The SECARB Anthropogenic Test: CO_2 Capture/Transportation/Storage

Project # DE-FC26-05NT42590

Jerry Hill, Southern Sates Energy Board
Richard A. Esposito, Southern Company

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National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and Building the Infrastructure for CO_2 Storage
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Presentation Outline

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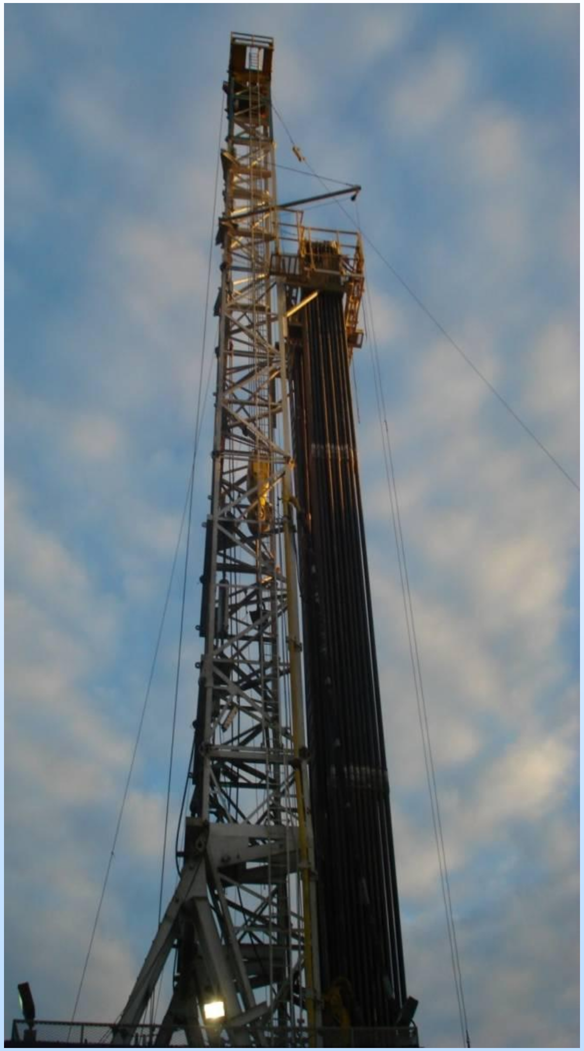


Benefit to the Program

1. Predict storage capacities within +/- 30%

- Conducted high resolution reservoir characterization of the Paluxy saline formation key reservoir parameters for calculating CO_2 storage capacity.
- Incorporated geologic model of the Citronelle Dome/Paluxy Formation CO_2 storage site into a state-of-the-art reservoir simulator to predict storage capacity and CO_2 plume.
- Established extensive subsurface monitoring to measure areal extent of CO_2 plume and actual CO_2 storage capacity.

2. Demonstrate that 99% of CO_2 is retained

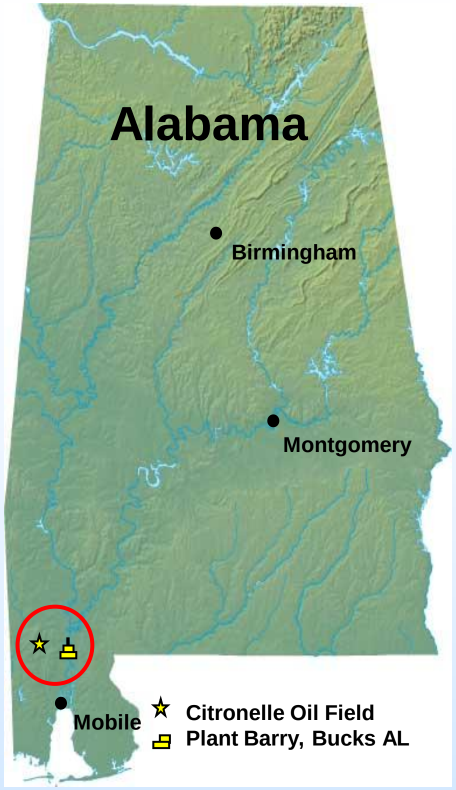
- Selected CO_2 storage site with 4-way closure, multiple confining units and secondary storage horizons.
- Reservoir characterization completed to identify residual CO_2 phase (pore space trapping), CO_2 dissolution in water; completed seismic- and log-based assessment of the integrity of the reservoir caprock.
- Established within and above zone pressure monitoring systems, CO_2 tracer programs, multiple cross-well seismic shoots and repeated use of cased hole neutron logging.

3. Conduct Field Tests supporting the development of Best Practices Manuals

- Served on the Review Board of the DOE/NETL Drilling Manual; edited the DOE/NETL Reservoir Simulation Manual; and wrote chapter on CO_2 leakage mitigation for California report on CCS.

Project Overview

- Fully integrated capture, transport and storage project
- Construct and operate a 25 MW (182,500 Mt) equivalent CO_2 capture unit at Alabama Power Plant Barry
- Construct and operate a pipeline that will transport CO_2 from Plant Barry to a saline formation in Citronelle Dome
- Inject > 200,000 metric tons of CO_2 into a saline reservoir over a period of 2 years
- Conduct 3 years of monitoring after CO_2 injection is concluded and then close the site

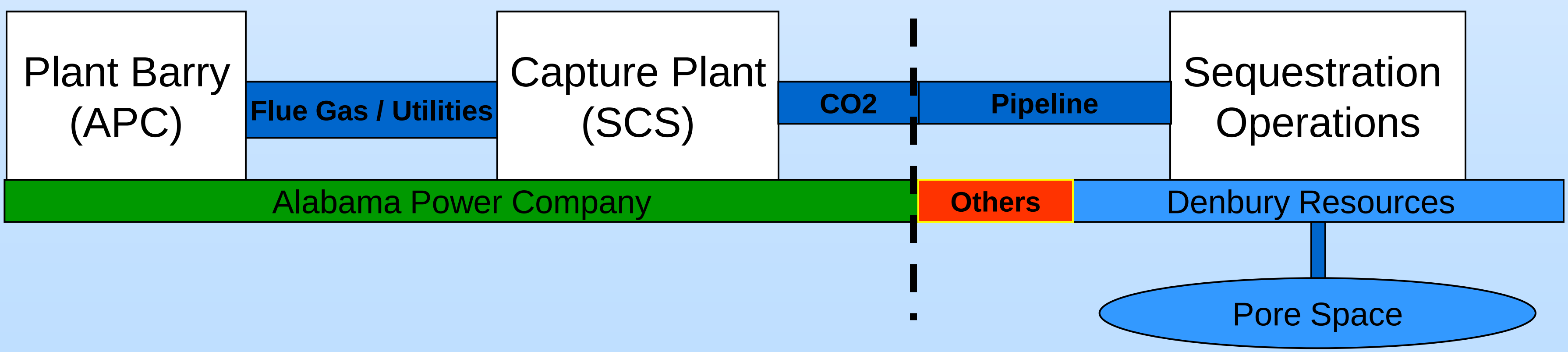


Capture Project

- SO collaborating with MHI
- Location: APC's Plant Barry
- Execution/contracting: SO

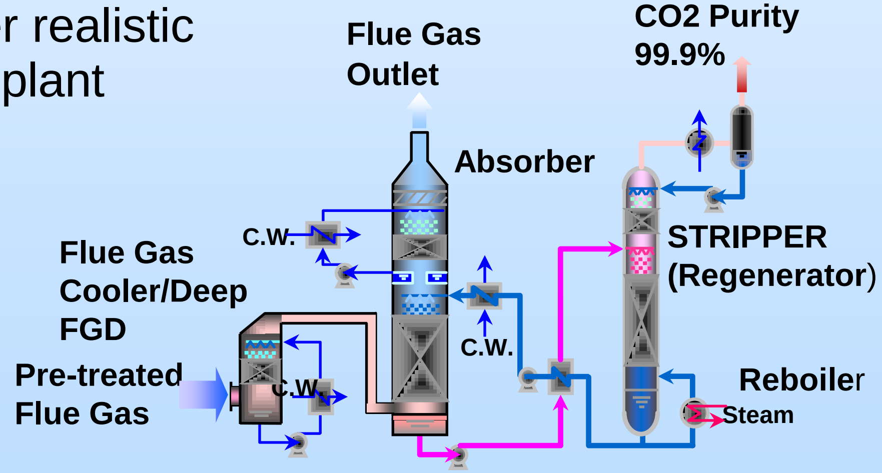
Sequestration Project

- Project: DOE's SECARB Phase III
- Prime contractors: SSEB and EPRI
- CO_2 : SO supplying
- Sequestration: Denbury Citronelle Field



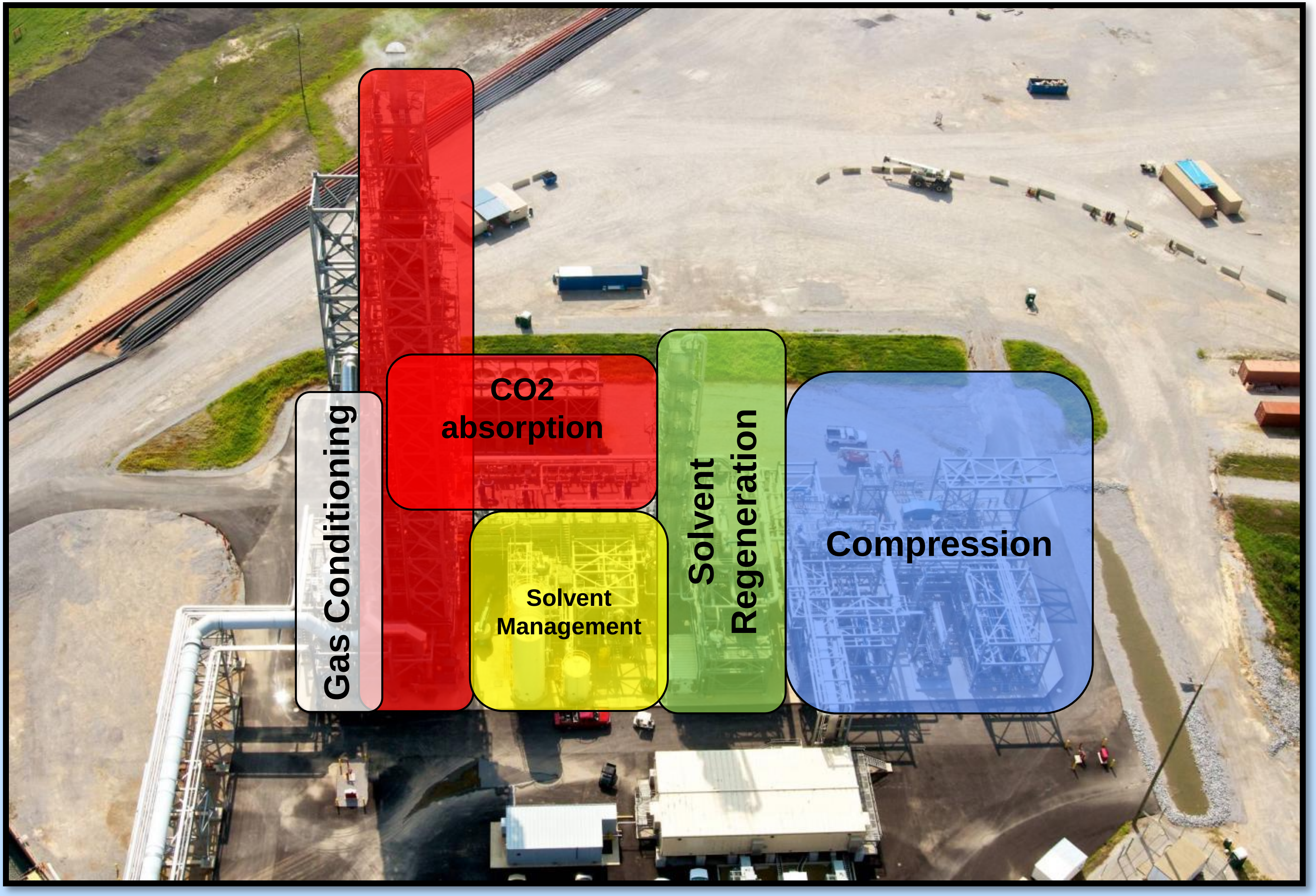
Capture Scope & Objectives

- **Project Scope:**
  - Demonstrate post-combustion capture of CO_2 from flue gas using MHI's advanced amine process
- **Project Philosophy:**
  - Fully representative of full scale design
  - Establish and demonstrate a contracting and execution strategy
  - Operation and maintenance in realistic conditions
  - Establish strategy for future commercial projects
- **Project Objectives:**
  - Demonstrate integrated CO_2 capture under realistic operating conditions typical of a coal-fired plant
  - Establish values for the energy penalty
  - Test reliability of solvent-based capture
  - Source CO_2 for injection demonstration



Simplified schematic post-combustion solvent process

25MW, 500 TPD Demonstration




11/04/2010

Capture Plant Update

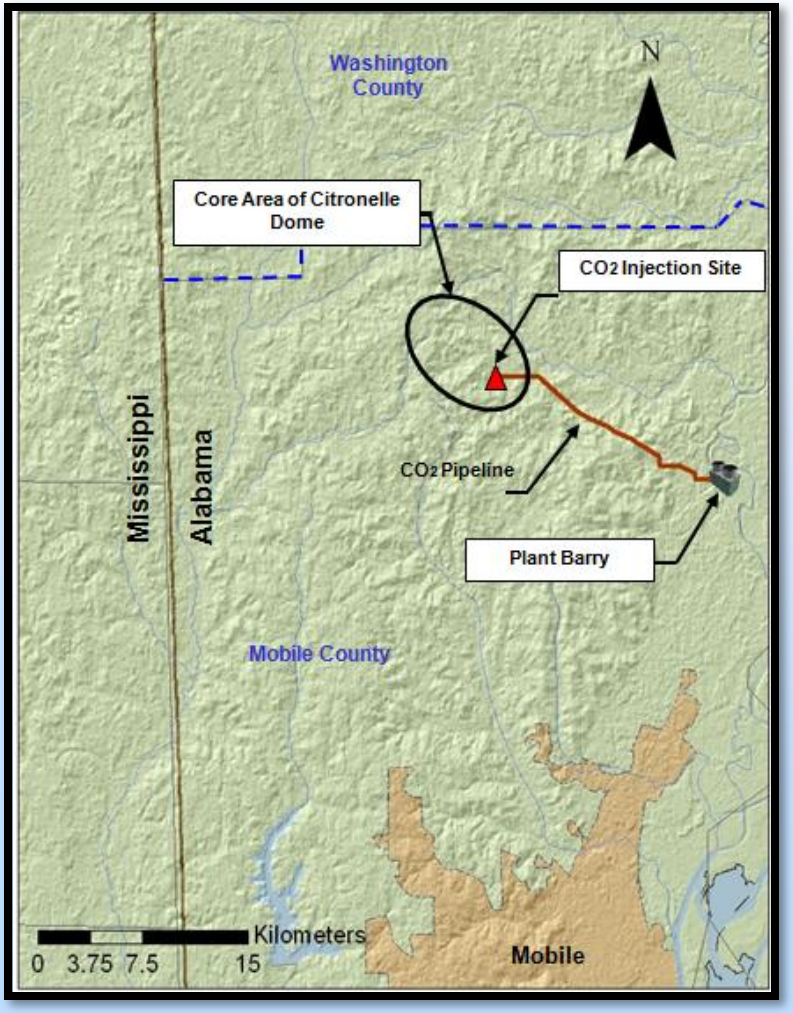
2010

2012

Capture plant & compressor started operations on June 4, 2011 with 70,000 metric tons CO_2 captured to date.

CO_2 Pipeline Overview

- Approx. 12mi (19km) to the SE operators unit in Citronelle Field
- Pipe specifications
  - 4-in (10cm) pipe diameter
  - X42/52 carbon steel
  - Normal operating pressure of 1,500 psig (10.3 MPa)
  - DOT 29 CFR 195 liquid pipeline; buried 5 feet with surface re-vegetation and erosion control



- Denbury pipeline purity requirement:

  > 97% dry CO_2 at 115ºF (46ºC)

  < 0.5% inerts (including N_2 & argon)

  < 30 lb water per 1MMSCF

  < 20 ppm H_2S

Pipeline Right-of-Way

- Right-of-Way Ownership
  - 1¼ mi (2 km) inside Plant Barry property
  - 8 mi (13 km) along existing power corridor
  - 2 mi (3 km) undisturbed forested land
  - Permanent cleared width 20 ft (6 m)
  - Temporary construction width 40 ft (12 m)
- Right-of-Way Habitat
  - 9 mi (14.5 km) of forested and commercial timber land
  - 3 mi (5 km) of emergent, shrub, and forested wetlands
  - Endangered Gopher Tortoise habitat
    - 110 burrows in or adjacent to construction area

DOT 29 CFR 195 liquid pipeline; buried 5 feet with surface vegetation maintenance

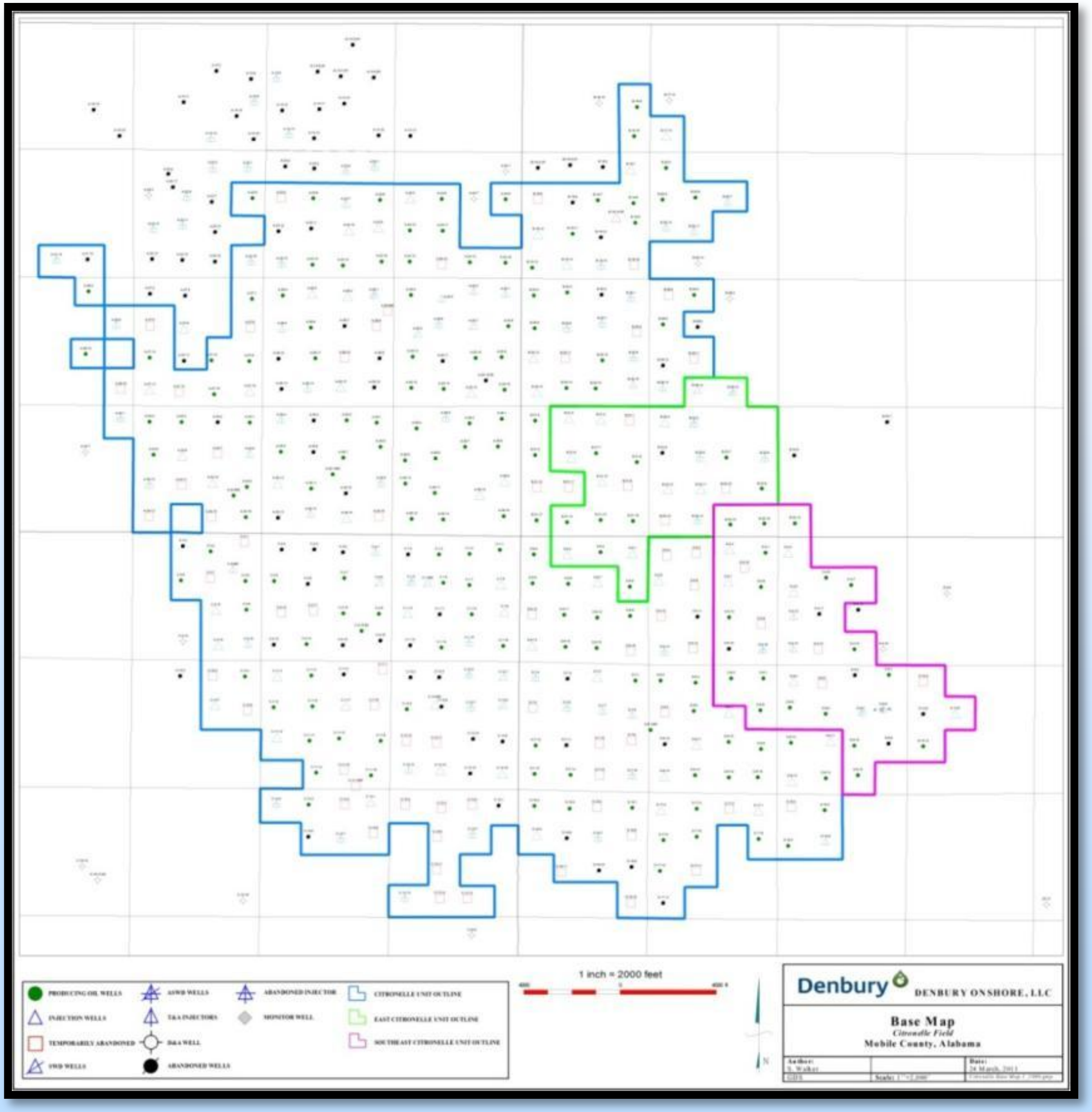
Directional drilled 18 sections of the pipeline under roads, utilities, railroad tracks, tortoise colonies, and wetlands (some up to 3,000 feet long and up to 60 ft deep).

Storage Scope & Objectives

- **Scope:**
  - Demonstrate safe, secure CO_2 injection and storage in regionally significant saline reservoirs in the southeast U.S. region
- **Objectives:**
  - Perform risk registry and assessment
  - Evaluate local storage capacity, injectivity and trapping mechanisms
  - Test the adaptation of commercially available oil field tools and techniques for monitoring CO_2 storage
  - Permit pipeline and injection, stakeholder acceptance through outreach & education

NETL SECARB Southeast Regional Carbon Sequestration Partnership EPRI Denbury Advanced Resources International, Inc. SOUTHERN COMPANY

Citronelle Field – Basic Facts



- Citronelle Field located in & around the City of Citronelle located on the crest of Citronelle Dome
  - Approx. 1 hour north of Mobile, AL
- Field is comprised of 3 active units: Main, East & Southeast
- There are 423 wells in the 3 Denbury operated units
  - 168 active producers
  - 62 active water injectors
  - 7 SWD wells
  - 93 TA/TP wells
  - 88 plugged wells
  - 5 SECARB wells
- Denbury took over operations on Feb. 1, 2006 from Merit Energy

Citronelle Dome Stratigraphy

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

Tertiary Injection Zone
(Eutaw Fm.)

Secondary Injection Zone
(Tuscaloosa Fm.)

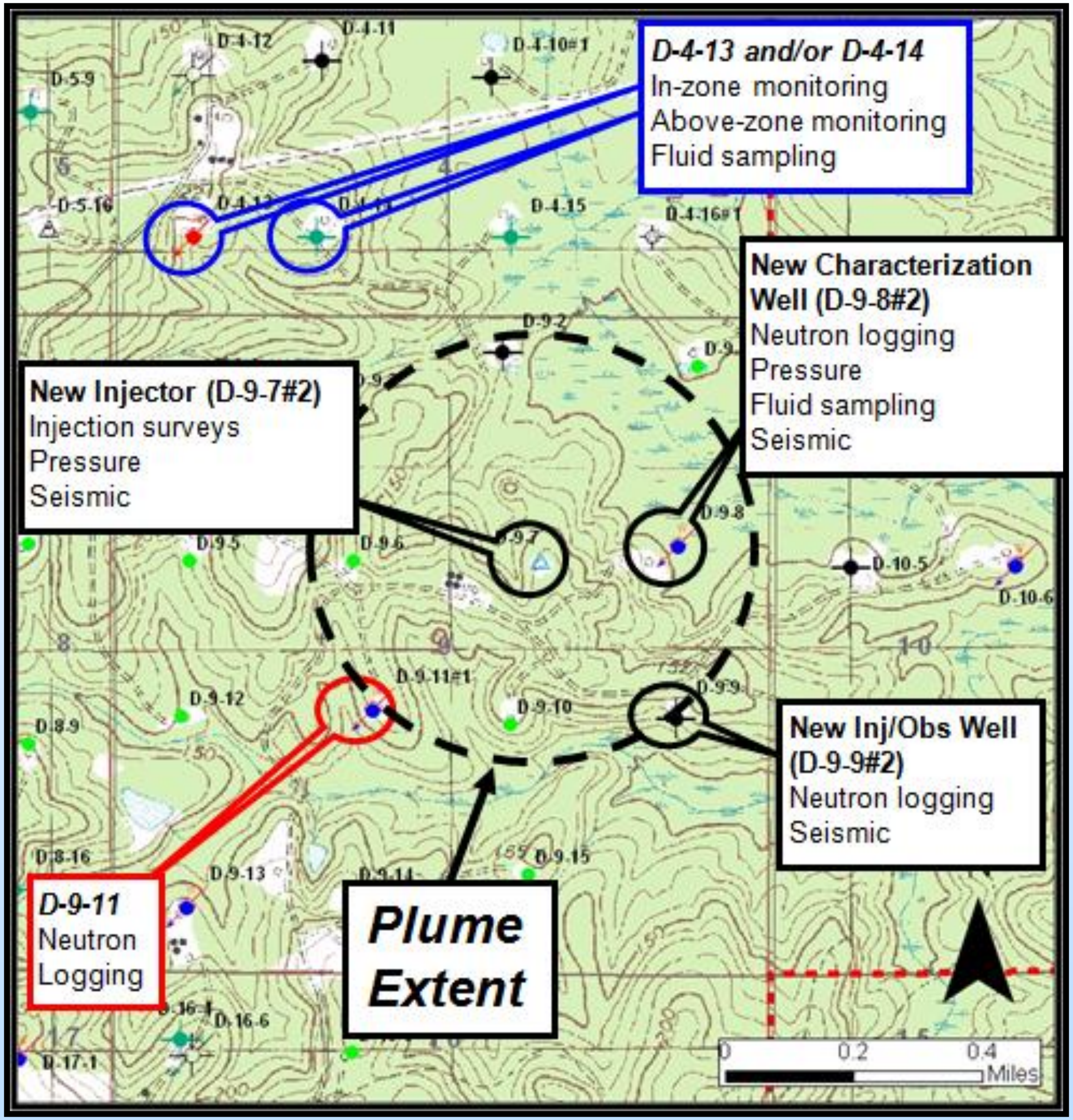
Proposed Injection Zone
(Paluxy Fm.)

Stacked Storage Reservoirs
with Multiple Seals
and Four-Way Closure

Injection Zone Characteristics

Top Depth (ft, log)	Gross Sand Thickness (ft)	Net 'Clean Sand' Thickness (ft)	Log Porosity (%)	Sidewall Core Porosity (%)	Permeability (md) *from porosity - permeability cross plot*
9,437	**41**	**36**	**20.9**	**21.3-21.9**	**450**
9,507	**20**	**11**	**20.3**	**21.6**	**360**
9,531	**18**	**13**	**18.6**	**n/a**	**190**
9,560	**23**	**9**	**19.0**	**n/a**	**220**
9,594	41	38	20.0	18.4-23.0	320
9,656	23	4	17.4	n/a	120
9,695	**24**	**21**	**18.9**	**18.6-19.8**	**210**
9,729	**20**	**13**	**19.2**	**19.2-21.2**	**230**
9,771	**36**	**27**	**16.9**	**16.0-19.2**	**100**
9,830	12	6	16.6	n/a	90
9,881	**22**	**10**	**17.7**	**16.3**	**130**
9,954	**23**	**3**	**13.7**	**n/a**	**30**
10,014	11	6	16.9	n/a	100
10,034	13	8	19.5	n/a	260
10,091	16	10	16.7	n/a	90
10,118	15	11	15.5	n/a	60
10,297	17	7	14.7	n/a	40
10,356	20	5	14.0	n/a	30
10,392	17	1	14.7	n/a	40
10,454	**30**	**13**	**15.9**	**n/a**	**70**
10,487	28	17	15.6	n/a	60
	Total Gross Thickness: 470	**Total Net Thickness: 263**	**Weighted Average: 18.2**		**Weighted Average: 208**

Monitoring Program



The test will use 5 deep wells to track the CO_2 plume and 3 shallow water monitoring wells.

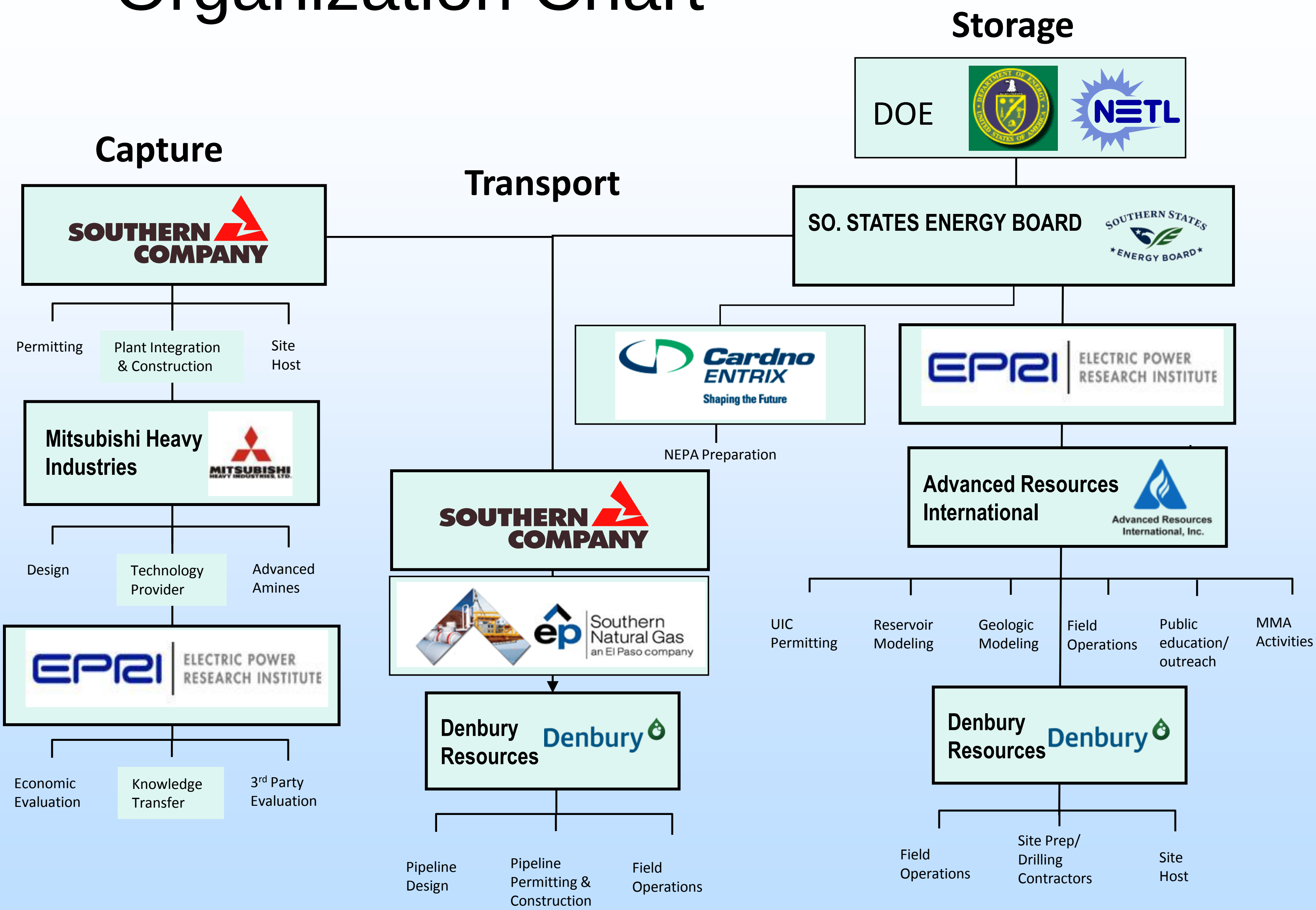
- Deep reservoir fluid sampling.
- In-zone and above-zone pressure and temperature monitoring.
- Cased-hole neutron logging.
- Crosswell seismic and VSP.
- Surface soil flux and tracer surveys

Results will be used to update the reservoir model and UIC Area of Review.

Accomplishments to Date

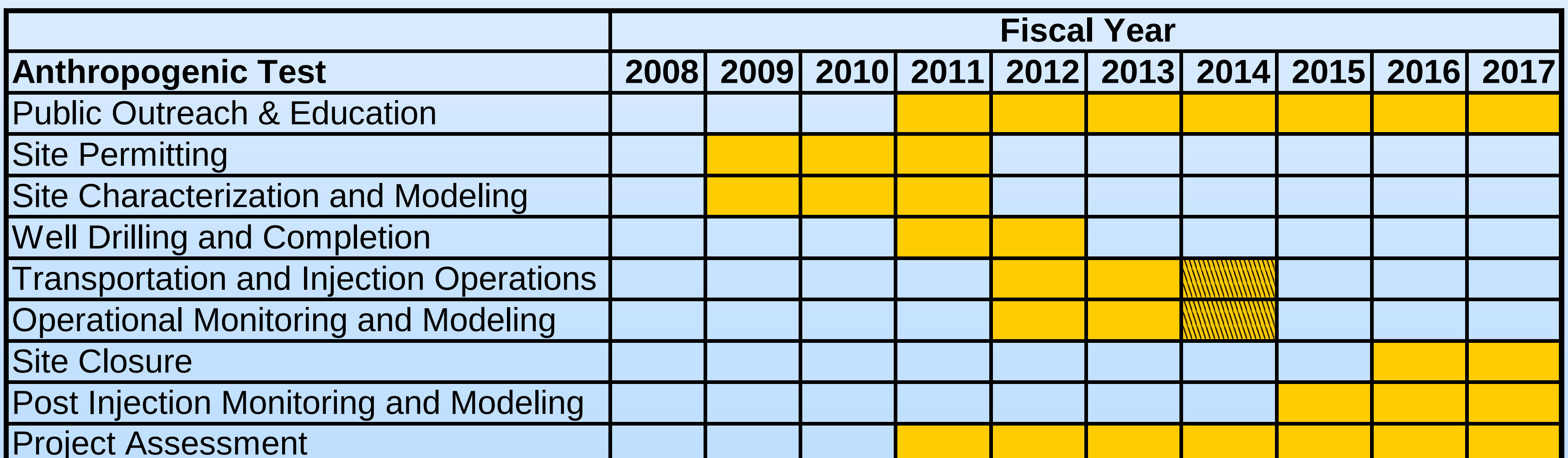
- Design, construction, and operation of the world's largest carbon capture on a coal fired power plant with over 72,000 metric tonnes of CO_2 captured to date.
- Design, permitting, construction, commissioning, and operation of a 12 mile CO_2 pipeline.
- Development of a sequestration demonstration including site characterization, detailed geologic analysis, MVA infrastructure, and well construction.
- Integration of CO_2 injection operations with pipeline transport and capture unit operations.
- MVA baseline monitoring including significant experimental/innovative technologies such as the modular borehole monitoring tool.
- First of a kind permit received for injection of CO_2 in the SE USA for geologic sequestration.

Organization Chart



Gantt Chart

- Baseline monitoring began in late 2011
- Permission to inject received on August 8, 2012
- CO_2 injection operations begin on August 20, 2012, continue for 2 years
- 3 years of post-injection monitoring, then close site



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Lessons Learned

1. Planning and operating a fully integrated, commercial prototype CO_2 capture, transportation and storage project requires extensive negotiations and flexibility in plans and schedules.

Accomplishment. The Anthropogenic Test storage team adapted its schedule and managed its activities to match the Alabama Power's CO_2 capture schedule and Denbury Resource's CO_2 transportation schedule.

2. Selecting and gaining approval for a high quality, regionally significant saline formation for storing CO_2 is a major challenge.

Accomplishment. The Anthropogenic Test storage team identified and gained access to the regionally extensive, low risk but geologically challenging Paluxy saline formation for storing CO_2.

Lessons Learned *(continued)*

3. Investing significant up-front time and effort in problem identification and risk avoidance was crucial for securing a safe, secure CO_2 storage site.

<u>Accomplishment.</u> The Anthropogenic Test storage team conducted extensive evaluation of the casing programs and cement integrity of the older wells surrounding the CO_2 storage site to assure an acceptable "area of review" for CO_2 injection and storage.

4. Investing in detailed site and reservoir characterization, particularly in a fluvial, complex formation such as the Paluxy, is essential for ensuring adequate CO_2 storage capacity, safe CO_2 injection operations, and effective CO_2 monitoring.

<u>Accomplishment.</u> The Anthropogenic Test storage team conducted flow unit descriptions of reservoir continuity and injectivity to enable the team to formulate a well design and completion scheme that minimizes the areal extent of the CO_2 plume.

Future Plans

- Continue monitoring the CO_2 capture, transportation, and injection operations and maximizing the efficiency of the integrated system.
- Maintain risk registry with capture, transportation, injection and monitoring operations reviews.
- Share lessons learned from the Anthropogenic Test with a broad audience through:
  - knowledge sharing opportunities;
  - community and stakeholder briefings;
  - posters and presentations at national and international conferences;
  - news and journal articles;
  - RCSP Working Groups;
  - SECARB website (secarbon.org) and social media (FB: SECARB1; Twitter: @SECARB1); and
  - site visits.