SECARB Anthropogenic Test Update

Project Number DE-FC26-05NT42590

Rob Trautz, Electric Power Research Institute

Anne Oudinot, Advanced Resources International

David Riestenberg, Advanced Resources International

U.S. Department of Energy

National Energy Technology Laboratory

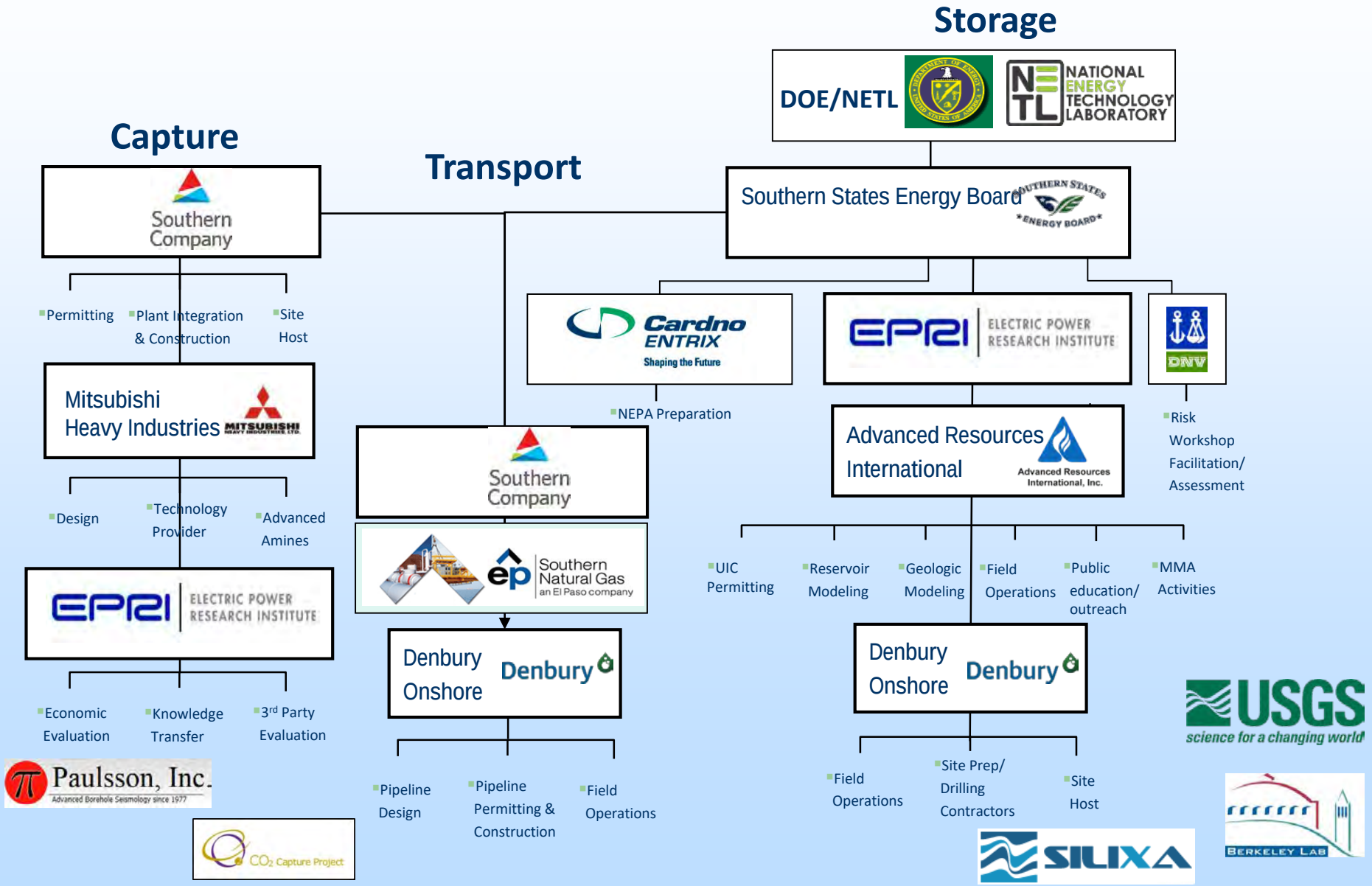
Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 13-16, 2018

Acknowledgement

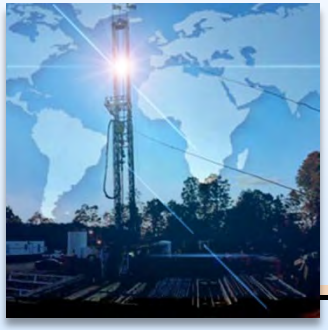
This presentation is based upon work supported by the Department of Energy National Energy Technology Laboratory under **DE-FC26-05NT42590** and was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor 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 favoring 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.

Organizational Chart



Presentation Outline

1. Project Introduction
2. Permit is closed!
3. Next (Last) Steps
4. Research and Operational Highlights (and lowlights…)

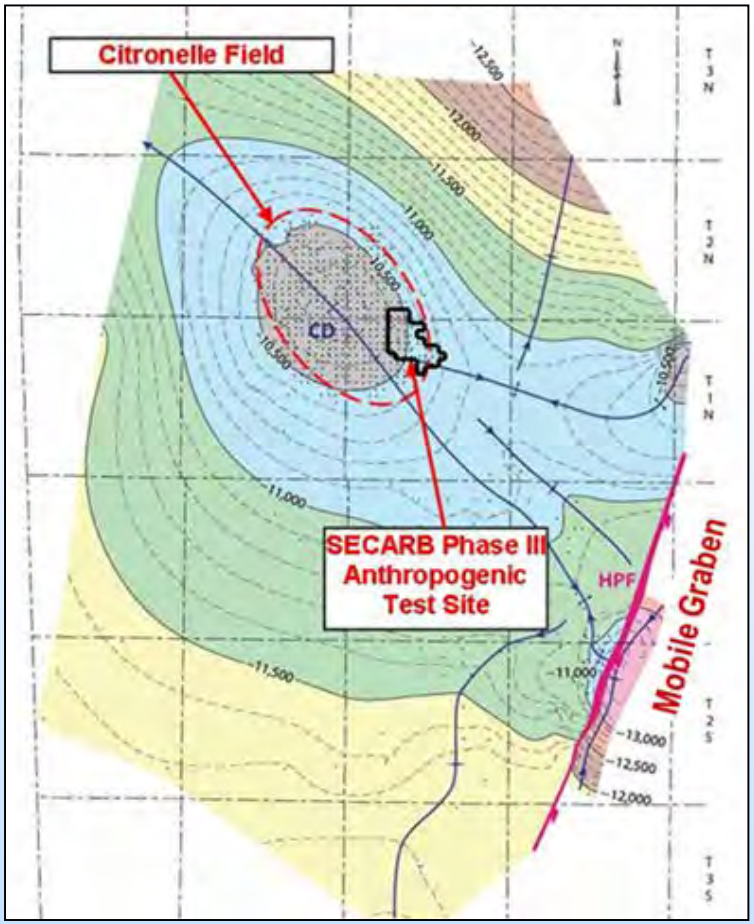


SECARB Anthropogenic Test Introduction

Project Goals and Objectives

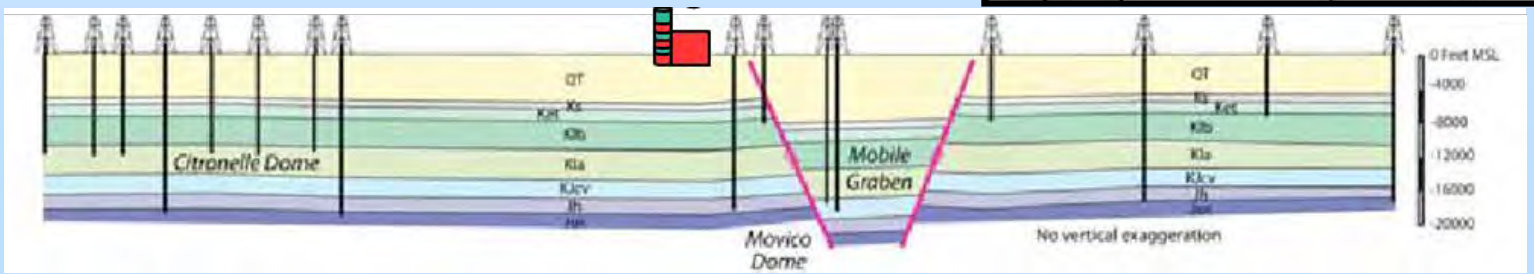
1. Support the United States' largest (*at the time*) prototype CO_2 capture and transportation demonstration, with injection, monitoring and storage activities;
2. Test the CO_2 flow, trapping and storage mechanisms of the Paluxy;
3. Demonstrate how a saline reservoir's architecture can be used to maximize CO_2 storage and minimize the areal extent of the CO_2 plume;
4. Test the adaptation of commercially available oil field tools and techniques for monitoring CO_2 storage;
5. Test experimental CO_2 monitoring activities, where such technologies hold promise for future commercialization;
6. Begin to understand the coordination required to successfully integrate all four components (capture, transport, injection and monitoring) of the project; and
7. Document the permitting process for all aspects of a CCS project.

Storage Site: The Citronelle Oilfield

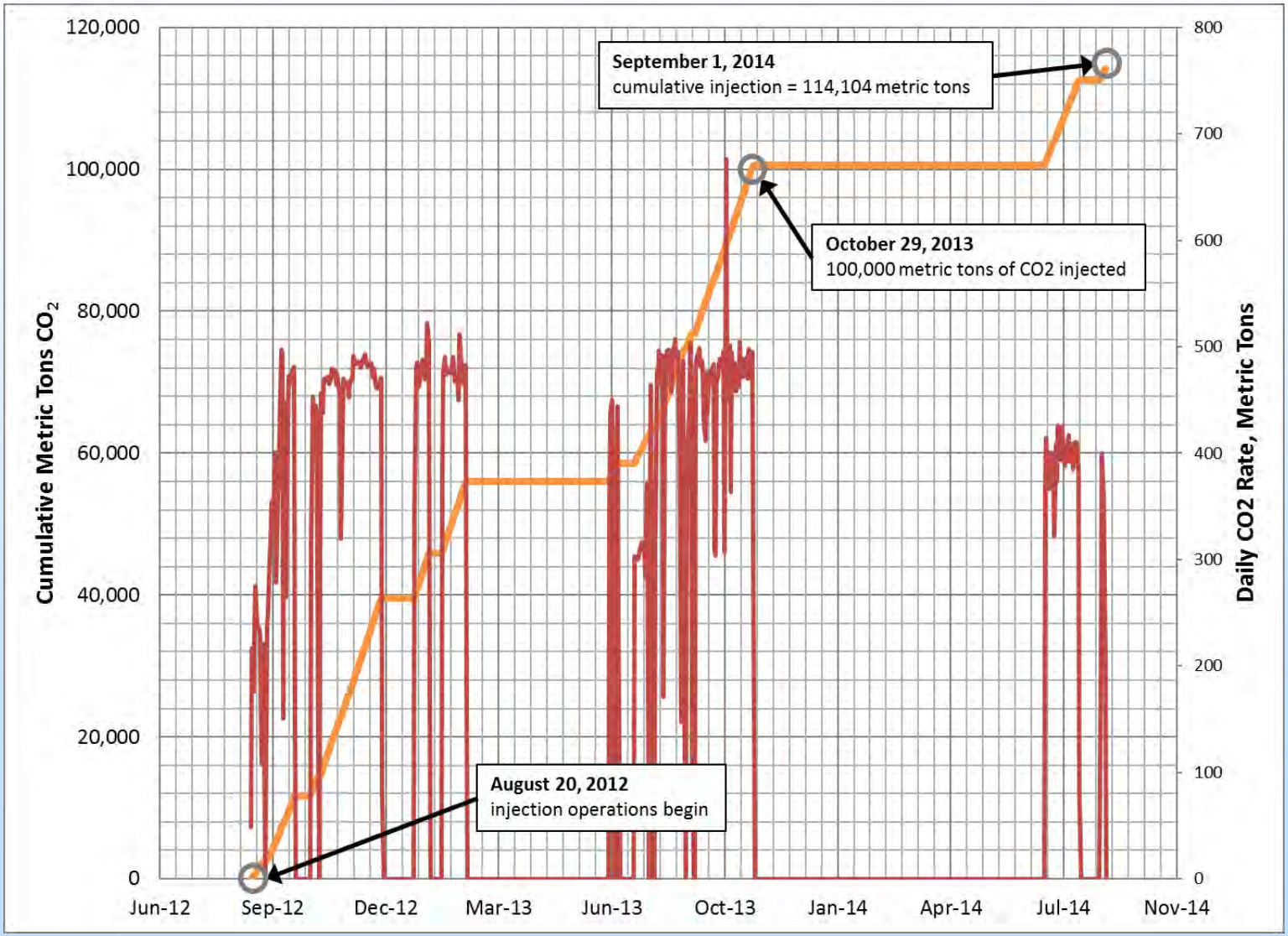


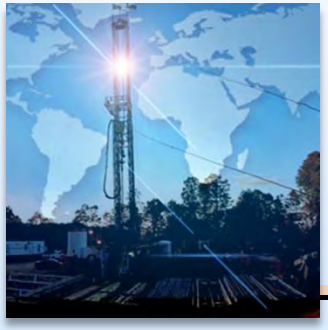
Structure map and cross section by GSA

System	Series	Stratigraphic Unit	Major Sub Units	Potential Reservoirs and Confining Zones
Tertiary	Plio-Pliocene		Citronelle Formation	Freshwater Aquifer
	Miocene	Undifferentiated		Freshwater Aquifer
	Oligocene		Chickasawhay 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
	Lower	Washita-Fredericksburg	Dantzler sand Basal Shale	Saline Reservoir Primary Confining Unit
		Paluxy Formation	'Upper' 'Middle' 'Lower'	Injection Zone
		Mooringsport Formation		Confining Unit
		Ferry Lake Anhydrite		Confining Unit
		Donovan Sand	Rodessa Fm. Upper' 'Middle' 'Lower'	Oil Reservoir Minor Saline Reservoir Oil Reservoir



CO_2 Injection History





Permit is closed!!

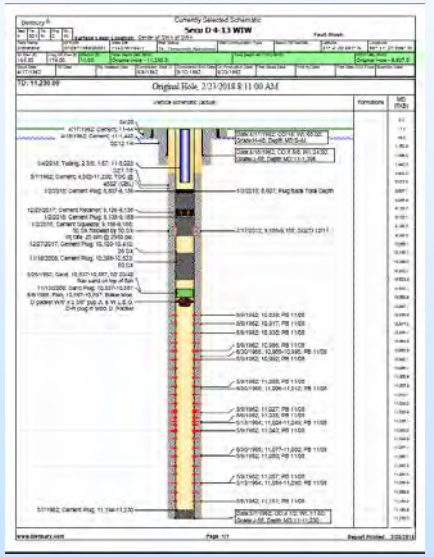
Permit Closure

- Permit was officially closed by ADEM on May 11th
- Temporary or permanent abandonment of all project wells is complete
- Post-injection monitoring (groundwater and soil flux) is complete
- Non-endangerment of USDWs and CO_2 confinement in the injection zone have been demonstrated using modeling and monitoring results to obtain closure

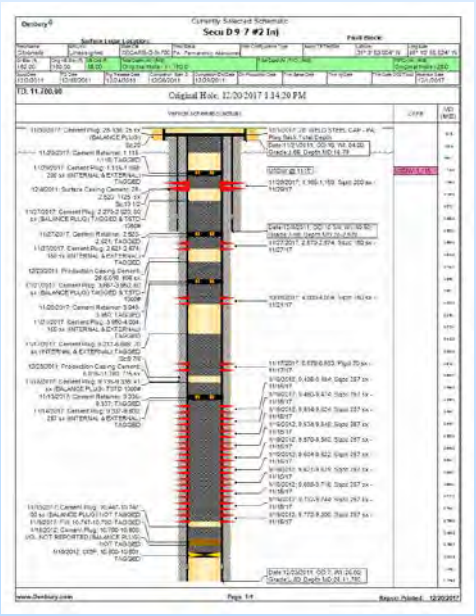
Wells Temporary and Permanent Abandonment

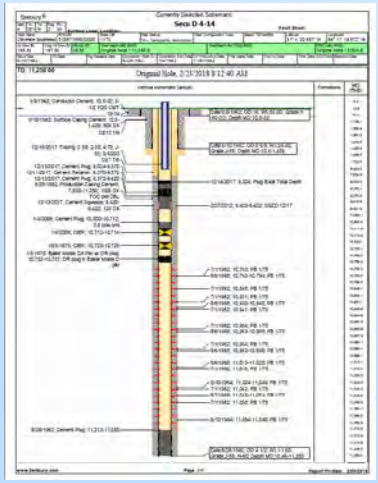
D 9-7#2 on December 10th, 2017

D 4-14 on December 10th, 2017



D 4-13





Demonstrating Non-Endangerment of USDWs and CO_2 Confinement

- The Class V permit required several levels of monitoring
  - Surface monitoring
    - Soil flux, tracers
  - Shallow groundwater monitoring
  - Deep reservoir monitoring
    - PNC logs, fluid sampling, seismic, pressure monitoring
- Experimental MVA activities
- Numerical modeling
  - Developed to determine the project's Area of Review (AoR) and investigate the advancement of the CO_2 plume

Surface Monitoring: Tracer

- Leakage most likely to occur along wellbores that penetrate the injection zone and/or confining unit
- Periodic injection of a mix of perfluorocarbon tracers (PFTs) into the CO_2 stream
- Surficial monitoring for PFTs occurred at the injection well and an additional 8 offset locations

⇒ **No evidence of tracer release at any of the nine monitoring locations.**

Date	Well ID	
August 2012	D-9-1	ND
	D-9-2	ND
	D-9-3	ND
	D-9-6	ND
	D-9-7-1	ND
	D-9-7 Air Blank	Invalid Data
	D-9-8	Invalid Data
	D-9-9	ND
	D-9-9 Air Blank	Air
	D-9-10	Invalid Data
	D-9-11	ND
	Air Blank 1	ND
	Air Blank 2	Invalid Data
	Air Blank 3	Invalid Data
June 21-22,2016	D-9-1	ND
	D-9-2	ND
	D-9-3	ND
	D-9-6	ND
	D-9-7	ND
	D 9-8 #2	ND
	D-9-9 +abandoned	ND
	D-9-10	ND
	D-9-11	ND
	D-982_gaugesample_1 (stream from D-9-8#2)	DETECTION
	voa_dec23cylinder_1 (Denbury cylinder from Dec 23)	ND
	System Blank	ND

Shallow Groundwater Monitoring

- Performed on a quarterly basis as required by the UIC permit at 4 locations
- A total of 24 events occurred (3 baseline, 8 during injection and 13 post-injection)
- Multiple lines of evidence are required to determine that injected CO_2 is not influencing the USDWs

Monitoring Well	Decrease in pH	Increase in TIC	Increase in Alkalinity	Increase in Metals Concentrations
D-9-7 MW-2D	Yes	No	No	No
D-9-7 MW-2S	No	No	No	No
D-9-9 MW-1	No	No	No	Fe
Water Supply Well	No	No	No	No

Purple Shading = A potential line of evidence for carbon dioxide influence is present
Blue Shading = A potential line of evidence for carbon dioxide influence is not present
TIC = total inorganic carbon

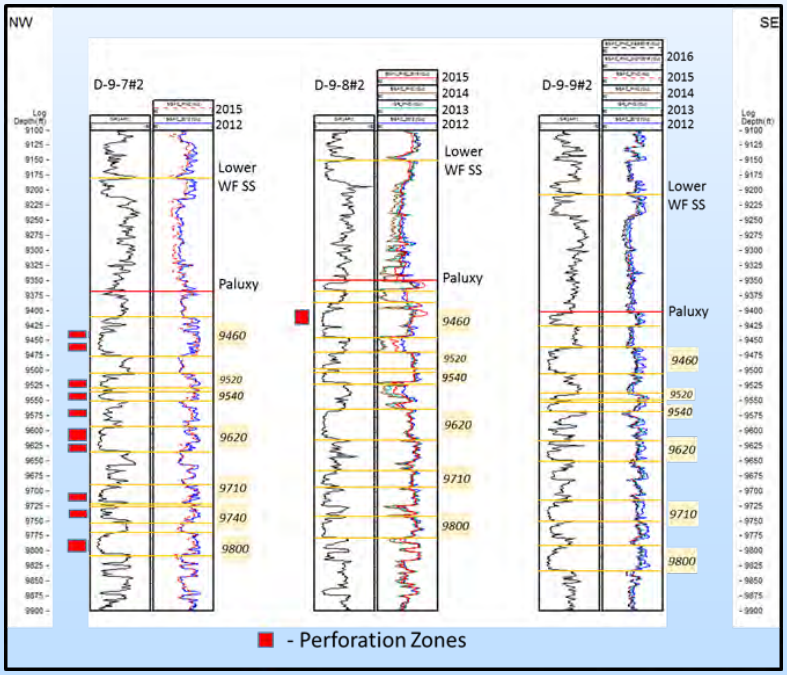
- **$\Rightarrow$ Multiple lines of evidence do not indicate CO_2 leakage into USDWs.**

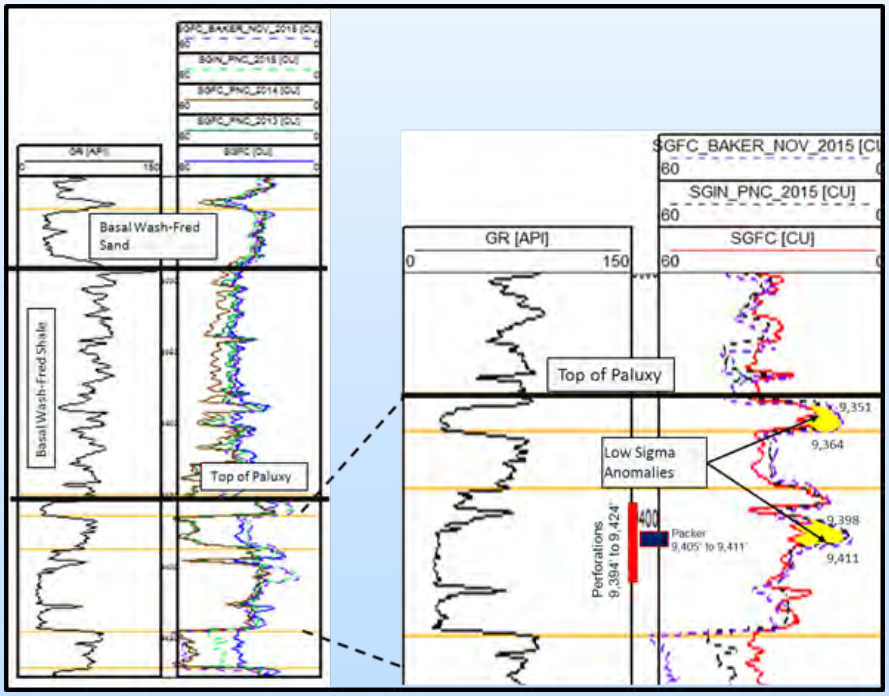
Deep Reservoir Monitoring

- Deep PNC logs
- Deep fluid sampling
  - Unreliable results due to poor sampling procedures
- Seismic Program
  - Cross-well seismic
  - Vertical Seismic Profile
    - Inconclusive
- Pressure monitoring

Pulsed Neutron Capture (PNC) Logs

- Application: measure changes in formation gas saturation behind casing
- CO_2 breakthrough was observed at the D 9-8 #2 well in the August 2015 PNC log and confirmed in a November 2015 repeat
- No evidence of gas saturation was observed within or above the confining zone

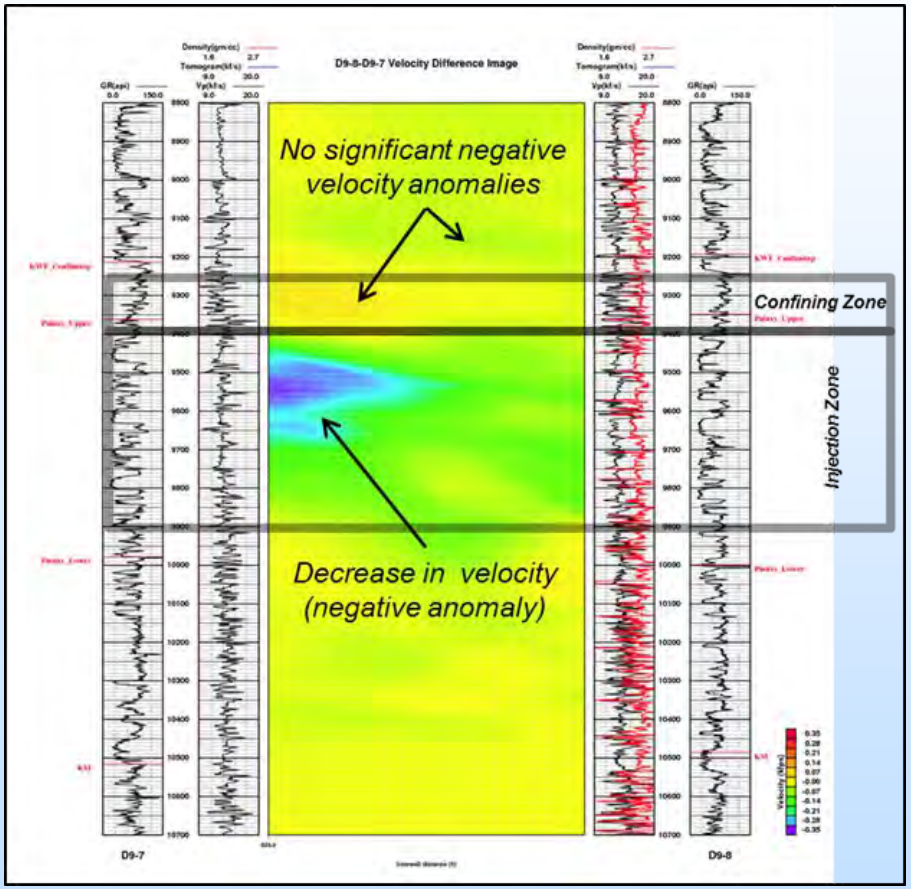




- ⇒ **Results of the PNC logs demonstrate confinement in the injection zone.**

Time-lapse Cross-well Seismic

- Replacement of brine with CO_2 will result in an increase in travel time through a geologic unit
- Crosswell seismic was acquired between the D 9-7#2, and the D 9-8 #2
- Baseline in January 2012 and time-lapse survey during injection in June 2014



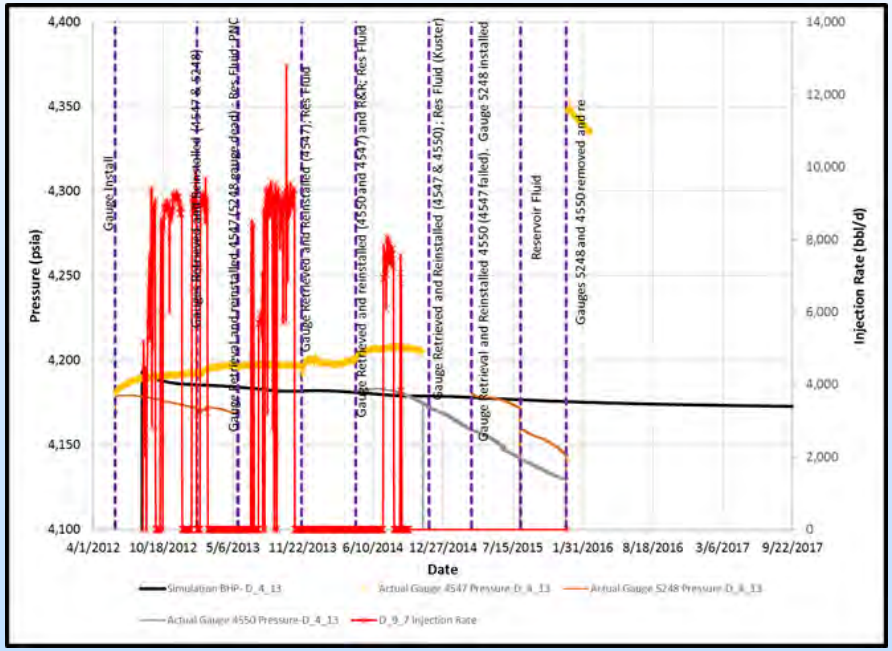
Comparison between 2012 and 2014

⇒ No anomaly in or above the confining unit.

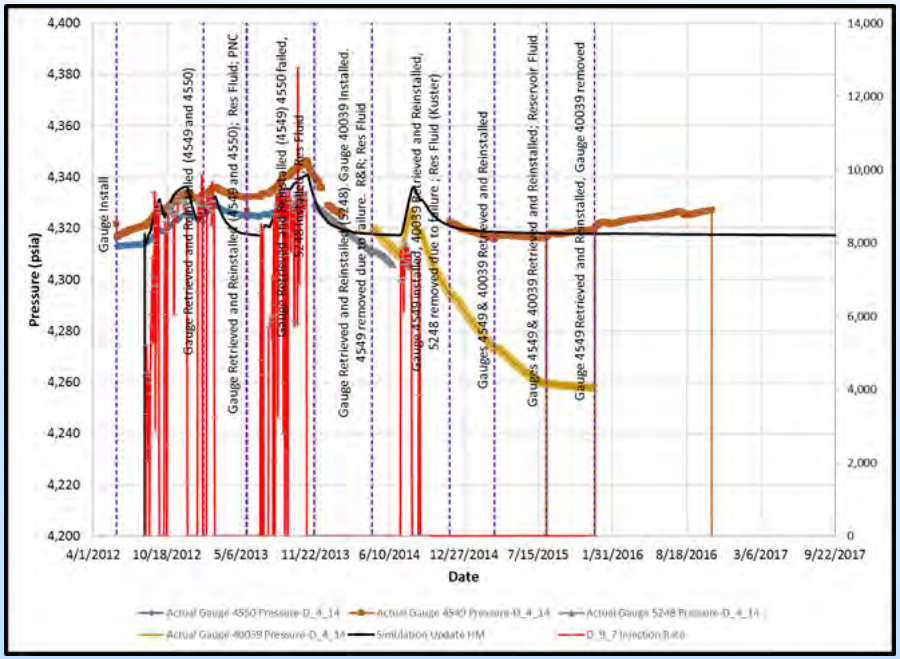
Pressure Monitoring

- Pressure monitored in 4 wells: D9-7#2, D9-8#2, D4-13 and D4-14

D4-13 Above Zone Monitoring



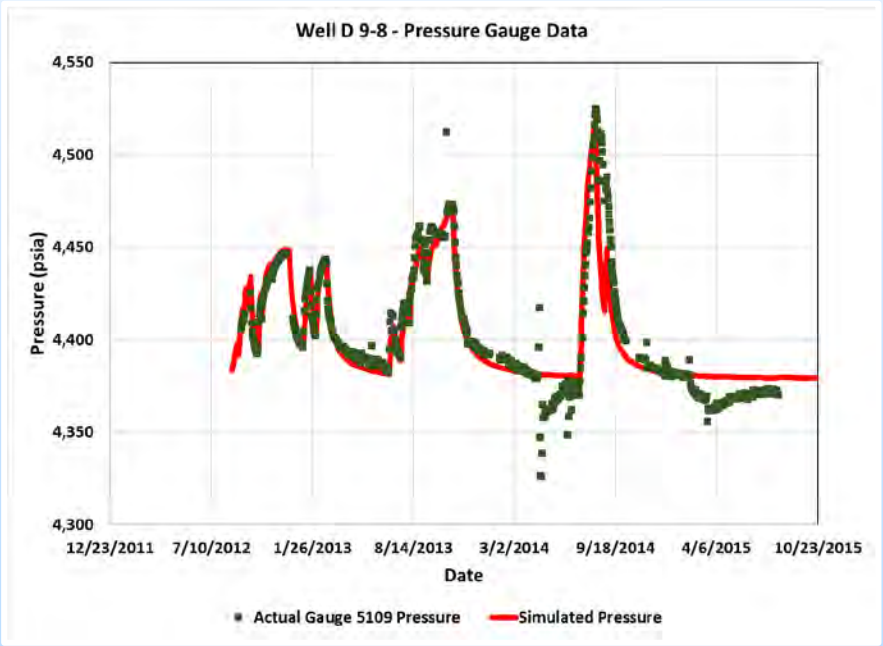
D4-14 In Zone Monitoring

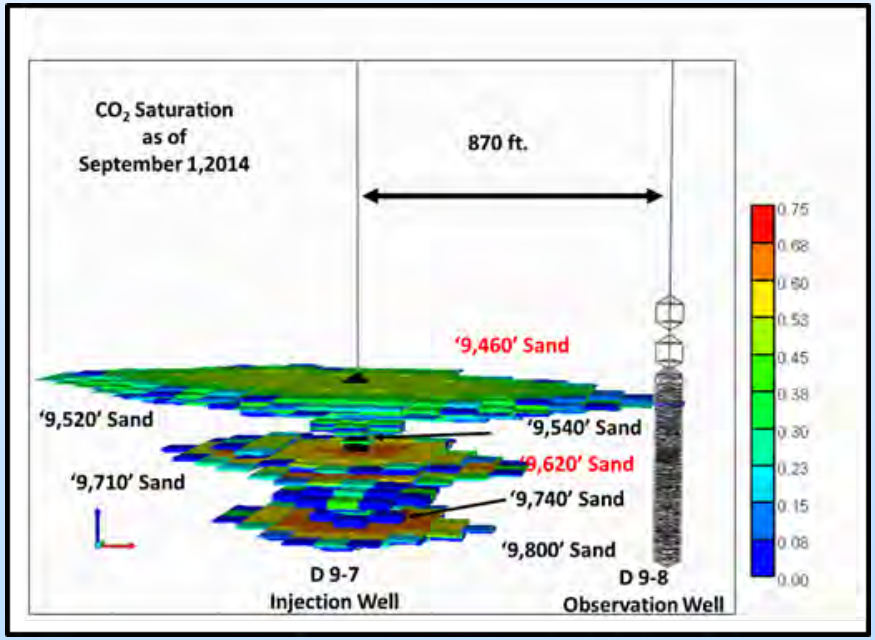


Pressure clearly follows the trend of injection in the D9-7#2

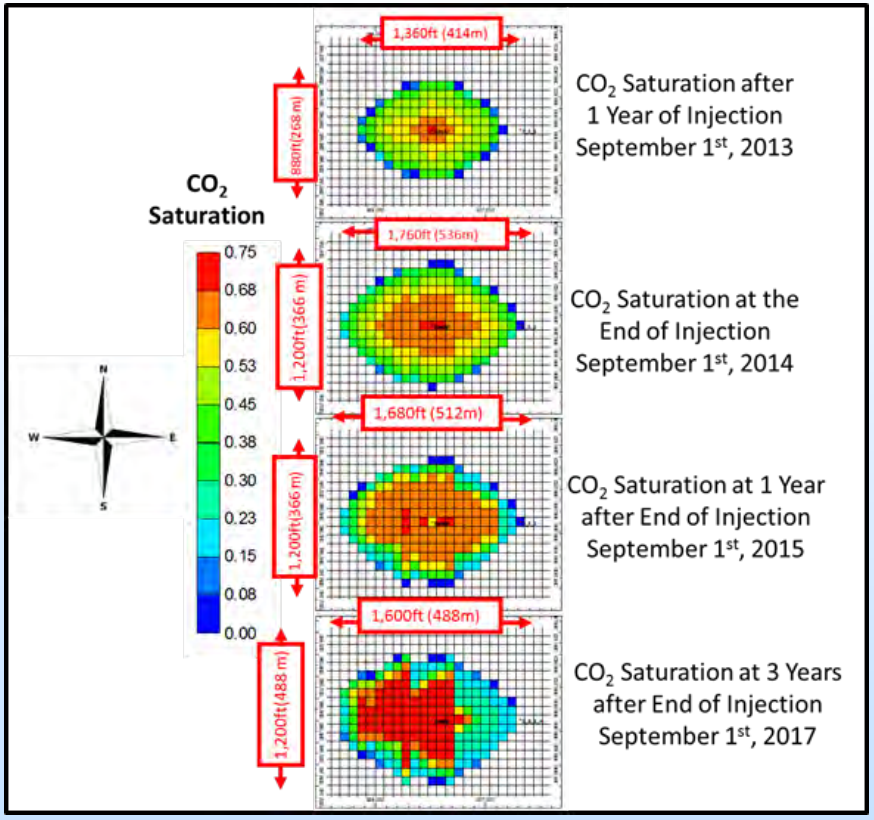
Numerical Modeling

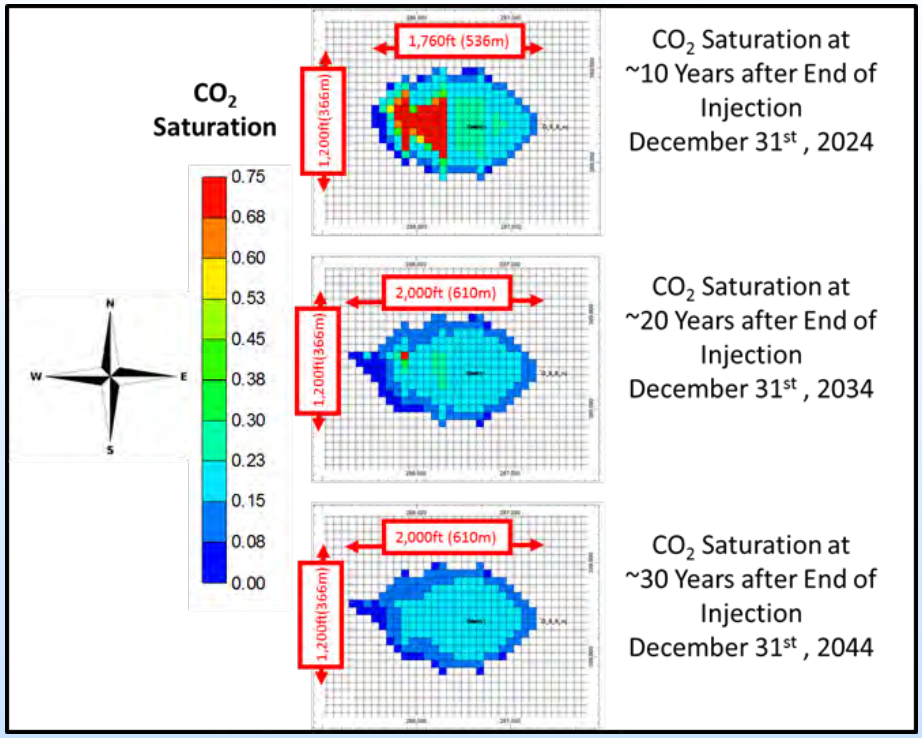
- Monitoring results are matched from the onset of injection through March 2016, which includes the observed CO_2 breakthrough at the D 9-8 #2 monitoring well
- With the addition of permeability anisotropy and a high permeability zone within the '9460' sand, CO_2 breakthrough at the D 9-8#2 is modeled within the timeframe delineated by the PNC logs.





Area of Review

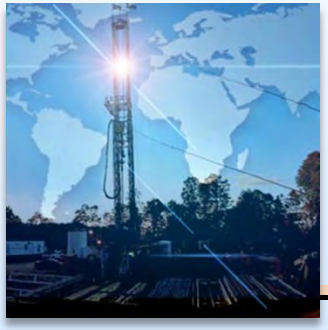




The estimated radius of the CO_2 plume 30 years after cessation of injection is approximately 1000 ft. (305m), which is less than the project's initial AoR of 1,700 ft.

Non-endangerment Summary

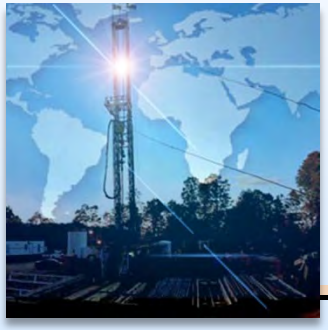
- Sufficient evidence was provided by the suite of surface and shallow monitoring, deep MVA and modeling efforts to indicate successful non-endangerment at the site.
  - No CO_2 release or buildup was detected using groundwater analysis, tracer detection, and soil flux monitoring.
  - PNC logs, cross-well seismic, VSP and pressure monitoring were all parts of deep monitoring activities.
  - No evidence of gas saturation was observed within or above the confining zone based on the results of repeated runs of the pulsed neutron capture (PNC) log during the injection operation.
  - Cross-well seismic results show no negative velocity anomalies in or above the confining unit implying no detectable leakage out of the injection zone, and containment of CO_2.
  - Simulated distribution of CO_2 through the injected geological layers demonstrated confinement within the injected zone
  - Models indicate that the plume does not exceed the original AoR predicted in the baseline model.
  - The maximum movement of CO_2 is less than 1,000 ft. (305 m) in any direction 30 years after the injection ceases



Next (Last) steps

Project's Last Steps

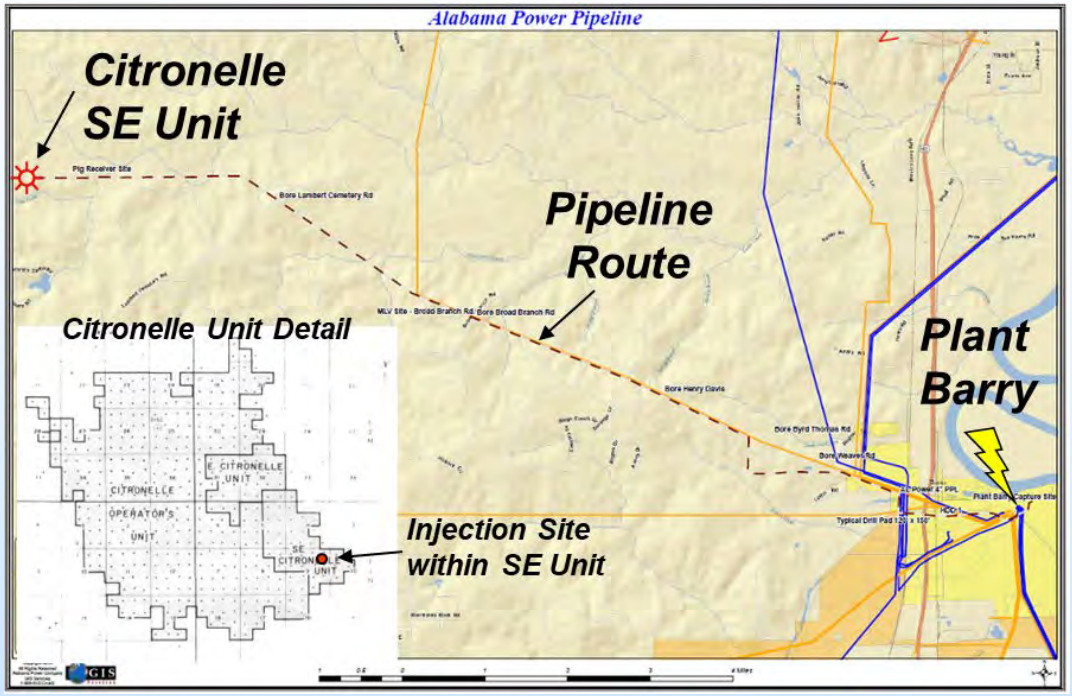
- Plugging and abandonment of groundwater wells is happening right now
- Transfer of test site to oilfield operator
- Peer reviewed geology and simulation papers in progress per DOE requirements
- EDX upload (currently 60% complete).



Operational and Research Highlights (and a few lowlights…)

CO_2 Transportation via Pipeline

- 12 mi to the Injection Site
- Right-of-Way
  - Utility corridor for 80%; 9 land owners
- Pipe specifications
  - 4-in pipe dia.
  - X70 carbon steel
  - DOT 29 CFR 195 liquid pipeline;
    buried 3 feet with surface vegetation and maintenance
  - Purity is 97% dry CO_2
    at 115ºF, 1,500 psig
    (< 20 ppm H_2S)



- **CO_2-EOR industry pipeline construction and operational standards worked quite well for CCS transportation**

Cardno ENTRIX Shaping the Future

Denbury

CO_2 Transportation via Pipeline

- Eighteen horizontal directional drills required (Esposito et al., GHGT-11)
  - Avoid Plant Barry surface facilities
  - Railroad and road crossings
  - Wet areas
  - However, most of the HDDs were performed to minimize impacts on gopher tortoise burrows or colonies
  - Directional drilling under tortoise burrows/colonies less expensive than temporary relocation
- **Routing complexity added considerably to pipeline installation costs**

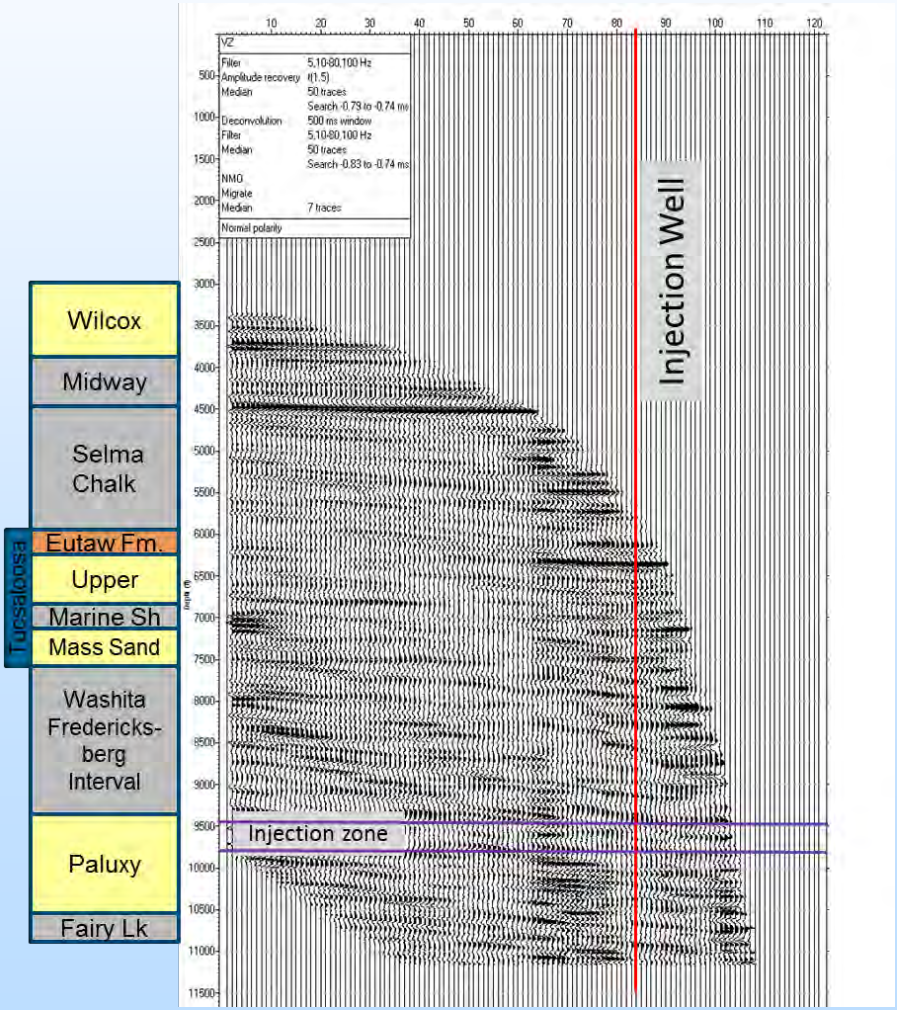
Horizontal Directional Drilling under Alabama Highway U.S. Route 43.

Cardno ENTRIX Shaping the Future

Denbury

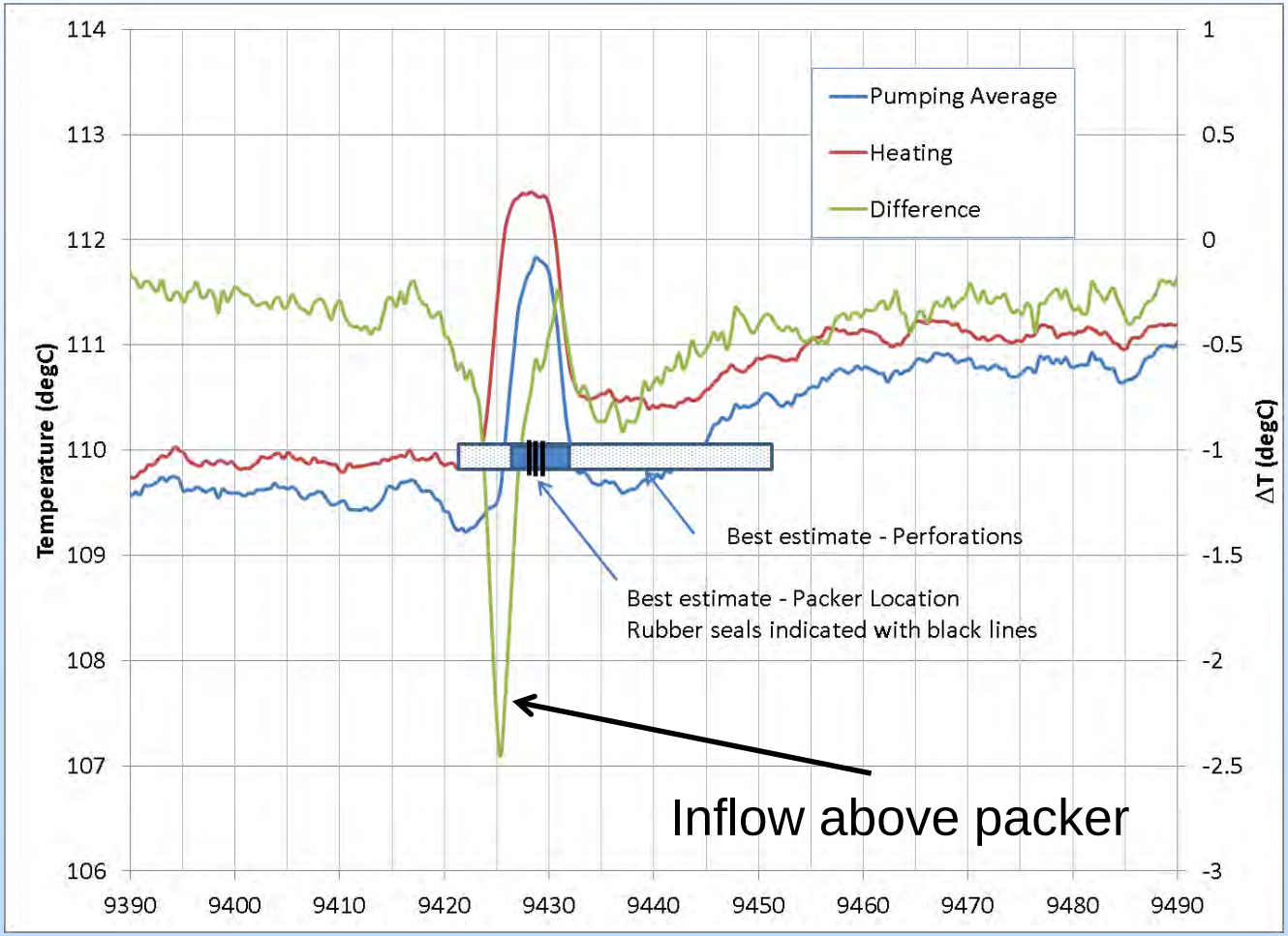
Fiber Optic Distributed Acoustic Sensing (DAS)

- Fiber optic cable for distributed temperature and acoustic measurements one sensing technology tested in the Modular Borehole Monitoring (MBM) System
- Migrated image →
  - Observed strong reflectors
  - Good tie to formation logs (e.g., Selma Chalk)
- No “bright” spot observed where CO_2 was injected
- Image has sufficient quality to conduct time-lapse analysis using results from the second (final) survey



Fiber Optic Distributed Temperature Sensing (DTS)

FO-Based Distributed Temperature Sensing (DTS) Allowed Us to Diagnose a Completion Problem with Our Observation Well



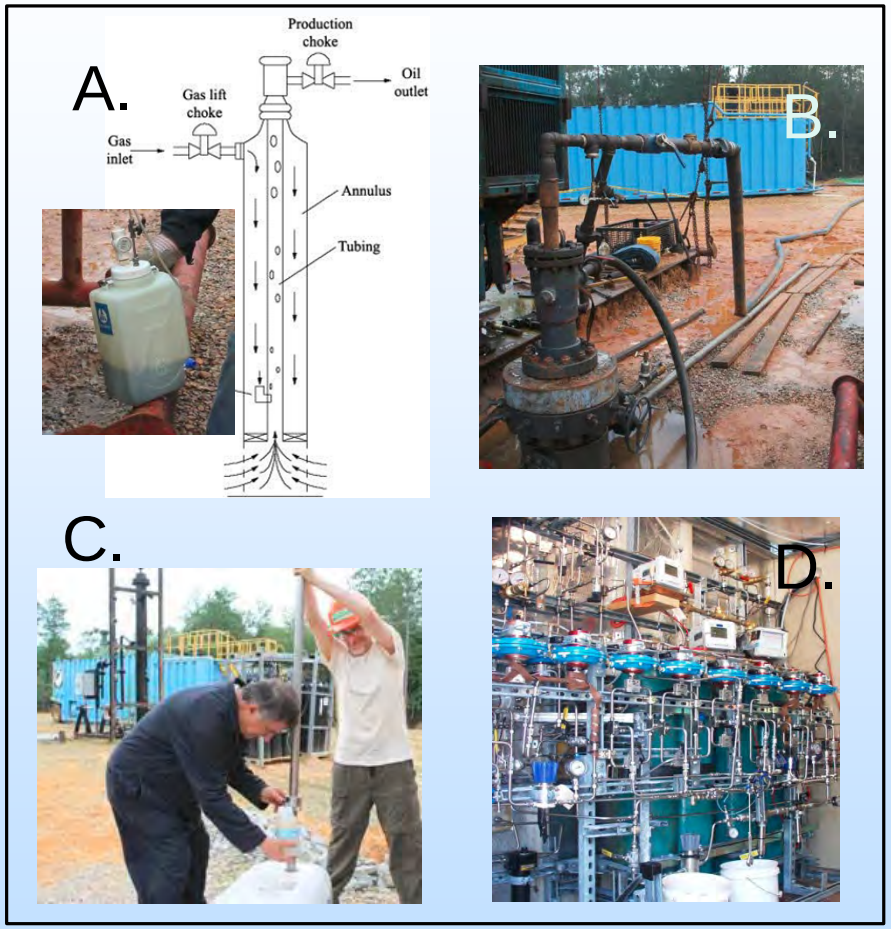
In-zone Comparison of Fluid Sampling Methods (U-tube, Gas lift, Pumping, Kuster Sampler) (Conaway et al., IJCG, 2016)

A. Gas-lift
   - Samples had the highest pH indicating possible loss of dissolved gas
   - Sampling method should be limited to major and unreactive solutes

B. Pumping
   - Relatively high Fe concentrations compared to other methods, showing evidence of contamination or geochemical changes in samples
   - Sampling method should be limited to major and unreactive solutes

C. Kuster sampler:
   - Field measurements of initial pH had the lowest value
   - Geochemical data consistent in repeated sampling

D. U-tube:
   - In general, sample results are comparable to the Kuster method



USGS collecting in-zone groundwater samples using:
A. gas-lift; B. electric submersible pump; C. Kuster sampler; and D. u-tube sampler

USGS science for a changing world

All Good Things Come to an End, but CO_2 Storage is Forever

Installation of Injection Well D9-7 #2

Abandoned Well Pad Prior to Drilling D9-7 #2