
Distributed down hole temperature with heater cable (DAS)	Measure zones of behind-casing fluid replacement and fluid movement	Additional data to constrain flow units, especially to determine flow-unit thicknesses under relevant conditions. Also assessment of cement integrity.
Pulsed neutron reservoirs saturation; cased hole sonic	CO_2 saturation	Distribution of CO_2 at measurements points, model match, validation and quantification of CASSM and cross-well ERT.
Time-lapse 3-D seismic imaging (surface deployed)	Change from baseline	Extent of CO_2 plume, lateral coalescence of plume from multiple injectors.
Time-lapse VSP (walk away and 3-D)	Increased vertical resolution	Complements and refines 3-D interpretation near DAS, refine down-dip plume edge measurement.
Continuous Active Source Seismic Monitoring (CASSM); Cross-well seismic tomography	Detect timing of CO_2 movement cross the plane of measurement	Co-inversion with ERT
Passive seismic monitoring	Assess value of technique in setting well below fracture pressure	Technique assessment
Above-zone pressure monitoring	Assess leakage signal (possible through well completions because of poor cement bond)	Continuation from Phase II to obtain long record ; behind casing pressure at DAS
Cross-well electrical resistance tomography (ERT)	Improve measurement of saturation	Tool development will extend the range of cross-well measurement of saturation and improve the rigor of history match and seismic inversion.
Soil gas	Measure N_2/ O_2/CO_2 /CH_4 ratios, introduced tracers, stable isotopes and noble gasses in vadose zone at plugged and abandoned well site	Determine sensitivity of soil gas techniques under regional conditions. Follow-on-tracer test.
Aquifer monitoring	Quarterly fresh water sampling at 200 ft depth at injection well sites, selected cations and anions, noble gasses.	Assessment of method in compact possibly contaminated setting, directly regulated recourse. follow-on tracer test.

Phase III Early Test Results

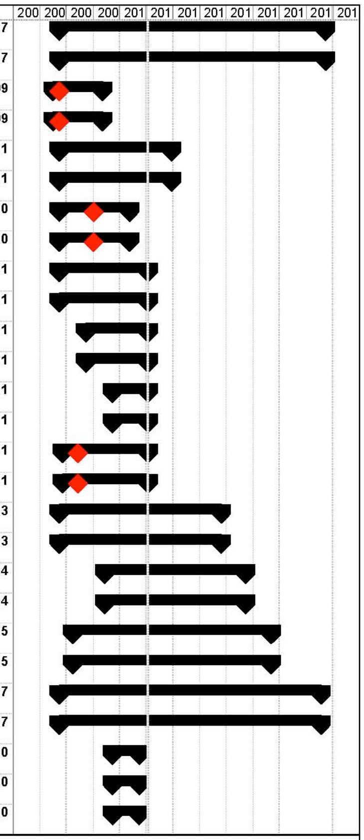
A large amount of interim project results have been collected. An additional two years of data analysis and project integration are planned, to sufficiently analyze the large amounts of data collected. Much of this analysis is being conducted collaboratively (for example modeling teams at BEG, LBNL, LLNL EFRC, SIMSEQ are all working on model approaches, some unique and some duplicative).

- Pressure response is most sensitive to boundary conditions. Open boundary conditions predicted during characterization are demonstrated by good model match.
- CO_2 moved down dip at the scale of the test (buoyancy did not dominate).
- Significant percentage of CO_2 dissolved in brine and methane exsolved. This methane contamination is a significant new finding.
- The plume continued to thicken over time.
- Tracer performance shows that with increased injection rates new parts of the reservoir were accessed: storage efficiency improved.
- Rock-brine integration shows slow and minor changes following introduction of CO_2.
- The repeat VSP shows change in seismic reflection strength at specific spatial locations. This will be used for interpretation/calibration of the repeat 3D surface seismic. The 3D-VSP should show spatial distribution of the CO_2 induced seismic reflection change at a resolution about an order of magnitude better than surface seismic.
- ERT appear to be sensitive to introduction of CO_2 and highlighted lateral heterogeneity between DAS wells. Cross well seismic includes an analogous assessment of the heterogeneous vertical and lateral distribution of CO_2 in the Tuscaloosa. Quantification of the seismic velocity change induced be CO_2 (used for interpretation/calibration of 3D seismic) and Improved understanding of scaling of seismic properties from core to well-log to VSP to surface seismic.
- CASSM receiver failure was caused by failure of internal seals in the pressure compensated components. The seals, which had pressure differential, apparently maintained seal due to deformation from the pressure. This is an important lesson for future monitoring design utilizing removable fluid-coupled sensors.

Project Cost and Key Dates

PHASE III PROJECT COST			KEY PROJECT DATES	
	Dollars	Percent	EARLY TEST	
DOE Share	$76,981,260	69.10%	**Baseline Completed**	9/2008 - 11/2010 (phased in five test areas)
Non-DOE Share	$34,432,171	30.90%	**Drilling Operations Begin**	4/2008 first new drill well 8/2009 DAS wells drilled (phased, 14 injection wells)
Total Value	$111,413,431 (includes $2,444,000 for Federal Laboratories)		**Injection Operations Begin**	10/2008 in area 12/2009 DAS injection
*Includes all Tasks for the Phase III Program			**MVA Events**	4/2009 - 12/2010
			Injection Operations End	2/2011 propose reduce DOE spend on CO_2

ID	Task Name	Start	Finish
1	Public Outreach and Education (TASK 2.0)	Mon 10/1/07	Sat 9/30/17
2	Subtask 2.1: SECARB Early Test Public Outreach and Education	Mon 10/1/07	Sat 9/30/17
17	Site Permitting (TASK 3.0)	Sat 7/7/07	Fri 5/15/09
18	Subtask 3.1: Permitting for the Early Test Site	Sat 7/7/07	Fri 5/15/09
26	Site Characterization and Modeling (TASK 4.0)	Mon 10/1/07	Thu 12/15/11
27	Subtask 4.1: Site Characterization and Modeling for the Early Test Site	Mon 10/1/07	Thu 12/15/11
38	Well Drilling and Completion (TASK 5.0)	Mon 10/1/07	Fri 5/21/10
39	Subtask 5.1: Early Test Site Well Drilling and Completion	Mon 10/1/07	Fri 5/21/10
49	Infrastructure Development (TASK 6.0)	Mon 10/1/07	Sun 1/30/11
50	Subtask 6.1: Early Test Site Infrastructure Development	Mon 10/1/07	Sun 1/30/11
53	CO2 Procurement (TASK 7.0)	Sun 9/28/08	Sun 1/30/11
54	Subtask 7.1: Early Test CO2 Procurement	Sun 9/28/08	Sun 1/30/11
57	Transportation and Injection Operations (TASK 8.0)	Wed 9/30/09	Sun 1/30/11
58	Subtask 8.1: Early Test CO2 Transportation and Injection Operations	Wed 9/30/09	Sun 1/30/11
60	Operational Monitoring and Modeling (TASK 9.0)	Thu 11/15/07	Sun 1/30/11
61	Subtask 9.1: Early Test Operational Monitoring and Modeling	Thu 11/15/07	Sun 1/30/11
80	Site Closure (TASK 10.0)	Mon 10/1/07	Wed 10/30/13
81	Subtask 10.1: Cranfield Test Discontinuation	Mon 10/1/07	Wed 10/30/13
84	Post-Injection Monitoring and Modeling (TASK 11.0)	Mon 6/15/09	Tue 9/30/14
85	Subtask 11.1: Early Test Post-Injection Monitoring and Modeling	Mon 6/15/09	Tue 9/30/14
95	Project Assessment (TASK 12.0)	Tue 4/1/08	Tue 9/15/15
96	Subtask 12.1: Early Test Project Assessment	Tue 4/1/08	Tue 9/15/15
100	Project Management (TASK 13.0)	Mon 10/1/07	Sun 7/30/17
101	Subtask 13.1: Project Management - GCCC	Mon 10/1/07	Sun 7/30/17
103	Preliminary Evaluation of Offshore Transport and Storage of CO2 (TASK 15.0)	Thu 10/1/09	Thu 9/30/10
104	Subtask 15.1: Offshore Gulf of Mexico Resource Mapping - Federal Waters	Thu 10/1/09	Thu 9/30/10
107	Subtask 15.2: Offshore Gulf of Mexico Resource Mapping - State Waters - Florida Panhandle, Alabama	Thu 10/1/09	Thu 9/30/10



Project: SECARB2
Date: Mon 1/17/11

Task | Summary | Rolled Up Progress | Project Summary
Progress | Rolled Up Task | Split | Group By Summary
Milestone | Rolled Up Milestone | External Tasks | Deadline

This material is based upon work supported by the U.S. Department of Energy National Energy Technology Laboratory under DE-FC26-04NT42590.