
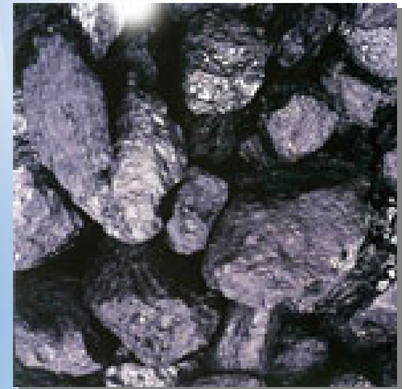


SECARB (Citronelle) Phase III

Prepared For:

2019 Carbon Capture, Utilization, Storage, and
Oil and Gas Technologies Integrated Review Meeting

Prepared By:

George Koperna
ADVANCED RESOURCES INTERNATIONAL, INC.

August 27, 2019

Acknowledgement

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NATIONAL ENERGY TECHNOLOGY LABORATORY

Southern Company

Denbury

ELECTRIC POWER RESEARCH INSTITUTE

SOUTHERN STATES ENERGY BOARD

Alabama Power

SECARB Southeast Regional Carbon Sequestration Partnership

Advanced Resources International, Inc.

Citronelle Phase III Project

Baseline 1 year	Injection 2 years	Post 3 years
APR 2011 to AUG 2012	SEPT 2012 to SEPT 2014	OCT 2014 to SEPT 2017

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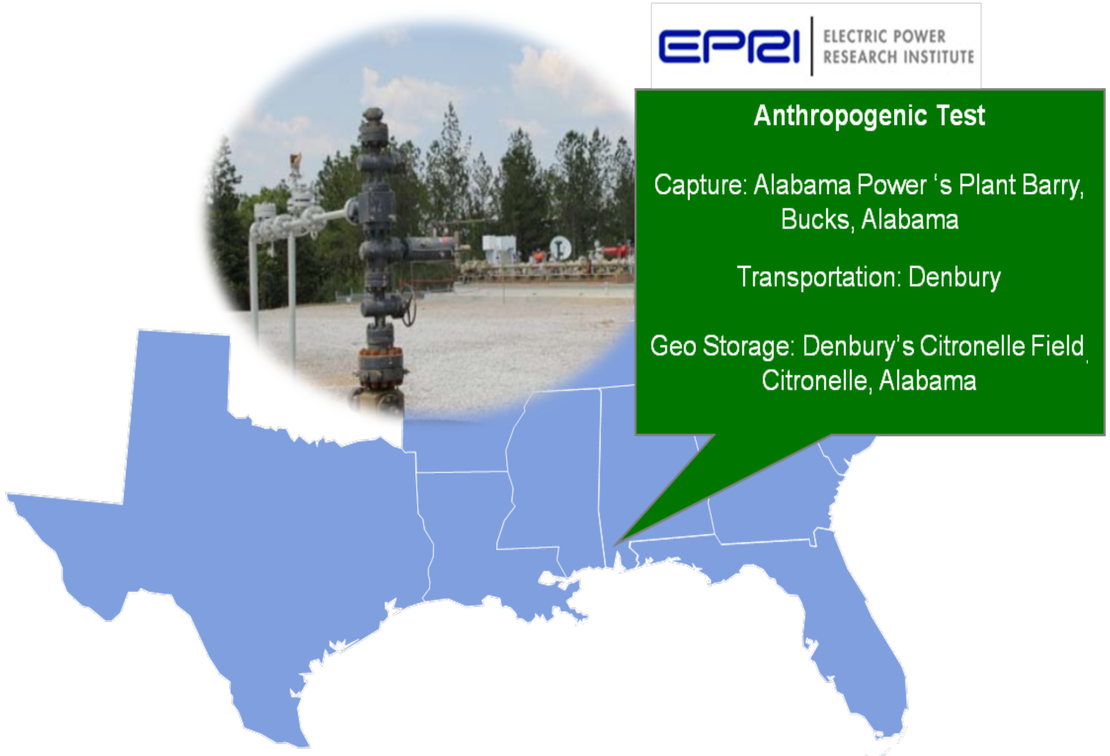
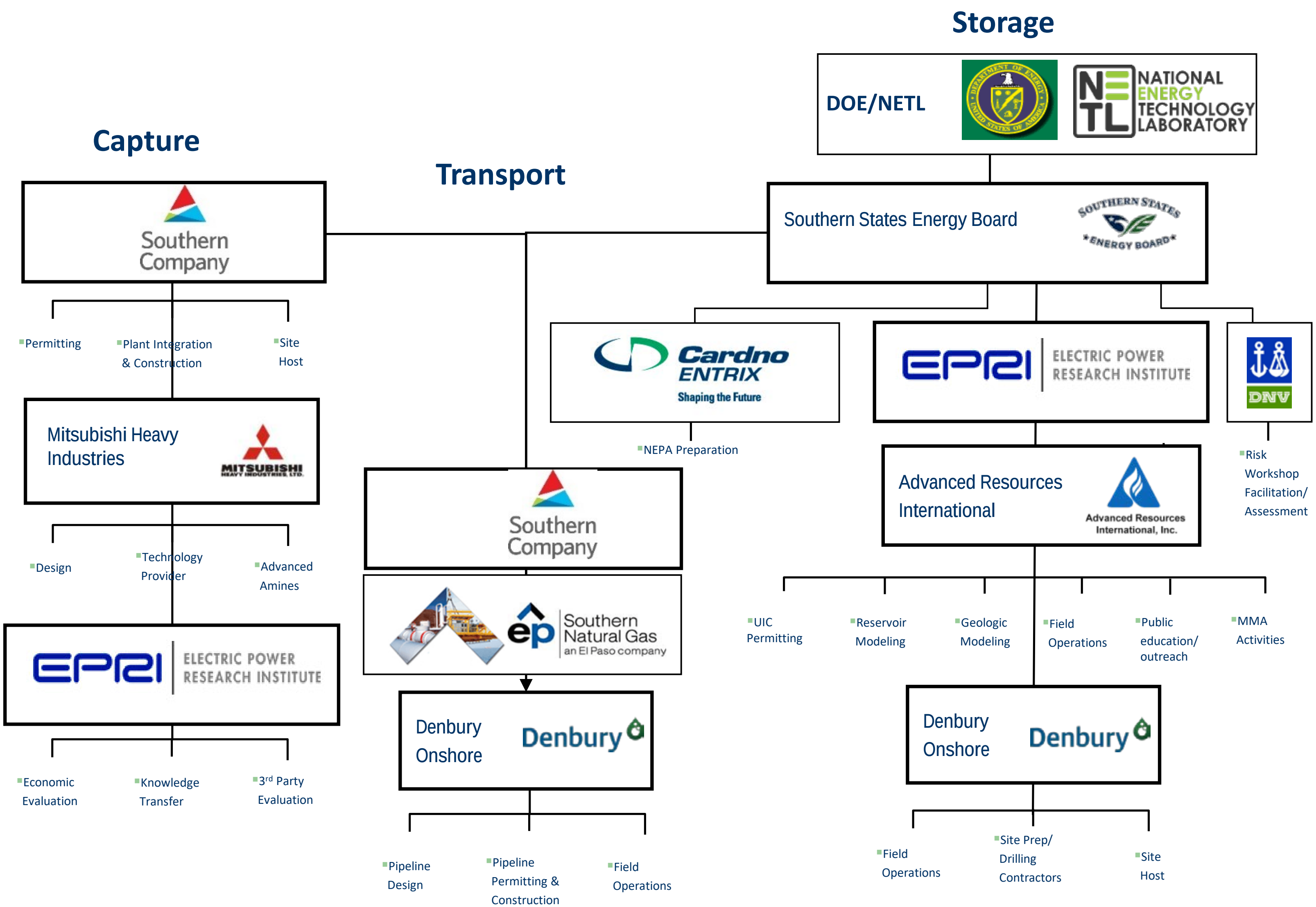


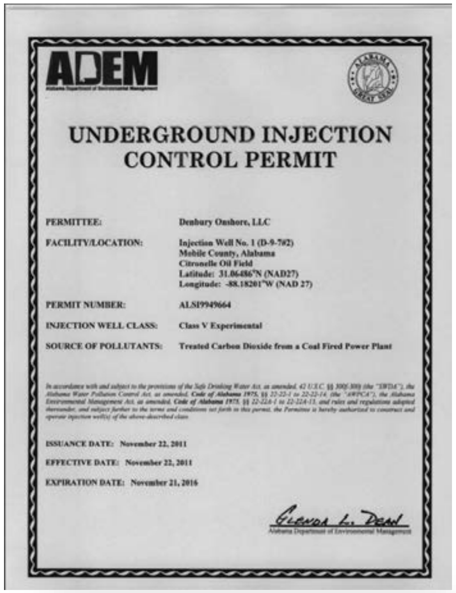
Project Objectives

1. Understand the coordination required to successfully integrate all four components (capture, transport, injection and monitoring) of the project;
2. Document the permitting process for all aspects of a CCS project;
3. Test the CO_2 flow, trapping and storage mechanisms of the Paluxy Formation, a regionally extensive Gulf Coast saline formation;
4. Demonstrate how a saline reservoir's architecture can be used to maximize CO_2 storage and minimize the areal extent of the CO_2 plume;
5. Test the adaptation of commercially available oil field tools and techniques for monitoring CO_2 storage (e.g., VSP, cross-well seismic, cased-hole neutron logs, tracers, pressure, etc.);
6. Test experimental CO_2 monitoring activities, where such technologies hold promise for future commercialization; and
7. Support the United States' largest commercial prototype CO_2 capture and transportation demonstration with injection, monitoring and storage activities.

1. Project Coordination



2. CCS Permitting Process



ADEM

Alabama Department of Environmental Management

UNDERGROUND INJECTION CONTROL PERMIT

PERMITTEE:	Denbury Onshore, LLC
FACILITY/LOCATION:	Injection Well No. 1 (D-9-7#2) Mobile County, Alabama Citronelle Oil Field Latitude: 31.06486°N (NAD27) Longitude: -88.18201°W (NAD 27)
PERMIT NUMBER:	ALSI9949664
INJECTION WELL CLASS:	Class V Experimental
SOURCE OF POLLUTANTS:	Treated Carbon Dioxide from a Coal Fired Power Plant

*In accordance with and subject to the provisions of the Safe Drinking Water Act, as amended, 42 U.S.C. §§ 300f-300j (the "SWDA"), the Alabama Water Pollution Control Act, as amended, **Code of Alabama 1975**, §§ 22-22-1 to 22-22-14, (the "AWPCA"), the Alabama Environmental Management Act, as amended, **Code of Alabama 1975**, §§ 22-22A-1 to 22-22A-15, and rules and regulations adopted thereunder, and subject further to the terms and conditions set forth in this permit, the Permittee is hereby authorized to construct and operate injection well(s) of the above-described class.*

ISSUANCE DATE: November 22, 2011

EFFECTIVE DATE: November 22, 2011

EXPIRATION DATE: November 21, 2016

Glenda L. Dean

Alabama Department of Environmental Management

LANCE R. LEFLEUR
DIRECTOR

ADEM

Alabama Department of Environmental Management
adem.alabama.gov

KAY IVEY
GOVERNOR

May 11, 2018

John E. Filiatrault
Senior Vice President-Operations Services
Denbury Onshore, LLC
5320 Legacy Drive
Plano, TX 75024

RE: Termination of Underground Injection Control Permit ALSI9949664
Denbury Onshore, LLC
Injection Well No. 1 (D-9-7 #2)
Citronelle Oil Field, Mobile County, Alabama

Dear Mr. Filiatrault:

Based on your March 28, 2018, letter requesting termination of the referenced Underground Injection Control Permit Number ALSI9949664, the permit is terminated, effective today **May 11, 2018**.

Please call Joe Kelly at 334-271-7844 if you have any questions.

Sincerely,

Glenda L. Dean

Glenda L. Dean, Chief
Water Division

GLD/SSM/JRK/qm

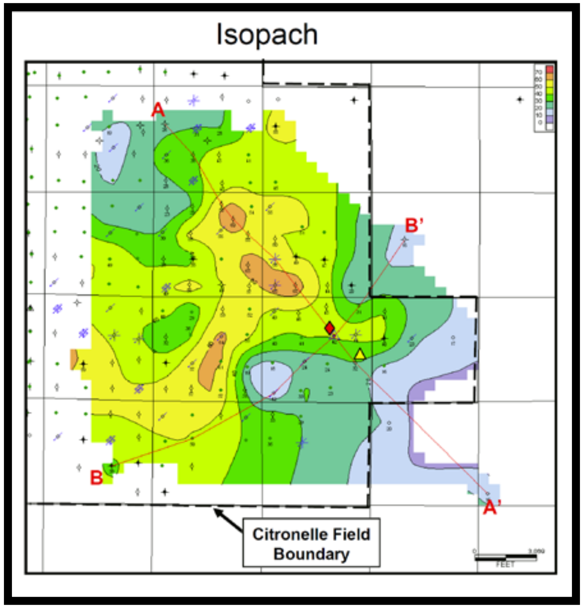
<u>Select References</u>

A. Oudinot et al. GHGT-14 **(2018)**
- Details UIC Class V permit application process, requirements and permit closure

D. Riestenberg et al. CMTC **(2015)**
- Details UIC Class V permit details including: injection well permit and CO_2 sequestration well standards

R. Esposito et al. Energy Procedia 4 **(2011)**
- Details capture facility permitting, transportation permitting and storage permitting

3. Test the CO_2 Flow, Trapping and Storage Mechanisms of the Paluxy



Baseline Reservoir Characterization:

- Analysis of over 80 existing oilfield well logs for porosity, thickness and depositional
- Sand mapping to determine “open” or “closed” sand units.

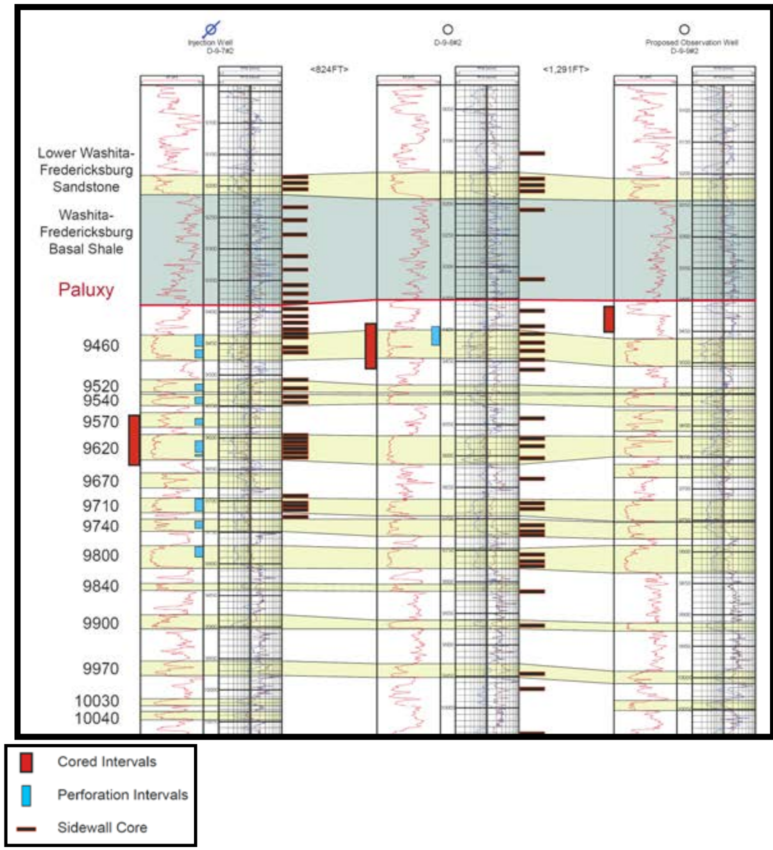
System	Series	Stratigraphic Unit	Major Sub Units	Potential Reservoirs and Confining Zones
Tertiary	Plio-Pliocene		Citronelle Formation	Freshwater Aquifer
Tertiary	Miocene	Undifferentiated		Freshwater Aquifer
Tertiary	Oligocene		Chickasawhay Fm.	Base of USDW
Tertiary	Oligocene	Vicksburg Group	Bucatunna Clay	Local Confining Unit
Tertiary	Eocene	Jackson Group		Minor Saline Reservoir
Tertiary	Eocene	Claiborne Group	Talahatta Fm.	Saline Reservoir
Tertiary	Eocene / Paleocene	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'	Injection Zone
Cretaceous	Lower	Mooringsport Formation		Confining Unit
Cretaceous	Lower	Ferry Lake Anhydrite		Confining Unit
Cretaceous	Lower	Donovan Sand	Rodessa Fm. Upper' 'Middle' 'Lower'	Oil Reservoir Minor Saline Reservoir Oil Reservoir

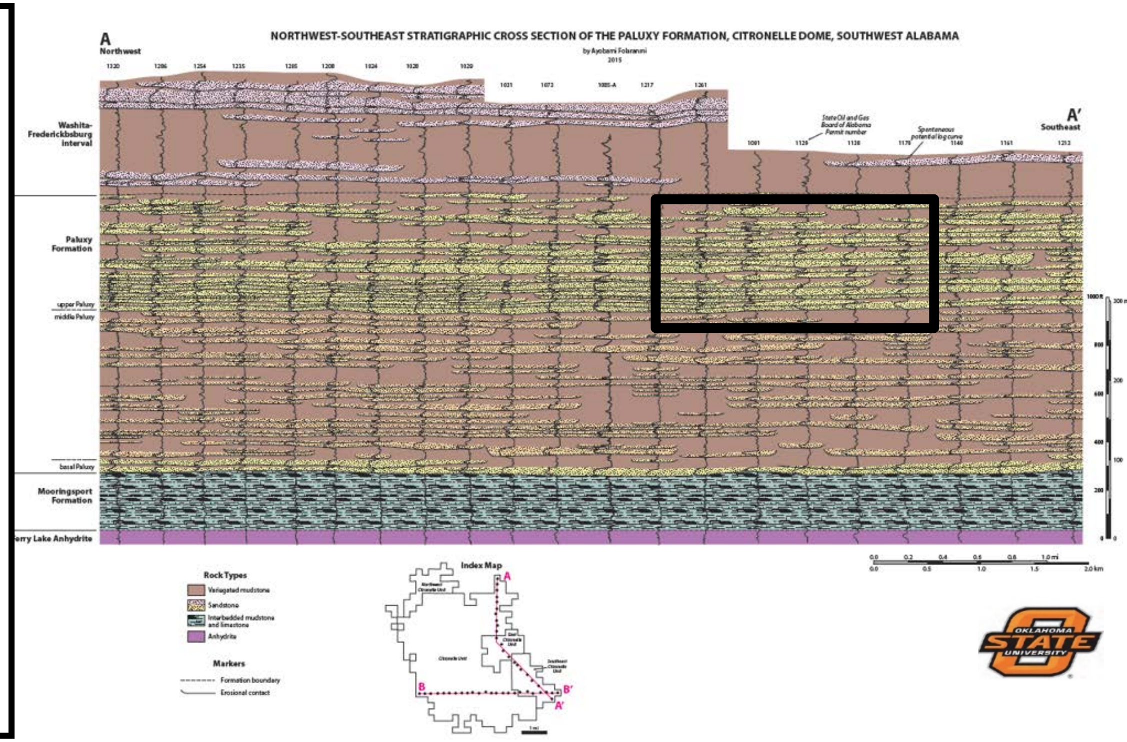
Collected new geologic data on the Paluxy reservoir and confining unit with the drilling of the project’s three new wells:

- 210 feet of whole core and 70 percussion sidewall cores
- Full set of open hole logs on all three wells (quad combo, MRI, spectral gamma, mineralogical evaluation, waveform sonic, cement quality, pulsed neutron capture)
- Baseline vertical seismic profiles and crosswell seismic collected in Feb 2012

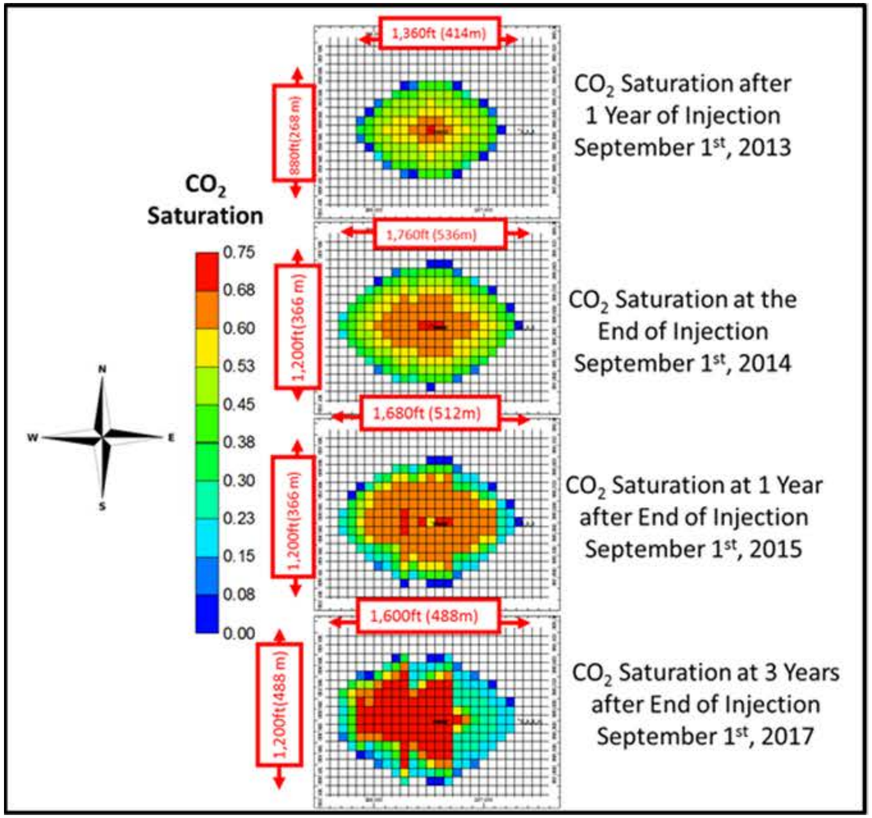
Geologic Characterization Results

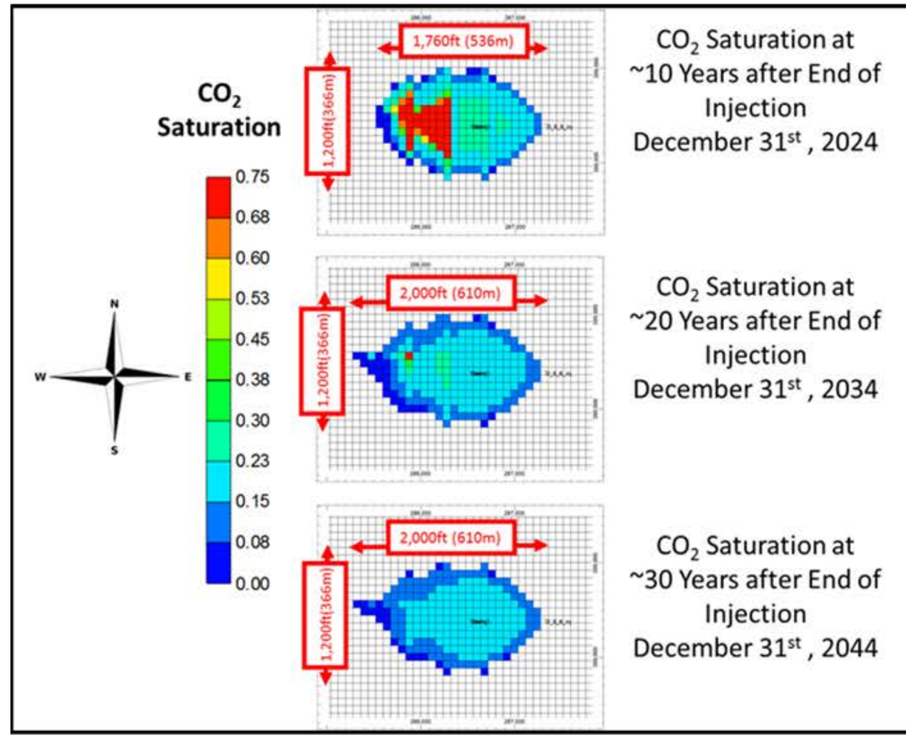
- Sandstone and mudstone units are continuous at this scale
- CO_2 dispersion vertically
- Multiple stacked plumes





Storage Mechanisms of Paluxy Form.

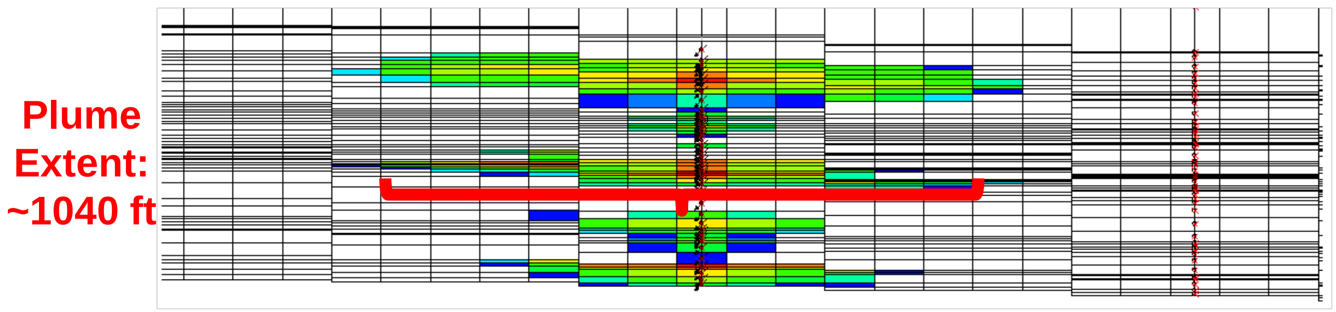




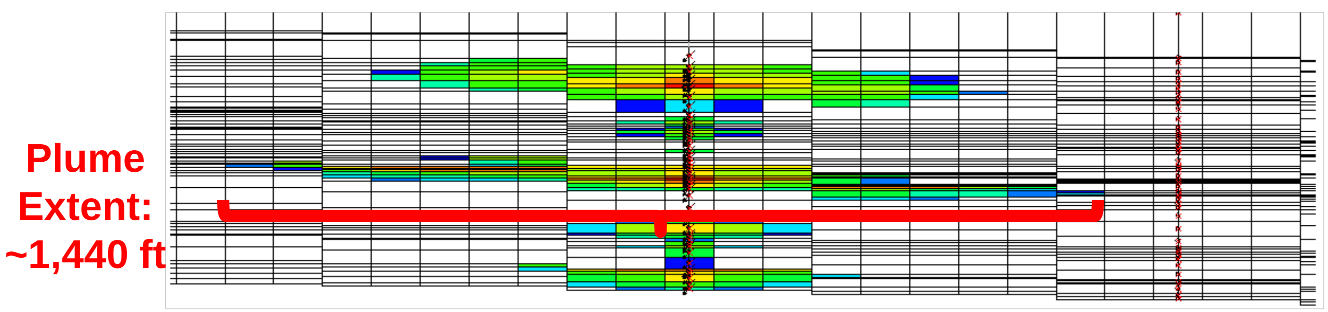
The estimated radius of the CO_2 plume 30 years after cessation of injection is approximately 1000 ft. (305m), which is less than the project's initial AoR of 1,700 ft.

4. Utilizing Reservoir Architecture

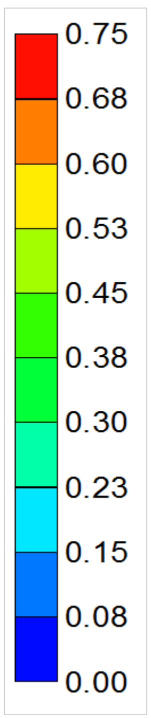
- Limiting the extent of the CO_2 plume by not completing high permeability sand layers
- By shutting in the high permeability sand layer, the plume radius was decreased by ~200 ft



High Permeability Sand Closed

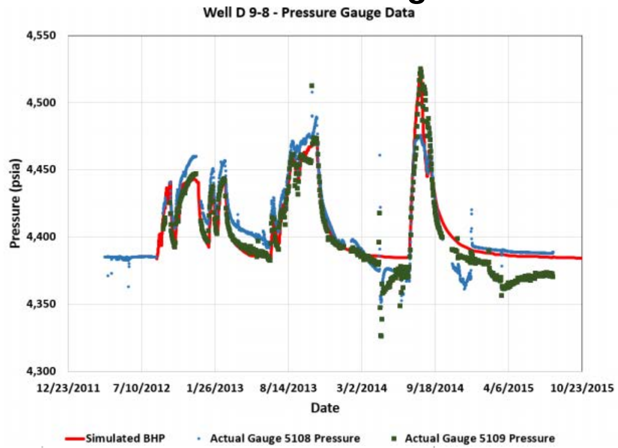


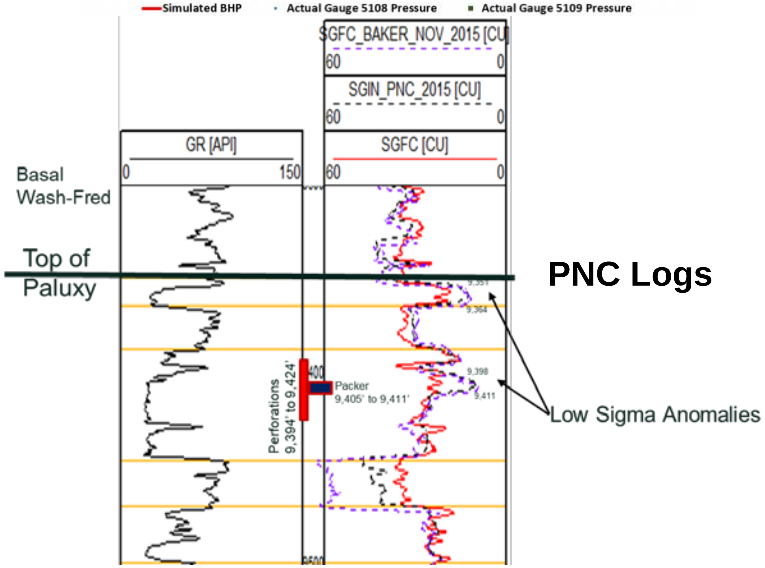
High Permeability Sand Opened



5. Commercial Monitoring Protocols

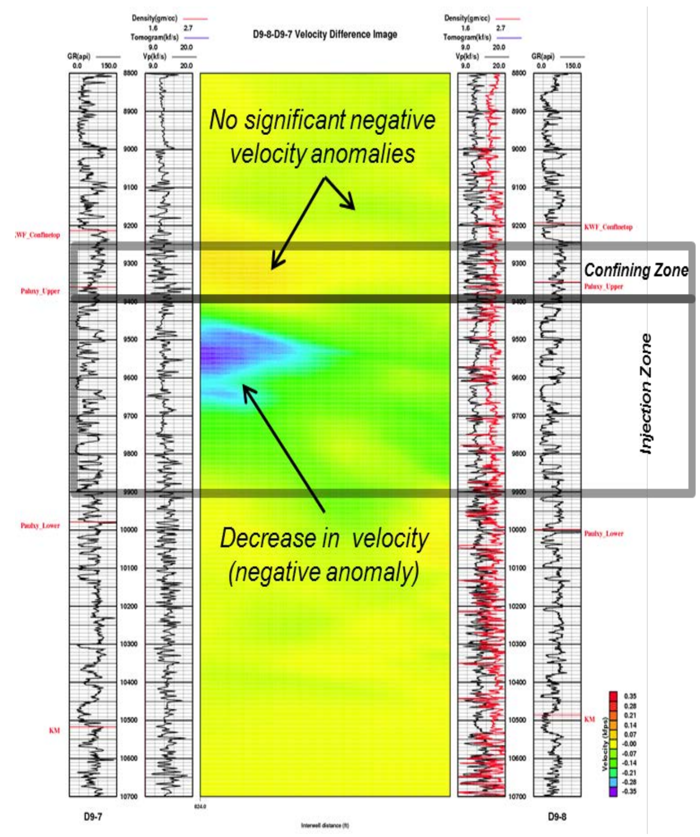
Pressure Gauges





PNC Logs

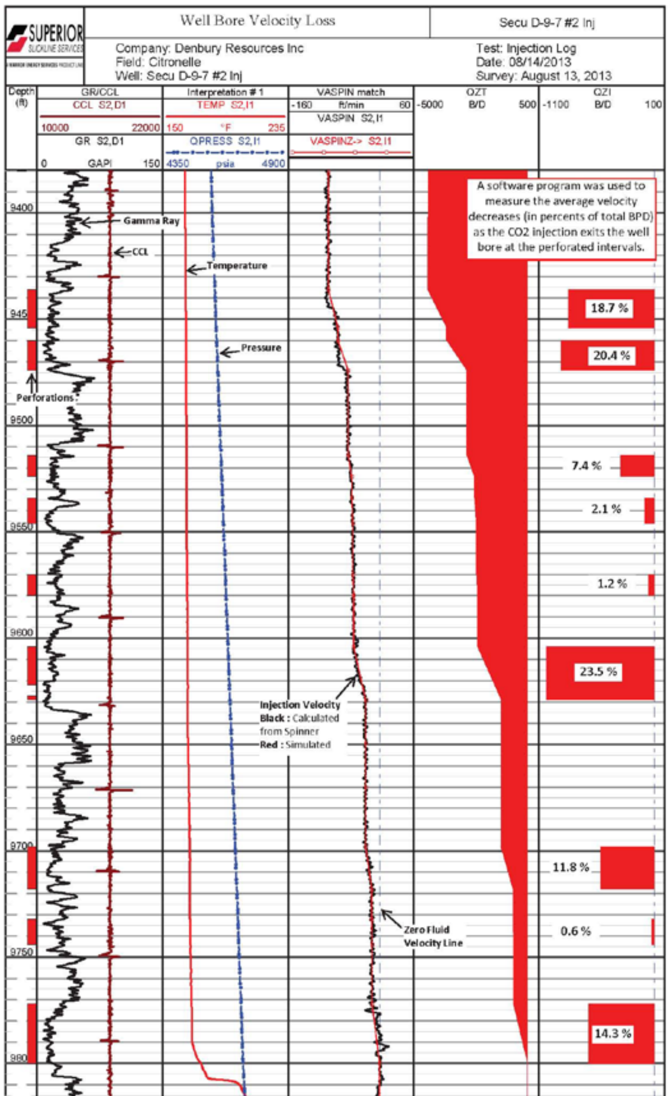
⇒ **Results of the PNC logs demonstrate confinement in the injection zone.**



Crosswell Seismic

- Replacement of brine with CO_2 caused a decrease in velocity through the storage geologic unit
- Time-lapse survey during injection in June 2014

Spinner Surveys

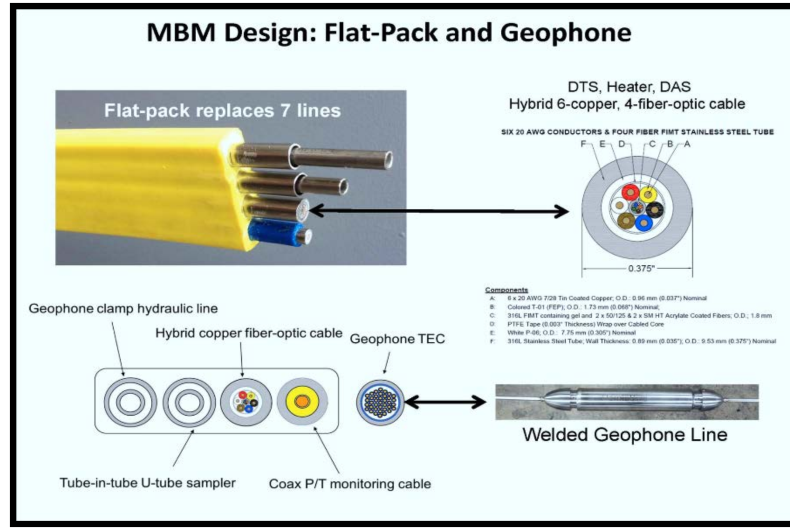


Sand	Sand Unit Properties (ft)			Nov 2012	Aug 2013	Oct 2013
Unit	Bottom	Top	Thickness	Flow %	Flow %	Flow %
J	9,454	9,436	18	14.8	18.7	16.7
I	9,474	9,460	14	8.2	20.4	19.6
H	9,524	9,514	10	2.8	7.4	7.7
G	9,546	9,534	12	2.7	2.1	0.9
F	9,580	9,570	10	0.0	1.2	1.2
E	9,622	9,604	18	26.8	23.5	30.8
D	9,629	9,627	2	0.0	0.0	0.0
C	9,718	9,698	20	16.5	11.8	10.3
B	9,744	9,732	12	4.9	0.6	0.4
A	9,800	9,772	28	23.3	14.3	12.4

Caged Fullbore Flowmeter (6 arm CFBM)

6. Experimental Monitoring: MBM

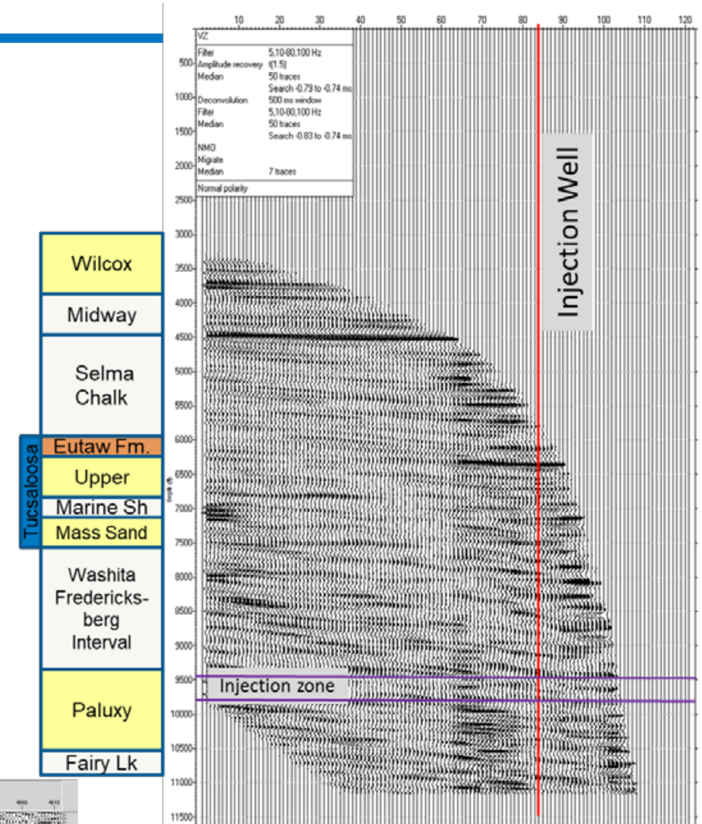
- 18 Level, tubing deployed, clamping geophone array (6,000-6,850 ft)
- Two in-zone quartz pressure/temperature gauges for reservoir diagnostics
- U-tube for high frequency, in-zone fluid sampling (tube-in-tube design)
- **Fiber optic cables** for distributed temperature (DTS) and acoustic measurements (DAS)
  - Heat-pulse monitoring for CO_2 leak detection
  - **Acoustic array for seismic (equivalent to 3m spacing)**
- 2 7/8" production tubing open for logging



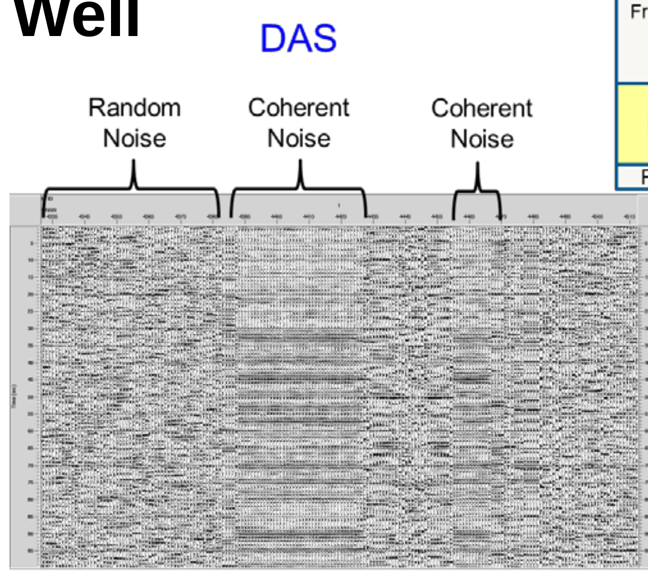
Experimental Monitoring: DAS

2014 DAS-VSP Survey Results

- Migrated image →
  - Observed strong reflectors
  - Good tie to formation logs (e.g., Selma Chalk)
- No “bright” spot observed where CO_2 was injected



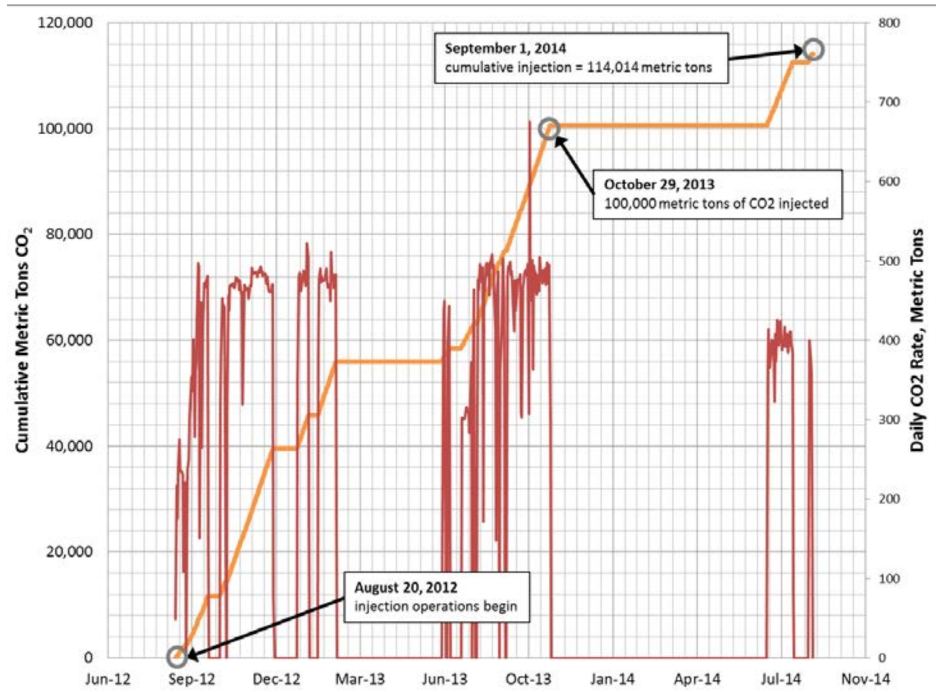
2014 DAS-Cross Well Survey Results



DAS Data at 9,340 ft – Only See Random Noise, Except Some Coherent Noise Not related to sweep

7. Support the United States' Largest Commercial Prototype CO_2 Capture and Transportation Demonstration

1. Injected, stored, and monitored 114 kt for the largest (at the time) integrated commercial prototype CCTS project at a coal-fired power plant.
2. First time CO_2 transfer of custody occurred between an anthropogenic source and a transport/storage operator.
3. First with Class VI elements in their CO_2 injection permit.
4. Demonstrated non-endangerment (Class VI protocols) and closed permit (first).



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