the ENERGY lab

PROJECT FACTS

Carbon Storage - RCSP

Southeast Regional Carbon Sequestration Partnership—Development Phase

Cranfield Site and Citronelle Site Projects

Background

The U.S. Department of Energy Regional Carbon Sequestration Partnership (RCSP) Initiative consists of seven partnerships. The purpose of these partnerships is to determine the best regional approaches for permanently storing carbon dioxide (CO_2) in geologic formations. Each RCSP includes stakeholders comprised of state and local agencies, private companies, electric utilities, universities, and nonprofit organizations. These partnerships are the core of a nationwide network helping to establish the most suitable technologies, regulations, and infrastructure needs for carbon storage. The partnerships include more than 400 distinct organizations, spanning 43 states and four Canadian provinces, and are developing the framework needed to validate geologic carbon storage technologies. The RCSPs are unique in that each one is determining which of the numerous geologic carbon storage approaches are best suited for their specific regions of the country and are also identifying regulatory and infrastructure requirements needed for future commercial deployment. The RCSP Initiative is being implemented in three phases, the Characterization Phase, Validation Phase, and Development Phase. In September 2003, the Characterization Phase began with the seven partnerships working to determine the locations of CO_2 sources and to assess suitable locations for CO_2 storage. The Validation Phase (2005–2012) focused on evaluating promising CO_2 storage opportunities through a series of small scale field projects in the seven partnership regions. Finally, the Development Phase (2008-2020+) activities are proceeding and will continue evaluating how CO_2 capture, transportation, injection, and storage can be achieved safely, permanently, and economically at large scales. These field projects are providing tremendous insight regarding injectivity, capacity, and containment of CO_2 in the various geologic formations identified by the partnerships. Results and assessments from these efforts will assist commercialization efforts for future carbon storage projects in North America.

The Southeast Regional Carbon Sequestration Partnership (SECARB), led by the Southern States Energy Board (SSEB), represents the 11 southeastern states of Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, and Virginia, and counties in Kentucky and West Virginia. SECARB is comprised of more than 100 partners and stakeholders. In the SECARB region, there are more than 900 large, stationary CO_2 sources with annual CO_2 emissions in excess of 1 billion metric tons. SECARB's deep saline formations offer significant safe

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PARTNERS

Advanced Resources International
AGL Resources
Alabama Oil & Gas Board
Alawest
Alpha Natural Resources
American Coalition for Clean Coal Energy
American Electric Power
Amvest Gas Resources
Applied Geo Technologies
ARCADIS
Arch Coal
Arkansas Oil & Gas Commission
Association of American Railroads
Augusta Systems, Incorporated

PARTNERS (CONT.)

- Baker Hughes Incoporated
- Big Rivers Electric Corporation
- Blue Source
- BP America
- Buchanan Energy Company of Virginia, LLC
- Buckhorn Coal Company
- CDX Gas, Llc
- Cemex
- Chevrontexaco Corporation
- Clean Coal Technology Foundation of Texas
- Clean Energy Systems, Inc.
- Clemson University
- CO_2 Capture Project
- Composite Technology Corporation
- CONSOL Energy, Inc.
- Core Laboratories
- CSX Gas
- Dart Oil & Gas Corporation
- Denbury Resources, Inc.
- Dominion
- Duke Energy
- Eastern Coal Council
- Edison Electric Institute
- Electric Power Research Institute (Epri)
- Entergy Services, Inc.
- Equitable Resources
- Exxon Mobile
- Florida Municipal Electric Association
- Florida Power & Light Company
- Geological Survey Of Alabama
- Geomet, Inc.
- Georgia Environmental Facilities Authority
- Georgia Forestry Commission
- Georgia Power Company
- Halliburton
- Integrated Utility Services, Inc.
- International Coal Group
- Interstate Oil & Gas Compact Commission
- Kentucky Geological Survey
- Lawrence Berkeley National Laboratory
- Lawrence Livermore National Laboratory
- Louisiana Department of Environmental Quality
- Louisiana Geological Survey
- Marshall Miller & Associates
- Massachusetts Institute of Technology
- McJunkin Appalachian Oil Field Supply Company
- Mississippi Power Company
- Mississippi State University
- National Coal Council
- National Mining Association
- Natural Resource Partners

and permanent storage capacity for these emissions. Moreover, SECARB, along with the other RCSPs, continues to develop best practices to support the wide-scale transfer and advancement of information and technology derived from its projects.

Project Description

Project Summary

SECARB is conducting two large-volume injection field projects; one in the lower Tuscaloosa Formation (Cranfield Site) and one in the Paluxy Formation (Citronelle Site). These formations are key components of a larger, regional group of similar formations, called the Gulf Coast Wedge.

Cranfield Site

The "Early Test," which was the first Development Phase field test to begin CO_2 injection operations, injects CO_2 into the lower Tuscaloosa Formation. The Early Test began injection in April 2009 after a successful Validation Phase field project that injected 627,744 metric tons of CO_2 into the Tuscaloosa and the same site. The Cranfield Site has injected a cumulative 8,461,864 metric tons through September 30, 2013. Denbury Resources, Inc. is scheduled to continue CO_2 injection while SECARB monitors the additional injection operations until September 2014.

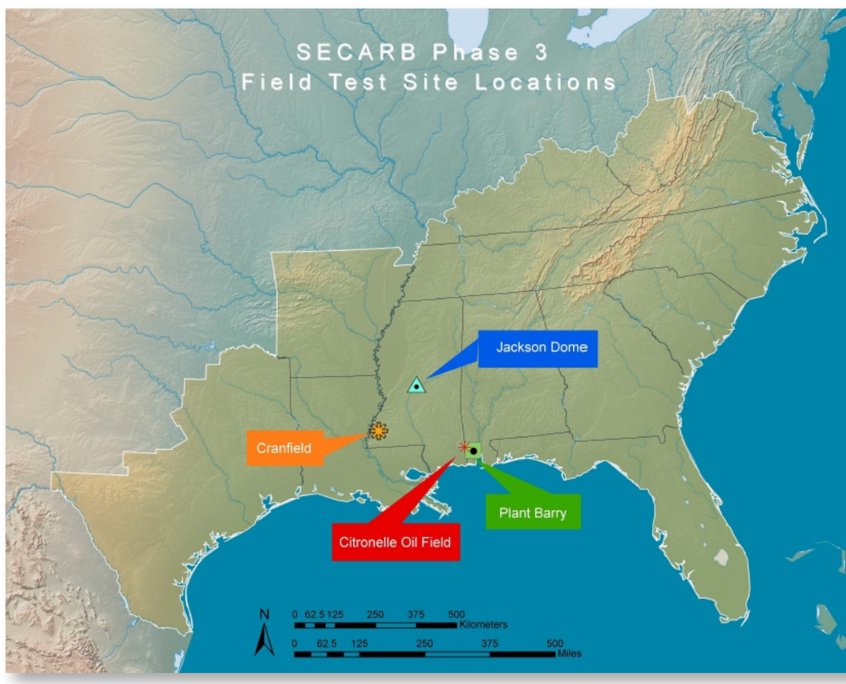

Figure 1 - Location of Early Test and Anthropogenic Test

Citronelle Site

The second SECARB project, the "Anthropogenic Test," is the world's largest fully integrated carbon capture and storage project utilizing anthropogenic CO_2 from a coal-fired power plant. The project became fully operational on August 20, 2012. Over the life of the project, 100,000 to 200,000 metric tons of CO_2 will be injected into the Paluxy Formation. The CO_2 is supplied by a pilot unit capturing CO_2 from flue gas produced from Alabama Power Company's (a Southern Company subsidiary) Plant James M. Berry Electric Generating Facility located in Bucks, Alabama (Figure 1). The CO_2 is transported 12 miles by a dedicated CO_2 pipeline to the Citronelle Field injection site (Figure 2). As of October 29, 2013, more than 100,000 metric tons of CO_2 have been injected and stored at the site (Figure 3).

Figure 2 - Construction of the CO_2 pipeline for the Plant Barry Site.

Injection Site Description

Cranfield Site

This project is focused on the down dip "water leg" of the Cranfield Unit, operated by Denbury Resources, Inc. in Adams and Franklin Counties, Mississippi, about 15 miles east of Natchez, Mississippi, and one and one-half miles north of Cranfield, Mississippi. The area selected for the Early Test is immediately north of SECARB's Validation Phase "Stacked Storage" study in the Cranfield oil field near Natchez.

Figure 3 - CO_2 Capture Unit at Plant Barry.

Citronelle Site

This project will be conducted approximately 12 miles northwest of Southern Company's Plant Barry in a saline formation within the Citronelle Oil Field in Mobile County, Alabama. CO_2 would be transported to the Citronelle Field from a capture unit located at Plant Barry via a 4-inch pipeline that Denbury Resources has proposed for construction.

PARTNERS (CONT.)

Norfolk Southern
North American Coal Corporation
North Carolina State Energy Office
Nuclear Energy Institute
Oak Ridge National Laboratory
Old Dominion Electric Cooperative
Peabody Energy
Penn Virginia Corporation
Phillips Group, The
Pine Mountain Oil & Gas, Inc.
Pocahontas Land Corporation
Powell River Project
Praxair
Progress Energy
QEA, LLC
Rentech, Inc.
RMB Earth Science Consultants
RMS Strategies
SCANA Energy
Schlumberger
Shell Oil Company
Smith Energy
South Carolina Department of Agriculture
South Carolina Electric & Gas Company
South Carolina Public Service Authority/Santee Cooper
Southern Company
Southern Natural Gas/El Paso
Southern States Energy Board
Susan Rice and Associates, Inc.
Tampa Electric Company
Tennessee Valley Authority
Texas Bureau of Economic Geology
TXU Corporation (Luminant Energy)
United Company, The
University of Alabama
University of British Columbia
Virginia Center for Coal and Energy Research
Virginia Department of Mines, Minerals & Enegy
Walden Consulting
Winrock International

PROJECT DURATION

Start Date	End Date
09/22/2007	09/30/2017

COST

Total Project Value
$93,689,241

DOE/Non-DOE Share
$64,949,078 / $28,740,163

AWARD NUMBER

FC26-05NT-42590

Description of Geology

Cranfield Site

The lower Tuscaloosa Formation is one of the named stacked sandstone formations of the Gulf Coast Wedge. It is a Cretaceous-age, sandstone saline formation that occurs in the subsurface along the Gulf of Mexico Coastal Plain from western Florida to Texas (where it is defined as the Woodbine Formation). The Tuscaloosa Formation contains an upper section of alternating shales and sands and a basal section, the Massive Sand Unit, which contains a thick layer of clean, coarse-grained sand. The formation was deposited during a major period of global sea level rise, and its deposition has been interpreted as an upward gradation from fluvial and deltaic sedimentation (the Massive Sand) to shelf deposition (alternating sands and shales). The reservoir is in the lower Tuscaloosa, above a regional unconformity, in valley-fill-fluvial conglomerates and sandstones separated by alluvial and overbank within-unit seals. The reservoir is composed of stacked and incised channel fills and is highly heterogeneous, with flow unit average porosities of 25 percent and permeability averaging 50 millidarcy (mD), ranging to a Darcy (D). Chlorite is the major cement in these relatively immature sediments. The well-sorted, clean, coarse-grained nature of the Massive Sand, a result of this environment, makes it an ideal candidate for CO_2 injection due to its high permeability and porosity. As the sea level continued to rise, the valley-fill depositional environment gave way to a deep marine environment, during which the overlying middle (Marine) Tuscaloosa Formation was deposited. This formation consists of about 500 feet of low-permeability shale, providing an excellent confining zone for CO_2 injection into the lower Tuscaloosa Formation (Figure 4).

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'	

Figure 4- Stratigraphy present at the Cranfield (Early Test) site.

Shale is also found in the lower portion of the Tuscaloosa Formation acting as a barrier to the vertical migration of sandy substrates. Deposition that occurred during the early Cretaceous Period was based on a cycle of marine and delta sedimentation and deposition. The high porosity and permeability of the sandstones in the region are due to the cycles of deposition throughout time.

Citronelle Site

The injection horizon is the Lower Cretaceous-age Paluxy Formation. The Paluxy is a 1,150 feet thick package of sand, silt and shale strata, which occurs at a depth of about 9,800 feet at the project site. The porous and permeable sands of the Paluxy Formation represent a typical fluvial deposition reservoir in terms of their areal extent and petrophysical characteristics. There are approximately 475 feet of net sand in the Paluxy Formation, which occurs in over 20 sand units that range in thickness from 9 – 80 feet. The Paluxy appears to contain a mix of continental, fluvial and marginal marine deposits. Relationships between sand units within the formation are complex. The average core porosity of the lower Paluxy sandstones is 18%. Sandstone permeability ranges from 0.6 to 167.5 millidarcies and averages 17.4 millidarcies. Several of the Paluxy sand units appear to be laterally extensive, and are targeted as the injection zones for the Anthropogenic Test.

Following this deposition was another marine transgression, which deposited the shales, limestones, and sandstones that are known as the Washita-Fredericksburg Shale. This shale would be the primary confining zone for carbon dioxide stored in the Paluxy Formation. The shale appears to possess the appropriate criteria (lateral continuity, low permeability) to act as an effective CO_2 seal. In addition to the basal Washita-Fredericksburg shale, there are secondary overlying confining units including the Middle (Marine) Tuscaloosa Formation, the Selma Group, and the Midway Shale, which occur stratigraphically between the injection zone and the base of the lowermost underground source of drinking water (USDW). As such, a vertical interval of over 8,000 feet with numerous low permeability barriers occurs between the proposed CO_2 injection zone and the base of the lowermost USDW.

Source of CO_2

Cranfield Site

The naturally occurring CO_2 for the Early Test will be provided by Denbury Resources' CO_2 pipeline from the Jackson Dome near Jackson, Mississippi. The source is commercially available, high purity, highly reliable, and low cost.

Citronelle Site

The CO_2 for the Anthropogenic Test will be supplied from a pilot unit capturing CO_2 from flue gas using amine capture technology from a 25 megawatt (MW) slipstream from Unit #5 of Southern Company's Plant Barry power plant.

Injection Operations

Injections will occur at a scale sufficient to successfully address issues of injection rate and cumulative injection impacts that may be factors in the design of future large-scale, commercial carbon storage deployments.

Cranfield Site

CO_2 from Jackson Dome is supplied to the Cranfield Site via pipeline and delivered to the center of Cranfield where the CO_2 is accurately measured at the purchase pump. Injection pressure is boosted to a constant 2,900 psi and the CO_2 distributed across the field via a buried pipeline system. Injection volumes and pressure is measured several times daily at each wellhead. Injection initiation was phased across the field. Injection began in the "High Volume Injection Test" (HiVIT) in a few wells in 2008 as part of the Validation Phase field project, and the 1 million metric tons per year rate for the HiVIT was obtained in December 2009 when the Detailed Area of Study (DAS) well injection rate was stepped up. The 1.5 million metric tons stored goal was reached in early 2011 (Figure 5). CO_2 injection for the Cranfield Site commenced in April 2009.

Figure 5– The Early Test's Detailed Area of Study.

Citronelle Site

The CO_2, once captured, will be dehydrated and compressed to approximately 2,000 pounds per square inch gauge (psig). It will be transported over a short distance (~12 miles) via 4-inch carbon steel pipe to the injection site at Citronelle, Alabama. Three new wells have been drilled for the project—a reservoir characterization well, a characterization/observation/backup injection well, and a dedicated CO_2 injection well. The fully integrated project began operations on August 20, 2012. As of October 29, 2013, more than 100,000 metric tons of CO_2 have been injected and stored at the site. In addition to the new wells, the project utilizes several existing oilfield wells surrounding the CO_2 injection site to monitor injection operations and to ensure public safety.

Simulation and Monitoring of CO_2

SECARB will adhere to a vigorous monitoring, verification, accounting (MVA) and assessment program during the 10-year Development Phase project. Each site will be well instrumented with multiple sensor arrays. For the Cranfield Site, sweep efficiency is monitored by saturation measurements along well bores, crosswell measurements, and vertical seismic profiling (VSP) and/or surface seismic methods. Proposed monitoring activities for the Citronelle Site includes: well bore integrity assessed through Ultrasonic Imaging Tool (USIT) logging, annular pressure monitoring, and tracer injection; assessment of areal extent of the plume through drilling and monitoring up-gradient wells, seismic surveys (3-D and VSP), and Reservoir Saturation Tool (RST) logs in observation wells; monitoring for formation leakage through RST logging and using the VSP geophones to map and trace potential CO_2 leakage; and potential CO_2 seepage through shallow subsurface monitoring for CO_2, carbon isotopes, and tracers. To help predict plume movement and assess the ultimate fate of the injected CO_2, the project team utilized Computer Modeling Group's GEM-GHG reservoir flow simulator.

Goals and Objectives

The primary objective of the DOE's Carbon Storage Program is to develop technologies to safely and permanently store CO_2 and reduce Greenhouse Gas (GHG) emissions without adversely affecting energy use or hindering economic growth. The Programmatic goals of Carbon Storage research are: (1) develop and validate technologies to ensure for 99 percent storage permanence; (2) develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness; (3) support industry's ability to predict CO_2 storage capacity in geologic formations to within 30 percent; and (4) developing Best Practices Manuals (BPMs) for monitoring, verification, accounting (MVA), and assessment; site screening, selection, and initial characterization; public outreach; well management activities; and risk analysis and simulation. SECARB's overall goal is to validate the efforts of the public outreach, research, and field activities implemented under the Characterization and Validation Phases. Specific objectives include:

- Conducting a large-volume, high-pressure injection field project that benefits from existing CO_2 infrastructure and reasonable CO_2 costs.
- Assessing the viability and logistics of injecting over 1 million metric tons (1.1 million tons) of CO_2 per year into a regionally significant saline formation in the Gulf Coast.
- Achieving a more thorough understanding of the science, technology, regulatory framework, risk factors, and public opinion issues associated with large-scale injection operations.

- Executing a geologic storage field project that covers all aspects of capture, separation, and storage, while fulfilling technical, regulatory, social, and economic considerations.

- Refining capacity estimates of the formation using results of the field project.

Accomplishments

Cranfield Site

Major field tests in Cranfield were completed by the end of January 2011, though monitoring operations are on-going. The remaining 2012 technical activities include data compilation, interpretation, intensive modeling, compilation of lessons learned, and application to next projects as well as long term pressure and soil gas, groundwater, and reservoir geochemistry. Public outreach and technical knowledge sharing remain focus areas also.

HiVIT (High Volume Injection Test):

- RITE installed six seismometers (Tokyo Sokushin three-component broadband geophone) 288 feet deep in an array of active, idle, and in-development parts of the field to collect continuous seismic data over the duration of the project. No local events have been detected

- A milestone of storing 1.5 million metric tons of CO_2 in the HiVIT was met early in 2011. As production increases in updip parts of the HiVIT, the volume stored will increase more slowly with time because of gas production and recycling. Current team efforts are focused on obtaining good quantification of recycle gas which is complicated by variable density because of entrained methane.

- Repeat 3-D seismic survey of HiVIT occurred in October 2012, including the DAS and adjacent areas including part of depleted gas cap. Image especially distribution of down-dip extent of CO_2.

DAS (Detailed Area Study)

- SECARB injection into brine leg below and east of oil-water contact started in November 2009 and is on-going. High frequency real-time CO_2 mass, bottom-hole injection well pressure, and temperature are being continuously monitored.

- High frequency real-time observation well parameters have been on-going since the start of the project, including bottom-hole pressure and temperature at the injection zone (before instrument failure), tubing pressure, and temperature at surface, casing pressure and temperatures, casing deployed bottom-hole pressure and temperature at the above-zone monitoring interval (AZMI).

Figure 6 - CO_2 injection well at Citronelle Site.

- On-going casing-deployed cross-well Electrical Resistance Tomography detects strong changes in conductivity believed to be attributed to replacement of brine by CO_2.

- Natural and introduced geochemical program with U-tube sampler was implemented between November 2009 - May 2010 to observe evolving flow field as plume matured and injection rate increased. Methane exsolved as CO_2 dissolved, which is an important indicator of CO_2-brine contact and dissolution. CO_2 developed preferred non-radial flow paths following sinuous channels.

- Maximum injection rates at field pressure (3,000 psi) were achieved between March and May 2011. Rates were limited by tubing diameter. Bottom-hole pressure remained stable and was not limiting injection rate.

- A repeat cross-well seismic tomography occurred in October 2010 in a three-well array, resulting in an imaged lateral variability in the plume.

- A repeat offset and walk-away VSP survey, as well as a 3D VSP survey was conducted in November 2010.

- Recovery of semi-permanent downhole instrumentations in December 2010 allowed the project team to troubleshoot several instrument failures in receiver strings for above-zone acoustic monitoring CASSM and bottom-hole pressure gauges and reinstall bottom-hole gauges and to assess U-tube component survivability.

- In 2012, 4D seismic analysis images CO_2. Signal is small compared to noise.

- In 2012, successful inversions of ERT data produce “movies” of daily changes in CO_2 saturation.

- Repeat reservoir fluid sampling in July 2013 showed subtle increase in reactivity and still small perturbation.

- Since 2011, microseismic data collection was performed by RITE with no local events detected.
- In 2013, geomechanical analysis extracts deformation signal from pressure response in above the AZMI.

Citronelle Site

- A major geologic characterization effort was conducted on the injection reservoir and confining units using existing well data. Detailed maps of the Paluxy Reservoir sand units and multiple overlying confining units were created."
- Drilling of the project's first characterization/observation well began in December 2010 and was completed in January, 2011. Reservoir data gathered from this well are being used to refine the geologic model, reservoir and simulation and injection operations. All observation and injection well drilling activities were completed by February 28, 2012.
- The Environmental Assessment prepared for the project to fulfill the requirements of the National Environmental Protection Act resulted in a Finding of No Significant Impact.
- The Underground Injection Control permit application was submitted to the Alabama Department of Environmental Management in December 2010. The ADEM UIC Class V Permit was issued on November 22, 2011. Permission to operate the injection pilot was requested from ADEM on April 2, 2012, and granted on August 8, 2012.
- A meeting was held in January 2011 with Det Norske Veritas (DNV) to begin assembly of the project's Risk Registry, documenting the risk assessment and risk mitigation strategies employed at the project site. The Risk Registry was reevaluated in June 2012 prior to injection and again in May 2013 after nine months of injection.
- The CO_2 stream from Plant Barry was sampled as baseline for injection on March 13, 2012.
- Completed all baseline MVA efforts by August 20, 2012.
- Began injection of CO_2 on August 20, 2012.
- Completed one year of CO_2 injection on August 20, 2013. The annual CO_2 injection totaled 75,133 metric tons.

Benefits

The lower Tuscaloosa Formation, which is representative of the Gulf Coast geology, could be used to store 50 percent of the CO_2 produced in the SECARB region during the next 100 years—an estimated 50 billion metric tons. The Gulf Coast Wedge includes the largest saline storage reservoir (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 billion metric tons. Using the range of reported capacity, the Gulf Coast Wedge can accommodate these emissions for approximately 300 to nearly 1,200 years, using capture and storage technologies. These volumes are sufficient to support commercialization of this CO_2 storage reservoir and demonstrate that CO_2 capture and sequestration can be a viable option for mitigating the region's GHG emissions.

NT42590, October 2013