THE SECARB ANTHROPOGENIC TEST: THE FIRST U.S. INTEGRATED CO_2 CAPTURE, TRANSPORTATION AND STORAGE TEST

Presented At
The 28th Annual International Pittsburgh Coal Conference
September 12-15, 2011

George J. Koperna, Jr.[1]*, Vello Kuuskraa, and David Riestenberg, Advanced Resources International, Inc.*
4501 Fairfax Drive, Suite 910, Arlington, VA 22203,
gkoperna@adv-res.com, vkuuskraa@adv-res.com, driestenberg@adv-res.com, 703.528.8420

Richard Rhudy and Robert Trautz, Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, CA 94304, rrhudy@epri.com, rtrautz@epri.com, 650.855.2421

Dr. Richard Esposito, Southern Company
600 North 18th Street, P.O. Box 264, Birmingham, AL 35203, raesposi@southernco.com, 205.257.6748

Dr. Jerry Hill, Southern States Energy Board
6325 Amherst Court, Norcross, GA 30092, hill@sseb.org, 770.242.7712, 770.242.9956

Abstract:

The United States Department of Energy (DOE) seeks to validate the feasibility of injecting, storing and monitoring CO_2 in the Earth's subsurface (geologic storage) as an approach to mitigate atmospheric emissions of CO_2. In an effort to "*promote the development of a framework and the infrastructure necessary for the validation and deployment of carbon sequestration technologies*," DOE established seven regional carbon sequestration partnerships (RCSPs), representing 40 States, 3 Indian Nations, 4 Canadian Provinces and over 150 organizations. The Southeast Regional Carbon Sequestration Partnership (SECARB), whose lead organization is the Southern States Energy Board (SSEB), represents 13 States within the south eastern United States of America (USA), and includes the core operating area of Southern Company (Alabama, Georgia, Mississippi, and the Florida Panhandle).

In the southeast USA, Advanced Resources International (ARI), in partnership with the SSEB, the Electric Power Research Institute (EPRI), and Southern Company, is participating in the DOE-RCSP Program, representing SECARB. This R&D project (the Anthropogenic Test) is an integral component of a plan by Southern Company, and its subsidiary, Alabama Power, to demonstrate integrated CO_2 capture, transport and storage technology originating at a an existing pulverized coal-fired power plant. The capture component of the test takes place at the James M. Barry Electric Generating Plant (Plant Barry) in Bucks, Alabama. The capture facility, equivalent to 25 MW, will utilize post-combustion amine capture technology licensed by Mitsubishi Heavy Industries America. CO_2 emissions captured at the plant will be transported by pipeline for underground storage in a deep, saline geologic formation within the Citronelle Dome, located in Mobile County, Alabama.

Starting in the fourth quarter of 2011, up to 650 tonnes of CO_2 per day will be captured and transported twelve miles by pipeline to the storage site for injection and subsurface storage. These transportation and injection operations will continue for two to three years. Subsurface monitoring will be deployed through 2017 in order to track plume movement in the deep subsurface and to monitor for leakage. This project will be one of the first and the largest fully-integrated commercial prototype coal-fired CCS projects in the USA. This paper will discuss the results to date, including permitting efforts, geologic data collection and analysis as well as detailed reservoir modelling of the storage site, framing the discussion in terms of the overall goals of the project.

Keywords: Carbon Sequestration; Paluxy Formation; Citronelle Dome; Permitting; Modeling; Monitoring

---

[1] Corresponding Author

Introduction

Commercial-scale CCS technology deployment for the electrical utility industry will require a robust international R&D program with governmental support both in cost-share and in risk management. In an effort to comply with environmental legislation or regulation related to CO_2, utilities hope to be in a position to make financial decisions on utility boiler sourced CCS technology and associated risk management by 2020.
The United States Department of Energy (DOE) seeks to validate the feasibility of injecting, storing and monitoring CO_2 in the Earth's subsurface (geologic sequestration) in the near-term as an approach to mitigate atmospheric emissions of CO_2. In an effort to "*promote the development of a framework and the infrastructure necessary for the validation and deployment of carbon sequestration technologies*," DOE established seven regional carbon sequestration partnerships (RCSPs), representing 40 States, 3 Indian Nations, 4 Canadian Provinces and over 150 organizations. The Southeast Regional Carbon Sequestration Partnership (SECARB), whose lead organization is the Southern States Energy Board (SSEB), represents 13 States within the south eastern United States of America (USA), and includes the core operating area of Southern Company (Alabama, Georgia, Mississippi, and the Florida Panhandle; **Figure 1**).

In the southeastern USA, Southern Company, in partnership with the SSEB, the Electric Power Research Institute (EPRI), and Advanced Resources International (ARI), is participating in the DOE-RCSP Program, representing the SECARB. In this program, a 3,000 tonne pilot injection into a saline reservoir was performed in 2008 at Mississippi Power Company's Plant Daniel generation facility, located in southeast Mississippi. This demonstration enabled the project team to gain valuable experience with site characterization, permitting, outreach & education, and the injection and monitoring of CO_2 into a saline reservoir.

Previous SECARB Phase II pilot-scale field tests in Mississippi, Alabama, and Virginia (in conjunction with numerous other sequestration field tests around the USA) have demonstrated the ability to safely inject and monitor CO_2 in coal seams, saline reservoirs, and depleted oilfields. The SECARB Phase III projects are now underway and consist of two parts; the early test, which is a large volume injection test utilizing natural CO_2 (associated with an enhanced-oil-recovery flood) located at the Cranfield Oilfield in Mississippi. The second part of this Phase III project, which is the focus of this paper, is a demonstration of integrated deployment of CO_2 capture, transport, and geologic storage technology for an existing pulverized coal-fired power plant.

The proposed large-scale capture, transportation and injection experiment, called the "Anthropogenic Test" is an integral component of a plan by Atlanta-based Southern Company, and its subsidiary, Birmingham-based Alabama Power, to demonstrate CO_2 capture and storage technology at the James M. Barry Electric Generating Plant (Plant Barry) in Bucks, Alabama utilizing capture technology licensed by Mitsubishi Heavy Industries America [1]. CO_2 emissions captured at the plant will be transported by pipeline for underground storage in a deep, saline geologic formation in the Citronelle Dome, located in Mobile County, Alabama (**Figure 1**). Southern Company, along with Mitsubishi Heavy Industries are funding and constructing a CO_2 capture facility at Alabama Power's 2,657-megawatt Plant Barry. Starting in the fourth quarter of 2011, up to 650 tonnes of CO_2 per day, the equivalent emissions from 25 MW of the plant's capacity will be captured for geologic storage. Transportation and injection operations will continue for up to three years, with subsurface monitoring deployed through 2017. This project will be one of the first and the largest fully-integrated pulverized coal-fired CCS projects in the USA.

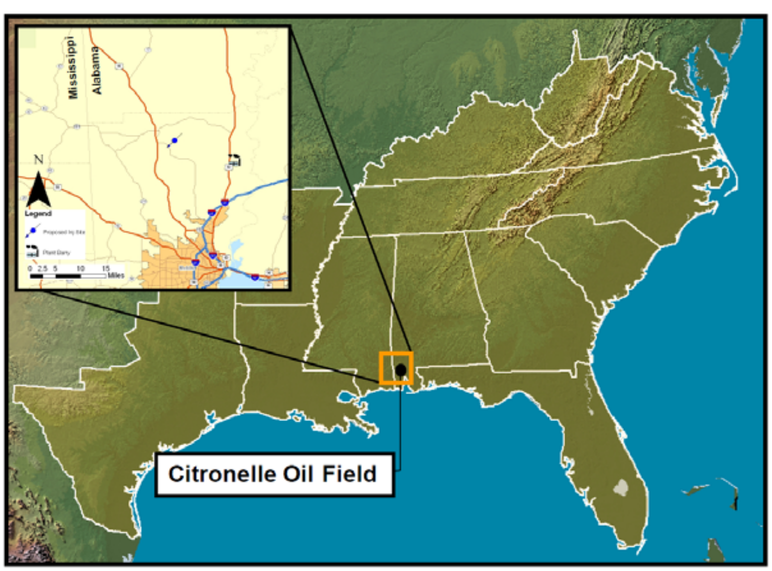

Figure 1: SECARB Partnership States are Outlined in White. The Inset Map Locates Plant Barry and the Injection Site

Project Design

Capture Technology. The technology to be deployed for capturing CO_2 from the power plant will be the Mitsubishi Heavy Industries (MHI) KM-CDR process, which utilizes the proprietary KS-1 solvent to achieve high levels of CO_2

retention with significant reductions in energy penalty from current technologies. The CO_2 capture and compression island will be a fully integrated and continuously operating unit, utilizing representative equipment and demonstrating MHI's approach for process scale-up, an optimized flow sheet, and improved unit operations within the base flow sheet. With an aggressive parametric test campaign, the project team expects to fully evaluate how the KM-CDR process will perform in utility service and collect the necessary data to develop a comprehensive process integration plan in preparation for the next phase of technology development. The process has been demonstrated at smaller scale at a coal-fired generating station in Japan, and is currently being deployed commercially on natural gas-fired systems around the world. This project represents the largest coal-fired demonstration of this technology in the USA with the plant designed to capture 650 tonnes per day.

Engineering and Procurement were completed in July 2010 and the the first shipment of components to Plant occurred in September 2010. The capture unit reached full operational capacity in June 2011 and is currently operating at full capacity.

Pipeline Transport. A 4-inch pipeline will be constructed that stretches approximately 12 miles (19 kilometers) from the outlet of the CO_2 capture facility to the point of injection at the Citronelle Oilfield. The fit-for-purpose pipeline will be constructed of standard API 5L X-65 grade pipe with wall thickness between 0.48 and 0.56 centimeters. The route will have a 6.5-meter wide permanent easement that parallels an existing electric transmission line and will cross nine landowners who possess significant tract acreages. Some of the larger tract owners include Alabama Power Company, a timber company, a bank managed land trust, and land owned fee simple by Denbury Onshore. The main route encounters an undulating terrain with upland timber, stream crossings, and a variety of wetland types that must be avoided or mitigated if openly crossed to minimize impact to the environment.

Geologic Storage. The project team focussed on choosing an injection site and storage reservoir in proximity to Plant Barry that had attractive characteristics for long-term and safe geologic storage of CO_2. Those characteristics included structural closure, a lack of significant faults/fracture zones, a porous and permeable injection target, and multiple overlying low permeability confining units between the injection zone and underground sources of drinking water (USDWs). The Citronelle Dome structure located to the west of Plant Barry near the town of Citronelle, Mobile County, USA met all of these criteria and was chosen as the storage test site. The geological characterization of the test site is detailed in the next section.

Geologic Assessment

The Cretaceous-age strata within the Citronelle Dome structure met all of the criteria necessary for safe, long-term geologic storage. Citronelle Dome is a giant salt-cored anticline in the Mississippi Interior Salt Basin of South Alabama [2-14]. The Citronelle oilfield lies at the crest of the dome and produces oil from the Cretaceous age Donovan sand. Recently, investigations of the geologic sequestration potential of the deep saline reservoirs in the area have been conducted, which have further characterized the dome [2, 13]. In January 2011 a characterization well was drilled near the test site from which extensive geologic data, including geophysical logs and whole and sidewall core, were acquired.

The dome is a gently-dipping elliptical-shaped structure with four-way closure, providing potential opportunities for both CO_2-enhanced oil recovery (EOR) in the Citronelle oilfield and large-capacity saline reservoir storage. Preliminary static CO_2 storage capacity estimates for the Citronelle Dome are about 1.7

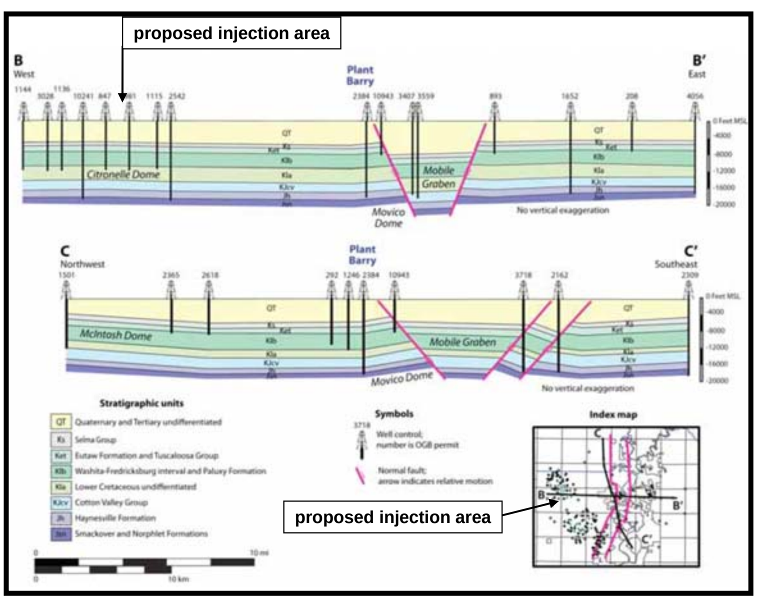

Figure 2: Structural Cross Sections Showing the Geometry of the Mobile Graben and Citronelle Dome (from Pashin et al., 2008[12])

billion metric tonnes [2]. Structural contour maps demonstrate that structural closure occurs in all Cretaceous and younger strata in the dome and the area of closure increases upward in section [2].

The proposed CO_2 injection site is located in the southeast flank of Citronelle Dome (**Figure 2**), within the boundaries of the unitized Citronelle oilfield. The producing oil reservoir at Citronelle is in the Cretaceous-age Donovan sand, which occurs beneath the injection target for CO_2 sequestration (the Paluxy Formation). The presence of an active oilfield at Citronelle provided high-density subsurface data for initial geologic characterization in the form of well logs.

Figure 2 shows two geologic cross sections generated as part of a regional assessment of CO_2 sequestration potential in southwestern Alabama [13]. The cross section B-B' shows the regional structural character from the Mobile Graben fault system to the east (where Plant Barry is located) across the Citronelle Dome to the west. Regional dip is less than one degree to the east-southeast towards the Mobile Graben. As such, the injected CO_2 will move updip from the injection site to the west-northwest towards the crest of the Dome. No significant faults associated with the Citronelle Dome have been identified in the geologic literature, existing surface seismic reflection data, or in the detailed characterization developed for this project [2, 13].

System	Series	Stratigraphic Unit	Major Sub Units	Potential Reservoirs and Confining Zones
Tertiary	Plio-Pliocene		Citronelle Formation	Freshwater Aquifer
	Miocene	Undifferentiated		Freshwater Aquifer
	Oligocene		Chicasawhay Fm.	Base of USDW
		Vicksburg Group	Bucatunna Clay	Local Confining Unit
	Eocene	Jackson Group		Minor Saline Reservoir
		Claiborne Group	Talahatta Fm.	Saline Reservoir
		Wilcox Group	Hatchetigbee Sand Bashi Marl Salt Mountain LS	Saline Reservoir
	Paleocene	Midway Group	Porters Creek Clay	Confining Unit
Cretaceous	Upper	Selma Group		Confining Unit
		Eutaw Formation		Minor Saline Reservoir
		Tuscaloosa Group	Upper Tusc.	Minor Saline Reservoir
			Mid. Tusc. — Marine Shale	Confining Unit
			Lower Tusc. — Pilot Sand Massive sand	Saline Reservoir
Cretaceous	Lower	Washita-Fredericksburg	Dantzler sand	Saline Reservoir
			Basal Shale	Primary Confining Unit
		Paluxy Formation	'Upper' 'Middle' 'Lower'	Proposed Injection Zone
		Mooringsport Formation		Confining Unit
		Ferry Lake Anhydrite		Confining Unit
		Donovan Sand	Rodessa Fm. 'Upper'	Oil Reservoir
			'Middle'	Minor Saline Reservoir
			'Lower'	Oil Reservoir

Figure 3: Stratigraphic Column for Southwest Alabama

Figure 3 shows a general southwest Alabama stratigraphic column that highlights regionally extensive Cretaceous through Tertiary-age saline reservoirs and potential confining units. The proposed injection target is the Paluxy Formation, a fluvial deposit containing 1,100 feet (355 meters) of interbedded sandstone, siltstone and shale, which occurs a depth of 9,400 feet below ground surface (3,030 meters) at the proposed injection site. **Figure 4** is a type log of the Paluxy from the project's characterization well (well D-9-8 #2). The log shows that the Paluxy Formation in the injection area can be subdivided into

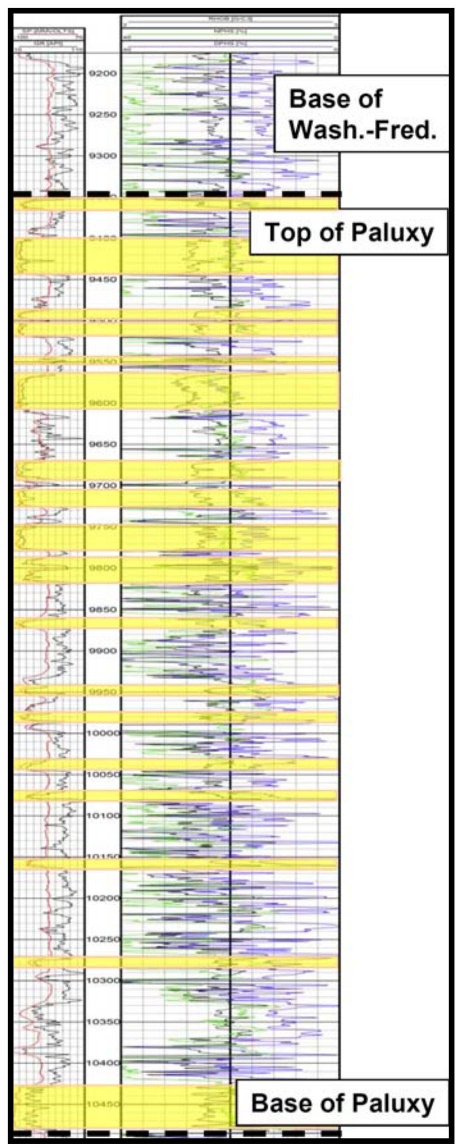

Figure 4: Paluxy Formation Type Log

twenty or more potential injectionintervals (highlighted in yellow). Individual sandstone units typically fine upward, and range in thickness from less than 10 feet to over 40 feet (3 meters to over 15 meters). Fine-grained and shaly strata occur between the sandstones contributing to both storage and the containment of injected CO_2. Overall, the abundance and thickness of individual sandstone bodies increases upward in the Paluxy Formation. Based on the analysis of D-9-8#2 whole and sidewall core and geophysical log data, ten of the thickest and most extensive upper Paluxy sands were selected for more detailed characterization and modeling, representing 210 feet (68 meters) or about 45% of the total net sand thickness in the Paluxy Formation (470 feet or 152 meters) [15]. Upper Paluxy sandstone porosities range from 10 percent to over 25 percent and permeabilities range from 1 millidarcy to over 3,000 millidarcies. Average porosity and permeability values for upper Paluxy sandstones are 19 percent and 200 millidarcies, respectively. Based on these characteristics, it appears that the Paluxy formation is quite capable of accepting the proposed CO_2 injection volume and can serve as a commercial CO_2 storage reservoir in the area.

The proposed confining zone for this CO_2 injection test is the basal shale of the Washita-Fredericksburg Formation. The Washita-Fredericksburg Formation is a coarsening-upward succession of variegated shale and sandstone [12]. Within the Citronelle Dome, the basal shale of the Washita-Fredericksburg interval is continuous, and has an average thickness of 150 feet (48 meters). This confining unit will be further characterized during the drilling of the project's injection wells through core collection and detailed log analysis.

Protected USDWs are defined by the Alabama Department of Environmental Management (ADEM) as aquifers that currently supply drinking water for humans or or contain water with total dissolved solids (TDS) content less than 10,000 mg/l (ADEM Admin. Coder. 335-6-8-.02). The base of the lowermost USDW in the Citronelle Field area occurs at an elevation of approximately -1,200 feet (-390 meters) below mean sea levels which corresponds to a depth of about 1,400 feet (450 meters) below ground surface [16]. Project wells will be surface-cased to a depth of 2,500 feet below ground surface, with full cement coverage.

Reservoir Modeling of the Injection Zone

The Computer Modeling Group's *GEM_GHG* geocellular and geochemistry based flow model was employed to describe the subsurface injection of CO_2 into the Paluxy Formation. Based upon interpretation of existing geophysical logs, available core data and published literature, a comprehensive description of the subsurface geology was developed for the test site. The geologic characterization effort also provided input parameters necessary for modeling the *in-situ* movement and fate of injected CO_2.

Primary input parameters for flow modeling included the thickness and elevation of the injection zone, the porosity and permeability of the injection zone, the structural dip at the reservoir horizon, the in situ reservoir pressure, and temperature, the estimated fracture pressure, the formation water properties, the CO_2-brine relative permeability curves and the injectate composition. As previously noted, eighteen Paluxy sandstones were selected for reservoir modeling. However, in an attempt to model the injection as realistically as possible, injection into only the eleven thickest sands was simulated. **Figure 5** shows a three dimensional image of the sand layers in the model.

The geophysical simulation results, based on the geologic and reservoir fluid information gathered to date, show that the Paluxy Formation has the capacity to accept the proposed injection volume of CO_2. The Paluxy Formation's thickness and permeability easily allow the injection of CO_2 for 3 continuous years into the 10 selected sandstone units of this brine-laden reservoir. From this injection simulation, several key findings were made:

1. The plume is slightly oval during the injection period (**Figure 6**).
2. The dip of the Paluxy Formation influences the migration of mobile CO_2 to a small degree after injection operations cease. However, the low angle of

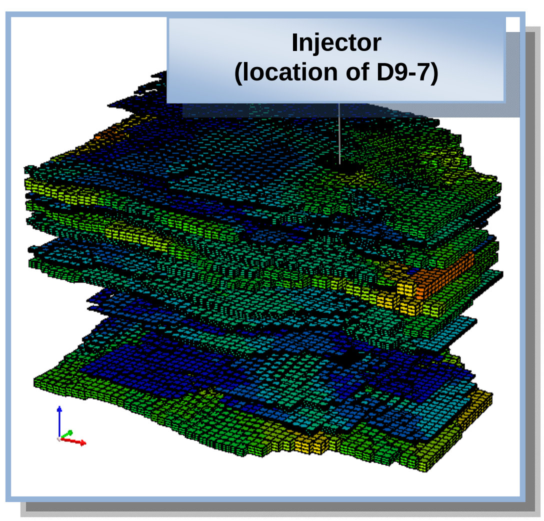

Figure 5: Three Dimensional View of the Model

dip (1.25 degrees) results in little post-injection updip migration (**Figure 6**).

3. The maximum movement of the CO_2 is less than 1,700 feet (550 meters) in any direction.
4. The high transmissivity of the Paluxy Formation results in a CO_2 plume extent that is greater than the extent of significant pressure build-up.
5. Injection into multiple sand layers and natural trapping mechanisms results in a plume of limited areal extent (approximately 200 acres or 0.8 square kilometers) ten years after injection operations have ceased.

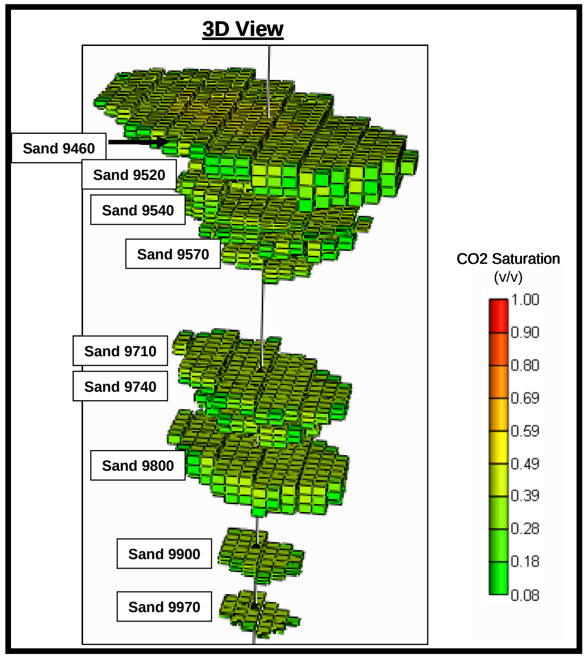

Figure 6: CO_2 Plume Development (t = __days___yrs)

CO_2 Monitoring, Verification, and Accounting (MVA)

The Anthropogenic Test MVA strategy is intended to mitigate risk and ensure the safety, integrity and information objectives of the CO_2 injection test by: (1) creating and sustaining wellbore integrity; (2) assuring safe CO_2 injection operations; (3) verifying the location and migration of the injected CO_2 plume; and (4) monitoring for any CO_2 leakage. In addition, a series of traditional reservoir characterization tools will be used to further support the MVA efforts. **Figure 7** shows the location of the wellbores that will be utilized for the MVA program.

Creating and Sustaining Injection Well Integrity. Leakage of CO_2 along a wellbore is the most likely vertical pathway for CO_2 migration from the injection zone into USDW's or to the ground surface. Cement bond evaluations will be conducted on the characterization and injection wells to ensure that good cement bond is present across the injection and confining zone intervals and that this bond continues up into the surface casing. Periodic internal mechanical integrity testing will be conducted on the injectors (regulated at once per year) to ensure that they remain in good operating condition throughout the CO_2 injection. Finally, injection tubing and annular pressure will be monitored at the wellhead to ensure external mechanical integrity throughout the injection.

Verifying the Location and Migration of the Injected CO_2 Plume. A variety of MVA methods, including in-zone and above-zone pressure, crosswell seismic, vertical seismic profiles, geophysical logging, in-situ fluid sampling, and temperature tools will be used to assess the extent of the CO_2 plume.

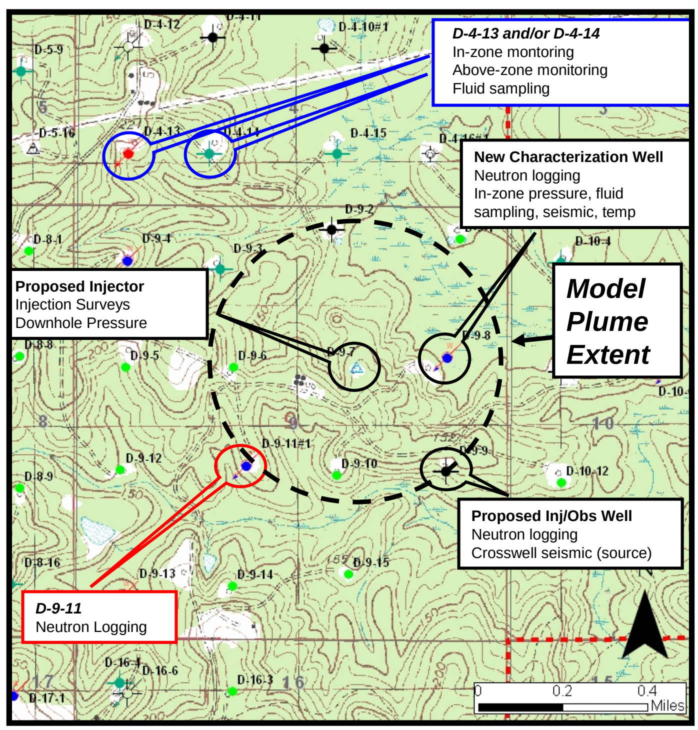

Figure 7: Location of Injection and Monitoring Wells Indicating Planned MVA Deployment

Monitoring in-zone and above-zone pressure serves two purposes. First, monitoring of the in-zone pressure provides direct evidence that the injection zone's permitted maximum injection pressure is not exceeded, mitigating the risk of fracturing the storage or sealing formation. Second, in-zone and above-zone (above the confining unit) pressure monitoring can provide indications of CO_2 migration and/or leakage. One or more existing updip Citronelle Oilfield wells will be used to monitor pressure within the injection interval and within a saline reservoir located above the confining unit. Seismic runs (vertical seismic and crosswell), logs (pulsed neutron), and fluid sampling will be conducted prior to CO_2 injection to establish baseline subsurface conditions. These tools will then be run in time-lapse during and after injection to monitor the changes in the reservoir conditions that occur as a result of the presence of CO_2 within the reservoir.

Shallow CO_2 Leakage Monitoring. Multiple surface monitoring methodologies will be deployed to monitor for shallow or surface CO_2 leakage. First, groundwater geochemical sampling will be utilized to monitor for CO_2 leakage into USDWs. Groundwater monitoring will focus on metals that have EPA defined primary and secondary maximum contaminant levels (MCLs). Additional geochemical measurements that will be made include pH, alkalinity, and sulfate concentrations. Groundwater wells, located near the injection well, will be completed in shallow and deep USDWs and will be used to sample the groundwater chemistry. Monitoring of groundwater geochemistry in one or more offset groundwater wells will also be conducted. Pre-injection sampling will establish baseline groundwater conditions.

A second surface monitoring method proposed for the test is the monitoring for the presence of perfluorocarbon tracers (PFTs) injected with the CO_2 stream. The PFTs are expected to remain in the CO_2 phase and can be detected at multiple orders of magnitude lower concentrations than CO_2. Surface monitoring for the presence of PFTs will occur at various points near the injection site including nearby existing and new deep wellsites. Finally, soil CO_2 flux will be measured at selected locations in and around the injection site in time-lapse to monitor for anomalous increases on CO_2 output.

Permitting

Capture Facility Permitting. The Alabama Department of Environmental Management (ADEM) requires an air permit to control and release emissions. Since the Plant Barry carbon capture project includes processes that will control emissions and potentially create new emission points, the project requires an air permit. The project also needed to modify the continuous emissions monitoring systems on the unit providing the slip-stream flue gas (Barry unit 5) due to the carbon capture process.

Transportation Permitting. Impacts to wetlands during construction are universally governed by the Army Corps of Engineers (CoE). The CoE's authorization is necessary because the project involves the placement of materials into waters of the U.S., including wetlands under the Corp's regulatory jurisdiction. A permit will be required for the 4-inch pipeline to cross approximately 61,000 square meters (15 acres) of wetlands along the route and for the construction of the injection site. The wetlands types include open water, scrub/shrub, and forested environments. This permitting process involves preparation of drawings and documentation to support the proposed methods of crossing wetlands within the path of the pipeline. Construction methods available include horizontally drilling under a wetland or "open cutting" where vegetation is removed and silt/storm-water management structures are employed to limit impacts to water quality. Open cutting is typically completed when a drill cannot be utilized due to technical difficulties.

In addition to wetlands, the route will encounter the endangered Gopher Tortoise, which is drawn to the open, sandy terrain near the longleaf pines typical in the vicinity of the habitat of the Plant Barry. Since the pipeline route follows a well maintained transmission easement for the majority of the route, the presence of tortoises was a strong possibility. Environmental surveys along the route encountered over 30 tortoise burrows within the proposed 40 foot (13 meter) construction easement and an additional 20 species within 8 meters of the proposed pipeline construction areas. The Fish & Wildlife Service (FWS) requires an extensive review and permitting process when construction has the potential to impact the tortoise. Similar to crossing of wetlands, horizontally drilling under the tortoises is an option that minimizes impact to individual and colonies of tortoises. Other options include directing tortoise movement away from active construction areas or temporarily relocating individuals using a federally-licensed contractor. Permitting for wetlands and gopher tortoises began in April 2011 and was completed in August 2011. Construction of the pipeline and measurement facilities should commence during the third quarter of 2011 and take approximately 6-8 weeks.

Storage Permitting. A significant portion of the project team's effort leading up to well drilling and injection operations has been permitting storage activities. Three critical permits are required for the well drilling and CO_2 injection portion of the project: 1) a USDOE-NEPA-approved Environmental Assessment (EA); 2) an ADEM underground injection control (UIC) permit; and 3) the Army Corps of Engineers permit governing wetland impacts. The purpose of these permits is to ensure that all of the project's subsurface operations, including well drilling, injection, and monitoring, are done in a manner that will not negatively impact the environment and protected drinking waters (USDWs). The NEPA process began in early 2010 with the assembly of an EA of the CO_2 storage effort. The EA covered the environmental effects of the project (including air quality, surface and subsurface water, land and wildlife impacts), socioeconomic impacts, and cultural resources impacts. After determining that the project's activities will not have significant environmental consequences or cultural impacts, the DOE issued a Finding of No Significant Impacts (FONSI) in March 2011 The UIC permitting process began in late 2009 and is expected to be completed in the third quarter 2011, after a public review period. The CO_2 injection wells will be permitted under the Class V Experimental Injection Well rules. However, several components of the permit application are designed to meet and test components of the recent EPA Class VI CO_2 Sequestration Well classification. Some of these items include periodic Area of Review updates based on updates to the reservoir model and monitoring efforts, a large MVA effort including surface CO_2 monitoring, monitoring of the injection and wellbore annular pressure, and frequent injection stream compositional monitoring. Finally, the CoE wetlands permit, discussed in the Transportation Permitting section, covers potential impacts resulting from well drilling and injection site construction operations. Once these three processes are completed, injection well drilling operations may commence.

Integrated Test Plan

MHI's advanced amine capture technology, while a proven small-scale success, has not been tested at the 25 Megawatt level. Therefore, numerous parametric tests will be undertaken to rigorously put this technology through its paces. As part of this testing protocol, there will be planned variations in the volume of flue gas processed by the capture system, which in turn will proportionately impact the supply of CO_2 available for transport and storage. These variations are expected to occur over matters of hours, with the capture rate ranging from 40% to 100% of process capacity. This may put additional operating constraints on the transportation and storage components of the integrated system due to the resultant variable CO_2 rates, pressures and temperatures, emphasizing the need to coordinate design and test specifications between the capture and storage teams. A direct result of this coordination is the need to have a variable-speed injection pump at the injection site to appropriately handle the range in CO_2 injection volumes.

With CO_2 volumes varying within a 24 hour period from 200 tonnes to over 600 tonnes per day, the effects of the proposed tests on the capture unit may result in dynamic transportation operations. Maintaining a liquid phase in the pipeline during changes in unit pressure, temperature, or compositional output will require active management of the pipeline's pressure, volume and temperature (PVT) conditions. Likewise, PVT conditions at the injection pump will have to be actively managed in order to maintain a dense CO_2 phase (liquid or supercritical phase) and to ensure the equipment operates efficiently.

During the testing of the capture facility, it is likely that there will periods of downtime during which the capture facility will not be operational, providing the first insights into the impacts of CO_2 supply downtime on transport and injection operations. Management of these periods will be crucial to ensure consistent phase behavior throughout the system as well as minimizing CO_2 residency at key junctures in the system. These downtime periods should also provide opportunities for routine safety inspections of the transportation and injection systems and for the collection of downhole transient data in the injection and observation wells, which should be useful for understanding the pressure behaviour in the storage reservoir during injection and pressure falloff periods.

Summary

The "Anthropogenic Test" stands to be the largest demonstration of a fully-integrated pulverized coal-fired CCS project in the United States to date, pulling together components of capture, transportation, subsurface storage and MVA. As a first-of-its-kind demonstration, this test will be very important for understanding the still as yet undefined challenges power plant capture can present to the emerging field of geologic CO_2 storage.

The demonstration is currently in the permitting and testing phase. The capture unit reached full operational capacity in June 2011 and is currently operating at full capacity. The project team has performed a baseline examination of the subsurface geology, which was uniquely detailed due to the numerous geophysical logs available from existing Citronelle oilfield well penetrations. A characterization well, drilled in January 2011 provided modern core and geophysical logs data which were used to construct a detailed reservoir model. A robust MVA plan has been set forth to monitor and track the CO_2 plume's movement in the subsurface. Perhaps most importantly, this novel integrated research and demonstration project is examining the multiple permitting pathways required for large-scale integrated storage projects in the United States.

Acknowledgement

Denbury Resources, owner and operator of Citronelle field, is gratefully acknowledged for their essential contribution to the CO_2 storage demonstration. This paper is based upon work supported by the Department of Energy National Energy Technology Laboratory under DE-FC26-04NT42590. This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favouring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

References

1. Esposito, R., Rhudy, R., Trautz, R., Koperna, G., and Hill, J.; "Integrating Carbon Capture with Transportation and Storage", GHGT-10 Proceedings, 2010.

2. Esposito R.A., Pashin J.C., Walsh, P.M.; "Citronelle Dome: A Giant Opportunity for Multi-Zone Carbon Storage and Enhanced Oil Recovery in the Mississippi Interior Salt Basin of Alabama", Environmental Geosciences, v 15, p. 53-62, 2008

3. Eaves, E.; "American Association of Petroleum Geologists Memoir 24", p. 259-275, 1976.

4. Mancini, E.A., and Benson, D.J.; "Regional Stratigraphy of the Upper Jurassic Smackover Carbonates of Southwest Alabama", Gulf Coast Association of Geologic Societies Transactions, v.30, p. 151-165, 1980.

5. Mancini, E.A., Mink, R.M., Bearden, B.L., and Wilkerson, R.P.; "Norphlet Formation (Upper Jurassic) of Southwestern Alabama", AAPG Bulletin, v. 71, p. 1128-1142, 1985.

6. Esposito, R.A., and King, D.T.; "Facies Analysis, Sea Level History and Platform Evolution of the Jurassic Smackover Formation, Conecuh Basin, Escambia County, Alabama", Gulf Coast Association of Geological Societies Transactions, v. 37, p. 335-346, 1987

7. Mancini, E.A., Mink, R.M., Payton, J.W., and Bearden, B.L.; "Environments of Deposition and Petroleum Geology of Tuscaloosa Group (Upper Cretaceous), South Carlton and Pollard Fields, Southwestern Alabama", American Association of Petroleum Geologists Bulletin, V71, No 10, p 1128-1142, 1987.

8. Bolin, D.E., Mann, S.D., Burroughs, D., Moore, H.E. Jr., and Powers, T.L.; "Petroleum Atlas of Southwest Alabama", Alabama Geological Survey Atlas 23, 1989.

9. Raymond, D.E.; "The Lower Cretaceous Ferry Lake Anhydrite in Alabama, Including Supplemental Information on the Overlying Mooringsport Formation and Petroleum Potential of the Lower Cretaceous", Alabama Geological Survey Circular 183, 1995.

10. Pashin, J.C., Raymond, D. E., Alabi, G.G., Groshong, R. H., Jr., and Guohai Jin; “Revitalizing Gilbertown Oilfield: Characterization of Fractured Chalk and Glauconitic Sandstone Reservoirs in an Extensional Fault System”, Alabama Geological Survey Bulletin 168, 81 p., 2000.

11. Kopaska-Merkel, D.C.; “Jurassic Cores From the Mississippi Interior Salt Basin, Alabama”, Alabama Geological Survey Circular 200, 2002.

12. Esposito, R.A., Pashin, J.C., Hills, D.J., and Walsh, P.M.; “Geologic Assessment and Injection Design for a Pilot CO_2-Enhanced Oil Recovery and Sequestration Demonstration in a Heterogeneous Oil Reservoir: Citronelle Field, Alabama, USA”, Environmental Earth Sciences, v. 60, n. 2, 431-444. 2010

13. Pashin, J.C., McIntyre, M.R., Grace, R.L. B., Hills, D.J.; “Southeastern Regional Carbon Sequestration Partnership (SECARB) Phase III, Final Report”, Report to Advanced Resources International by Geological Survey of Alabama, Tuscaloosa, September 12, 2008.

14. Mancini, E.A. and Puckett, T.M.; “Jurassic and Cretaceous Transgressive-Regressive Cycles, Northern Gulf Of Mexico, U.S.A.”, Stratigraphy, v. 2, p. 30-47, 2005.

15. Petrusak, R., Riestenberg, D., and Cyphers, S.; “Core and Log Analyses for Reservoir Characterization of the Paluxy Formation at Citronelle Dome for the Southeast Regional Carbon Sequestration (SECARB) Partnership Phase III Anthropogenic Test”, Proceedings of the 10th Annual Conference on Carbon Capture and Sequestration, May, 2011.

16. Gillet, B., Raymond, D.E., Moore, J.D., and Tew, B.H. Hydrogeology and Vulnerability to Contamination of Major Aquifers in Alabama: Area 13. Prepared by the Geological Survey of Alabama in cooperation with the Alabama Department of Environmental Management, 2000.