Southeast Regional Carbon Sequestration Partnership

Citronelle Project

Carbon Storage R&D Project Review Meeting
Pittsburgh, PA
August 18, 2015

Gerald R. Hill, Ph.D.
Senior Technical Advisor
Southern States Energy Board

Presentation Outline

- **Jerry Hill, SSEB**
  - SECARB Overview
- **Jerrad Thomas, Southern Company**
  - Capture Unit Overview
  - Capture R&D Accomplishments
- **Rob Trautz, EPRI**
  - Storage Overview
  - Storage R&D Accomplishments

SECARB Phase III

Anthropogenic Test

Capture: Alabama Power 's Plant Barry, Bucks, Alabama

Transportation: Denbury

Geo Storage: Denbury's Citronelle Field, Citronelle, Alabama

Early Test

Denbury Resources' Cranfield Field Near Natchez, Mississippi

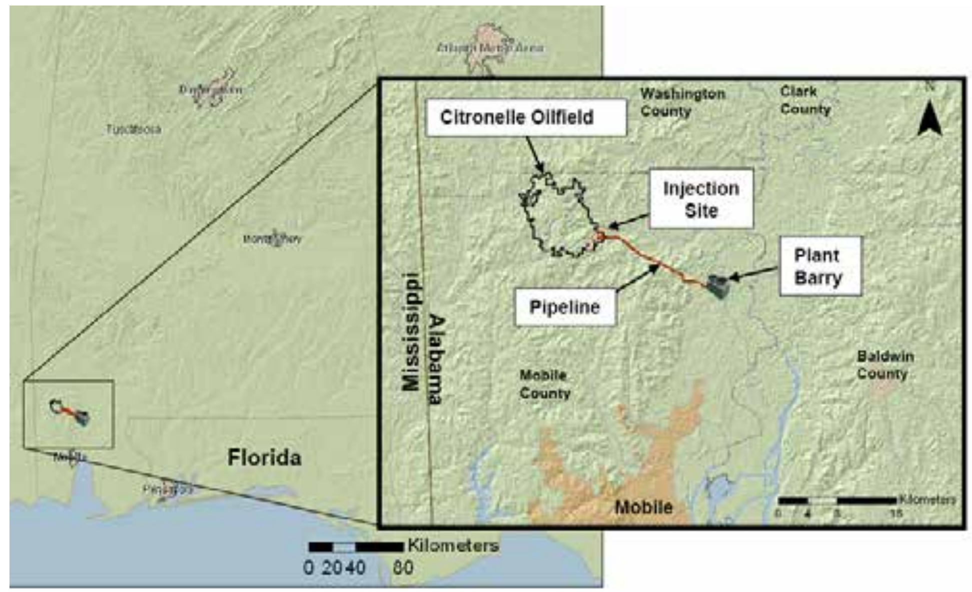
CO_2 Source: Denbury

CO_2 Transportation: Denbury

Saline MVA: GCCC

SECARB Phase III Anthropogenic Test

- Carbon capture from Plant Barry (equivalent to 25MW of electricity).
- 12 mile CO_2 pipeline constructed by Denbury Resources.
- CO_2 injection into ~9.400 ft. deep saline formation (Paluxy) above Citronelle Field
- Monitoring of CO_2 storage during injection and 3years post-injection.




Power Plant


Capture

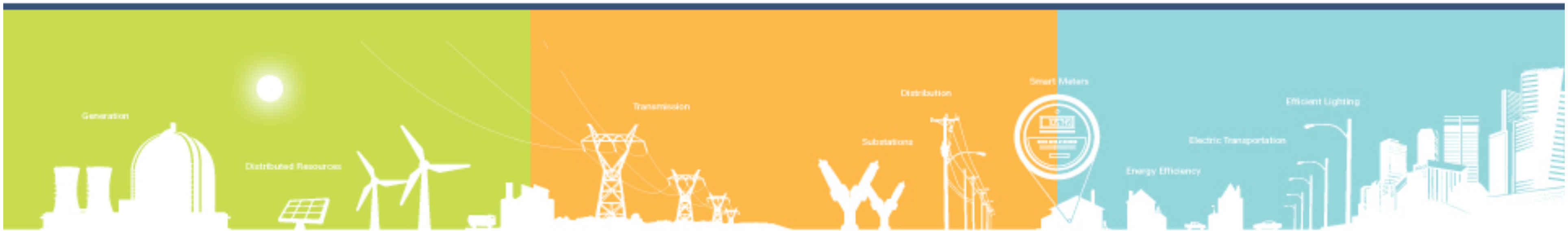
Transport


Storage

Plant Barry 25 MW Demo

Jerrad Thomas | Research Engineer

Southern Company Services, Inc.



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Carbon Capture and Storage Projects

National Carbon Capture Center

- U.S. DOE facility operated by Southern Company.
- Accelerates commercialization of technologies.
- Coal or natural gas constituents tests.
- Enables coal-based power plants to achieve near-zero emissions

25-MW CCS Demo at Plant Barry

- 90% CO_2 capture.
- Capture, compression, transport, sequestration.
- ~115,000 tons sequestered, ~240,000 tons captured.
- Largest CCS facility on a fossil-fueled power plant in the U.S.

Kemper County IGCC project

- 582 megawatts of power.
- State-of-the-art coal gasification design.
- Will use a four-billion-ton reserve of Mississippi lignite.
- Affordable, abundant, but little-used natural resource.
- Will capture at least 65% of its CO_2 emissions for EOR use.
- Will reduce nitrogen oxide, sulfur dioxide and mercury.

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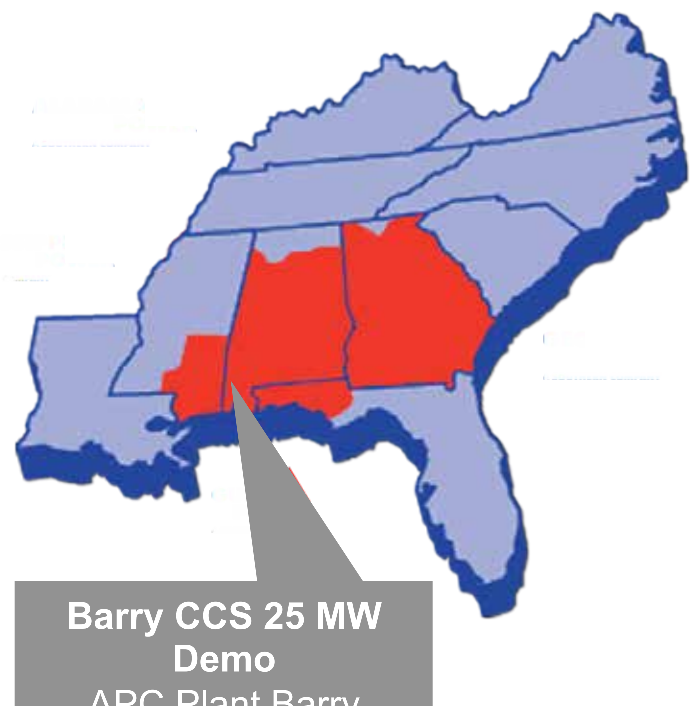
Project Overview

- Located just north of Mobile, Alabama at Alabama Power Plant Barry

- Largest CO_2 capture project on a coal-fired power plant in the United States

- First CO_2 pipeline permitted and constructed in the State of Alabama

- First integration of a CO_2 capture plant on a coal plant with pipeline transportation and injection for geologic storage



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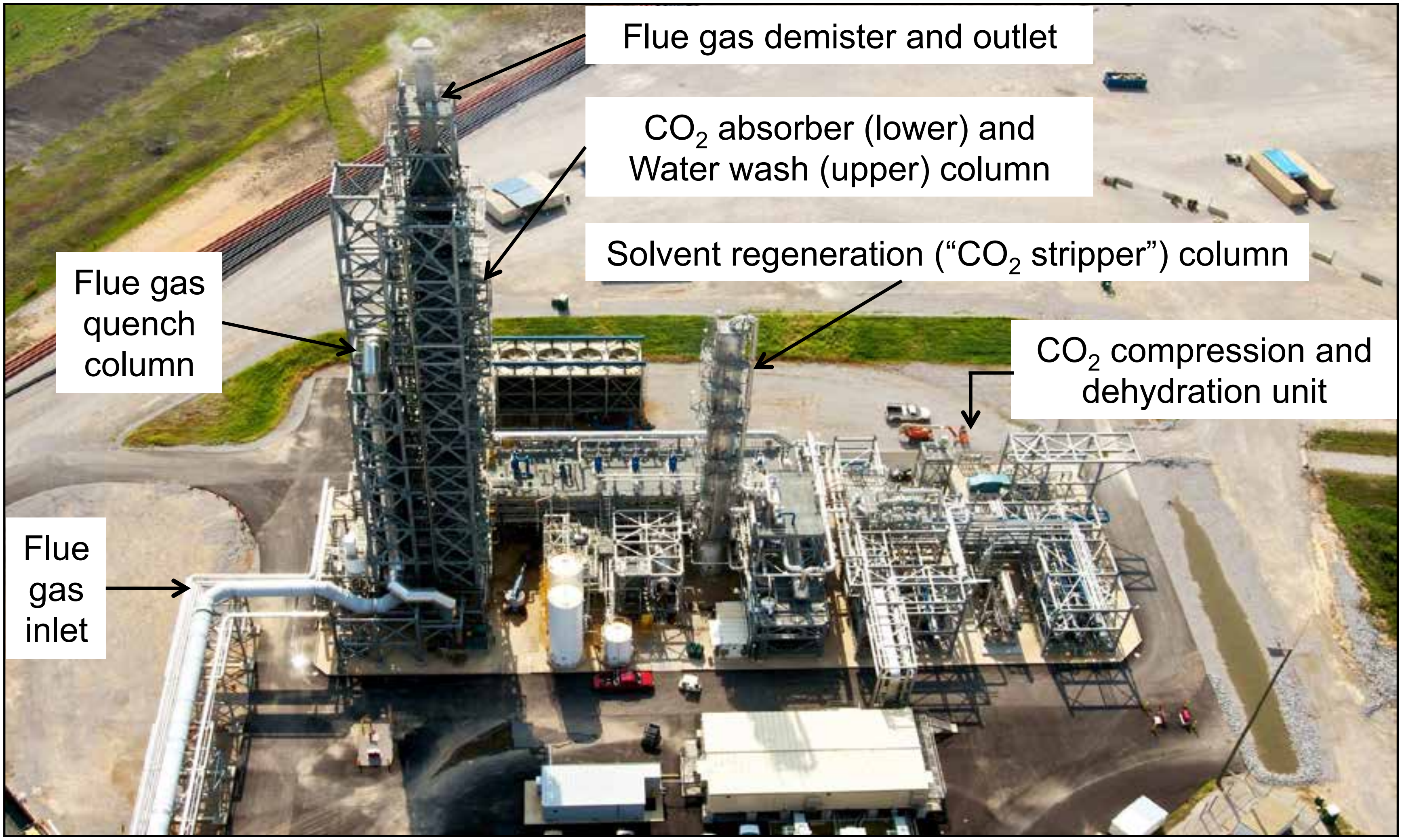
Information and Goals

- CO2 Capture and Compression
  - SCS/MHI collaboration with partners
  - KM-CDR capture technology
- Transportation and Sequestration
  - DOE SECARB Phase III “Anthropogenic Test”
  - 100-300 kMton of CO2 will be injected into a saline formation over 2-3 years
  - 12 mile CO2 pipeline to Denbury Resources, Inc. injection site into Citronelle Dome
- Objectives/Goals
  - Advance saline sequestration technology through large field test
  - Characterize CCS operations to support larger scale development and deployment
  - Continue outreach and education to ensure seamless deployment

CO2 Capture Plant



Plant Performance

- Gas In for CO_2 Capture Plant: June, 2011
- Commissioning of CO_2 Compressor: August, 2011
- Commissioning of CO_2 Pipeline: March, 2012
- CO_2 Injection: August, 2012
  (America's Largest Integrated CCS from a Coal-fired Power Plant)

Items		**Results**
Total Operation Time	**hrs**	**>10,000**
Total Amount of Captured CO_2	**metric tons**	**>220,000**
Total Amount of Injected CO_2	**metric tons**	**114,000**
CO_2 Capture Rate	**metric tons per day**	**500**
CO_2 Removal Efficiency	**%**	**90**
CO2 Stream Purity	**%**	**99.9+**
Steam Consumption	**ton-steam/ton-CO_2**	**0.98**

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Project Test Items

Item	Main Results
Baseline mass and heat balance	Verified that **steam consumption was lower than expectation** under the design condition (CO_2 removal efficiency: 90%, CO_2 capture rate: 500MTPD).
Emissions and waste streams monitoring	Successfully demonstrated **amine emission reduction** technologies under the various SO_3 concentration condition (2013)
Parametric test for all process systems	Verified **operation performance** under several controlled operating parameters changes. (2011-2012) Demonstrated several improved technologies for the cost reduction. (e.g. MHI Proprietary spray distributor) (2013)
Performance optimization	Achieved **0.95 ton-steam/ton-CO_2** by optimizing steam consumption. (2011)
High impurities loading test	Verified that the **amine emission increased** as a result of **higher SO_3 loading**. (Oct. 2011) Verified that the impurities were removed from the solvent by **reclaiming** operation. (2012, 2013)

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(1) Amine Emission Evaluation

- Amine emissions increased significantly with a small amount of SO3.
- MHI's amine emission reduction system decreases amine emissions down to less than 1/10 of the conventional system

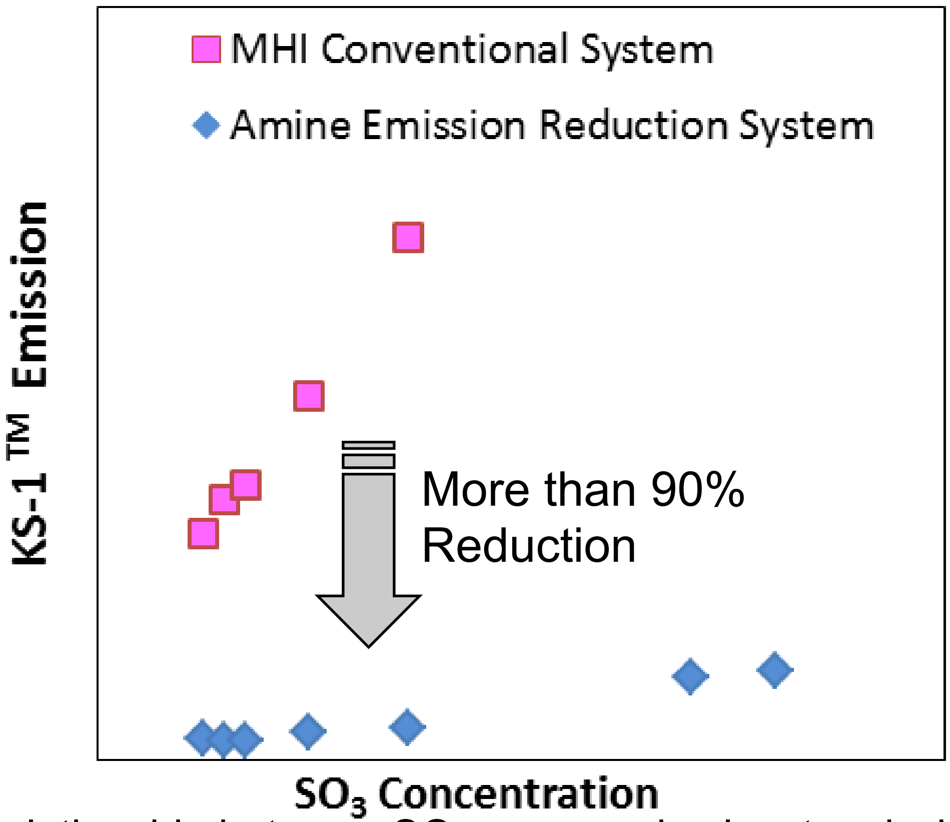

Fig. Relationship between SO_3 conc. and solvent emission

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(2) Improved Technology

- Proprietary spray type distributor developed by MHI to reduce weight of tower internals
- Keeping the same performance as the trough type distributor approximately 50% cost reduction of tower internals was achieved

Fig. Trough Type Distributer

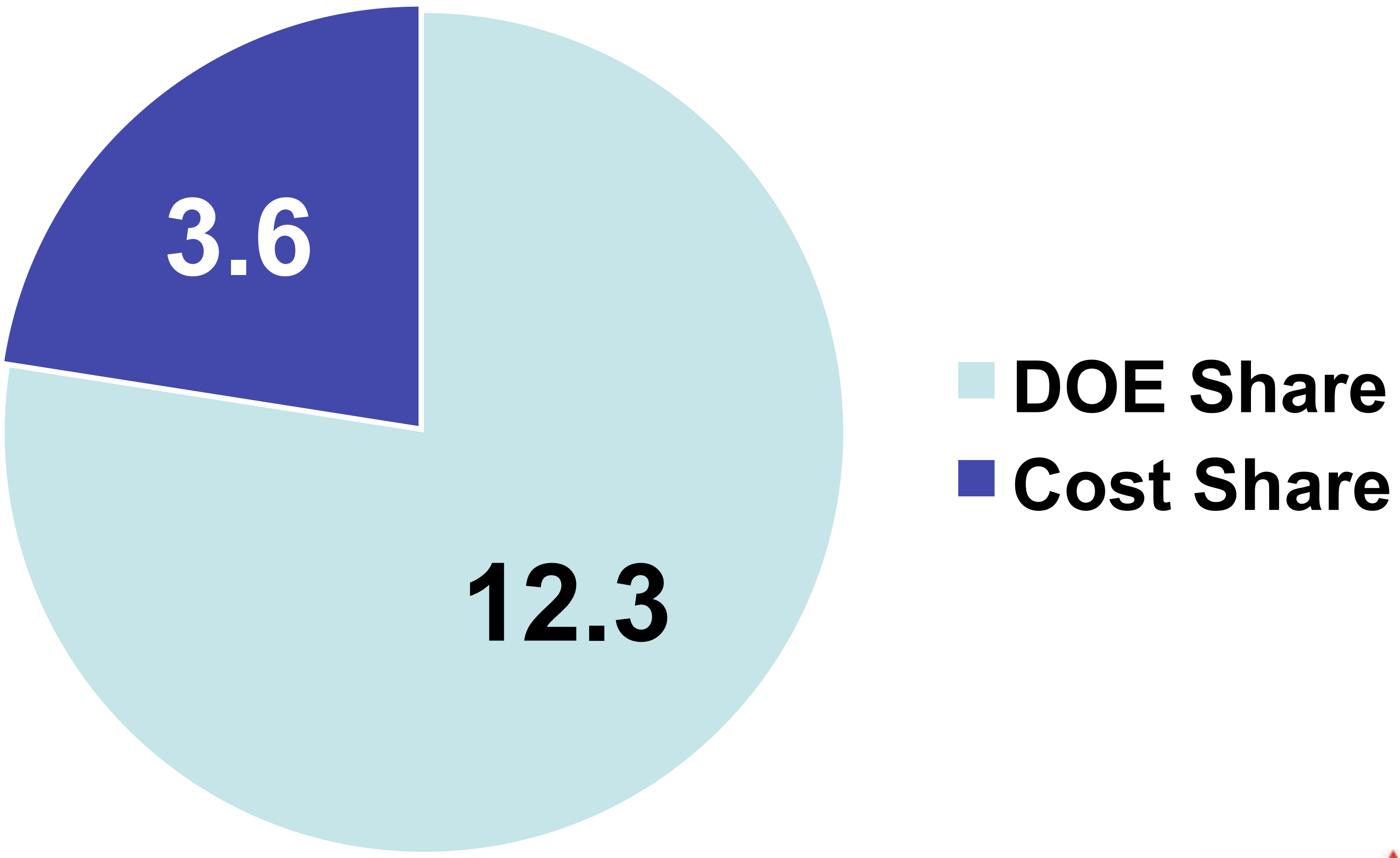
Fig. Spray Type Distributer (MHI Proprietary)

High Efficiency System

Project Scope

- Integrate a 25 MW ***waste heat recovery*** technology termed Mitsubishi High Efficiency System (HES) into 25 MW CCS plant and Plant Barry, Unit 5
- Recover low grade waste heat in flue gas and CO_2 to preheat condensate ***replacing LP steam***
- Evaluate improvements in the energy performance and emissions profile of the integrated plants
- Employ 0.5MW mini ESP to test effect of HES on SO3 and trace metals emissions

Total Project Budget ($MM)



Flue Gas Cooler captures SO_3

- Operates downstream of the APH
- Mechanism for removal of SO_3 from flue gas
  - SO_3 (g) + H_2O (g) --> H_2SO_4 (g)
  - H_2SO_4 (g) --> H_2SO_4 (l)
  - H_2SO_4 (l) condenses on fly ash in flue gas and a protective layer of ash on tube bundles
- Flue Gas Cooler tube skin temperature < SO_3 dewpoint
  - Alkaline species in fly ash (Ca, Na) neutralize H_2SO_4
  - Silicates, etc. physically adsorb H_2SO_4

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Other benefits of Flue Gas Cooler

- Improve removal of Hg, Se, SO_3 across the ESP
- Reduce AQCS cost
  - Improve ESP performance
  - Improve FGD performance
  - Improve CCS performance
- Potential to simplify boiler/steam turbine cycles
- Improve plant heat rate

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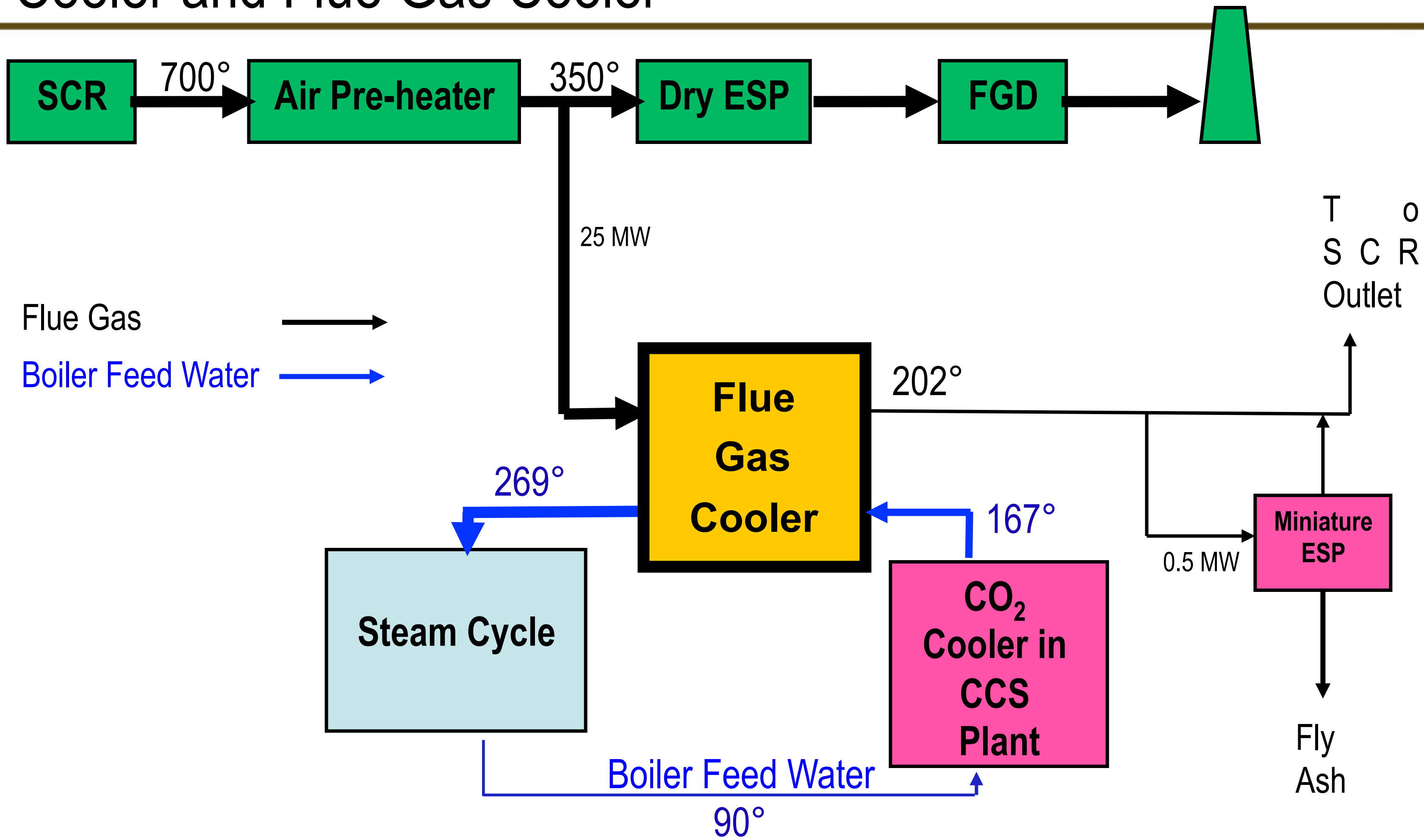
PROJECT = Boiler feed water will be heated with CO_2 Cooler and Flue Gas Cooler



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BP3 completes March 2016

BP1
- FEED and Target Cost Estimate ✓
- Permitting

BP2
- Engineering, Procurement, Construction ✓

BP3
- Operations
- Field Testing Analysis

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Remaining project work

Complete Construction → **Commission** → **Operations and Testing**

Dec 2014 | **May 2015** | **June 2015 – Nov 2015**

- Verify efficiency
- Estimate reduction in FGD water use
- Measure corrosion, erosion
- Test water quality
- Measure SO_3, trace metal removal

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Thank You!

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SECARB Phase III Citronelle Project (Anthropogenic Test) in Alabama

Rob Trautz, Princ. Tech. Leader, EPRI

Carbon Storage R&D Project Review Meeting

18-August-2015

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SECARB
Southeast Regional Carbon Sequestration Partnership

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Energy to Serve Your World℠

SOUTHERN STATES ENERGY BOARD

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Denbury

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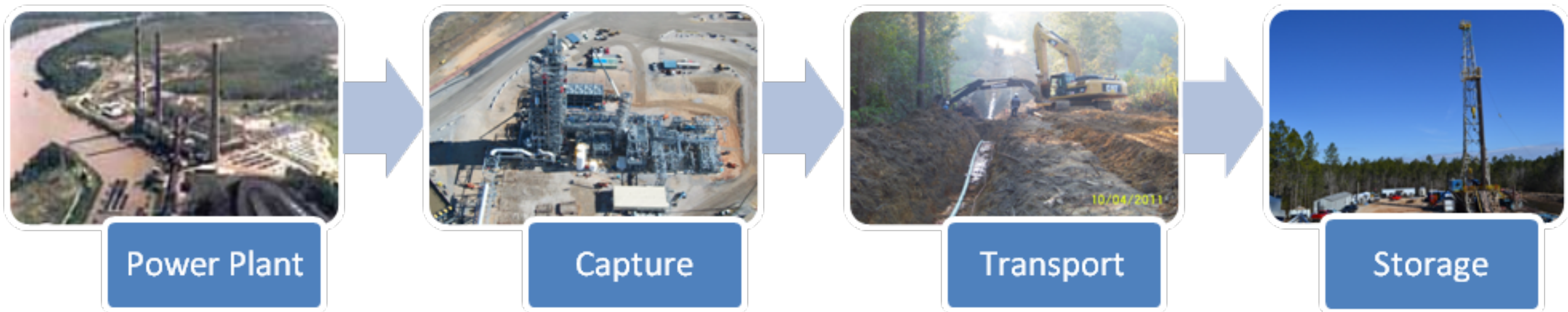
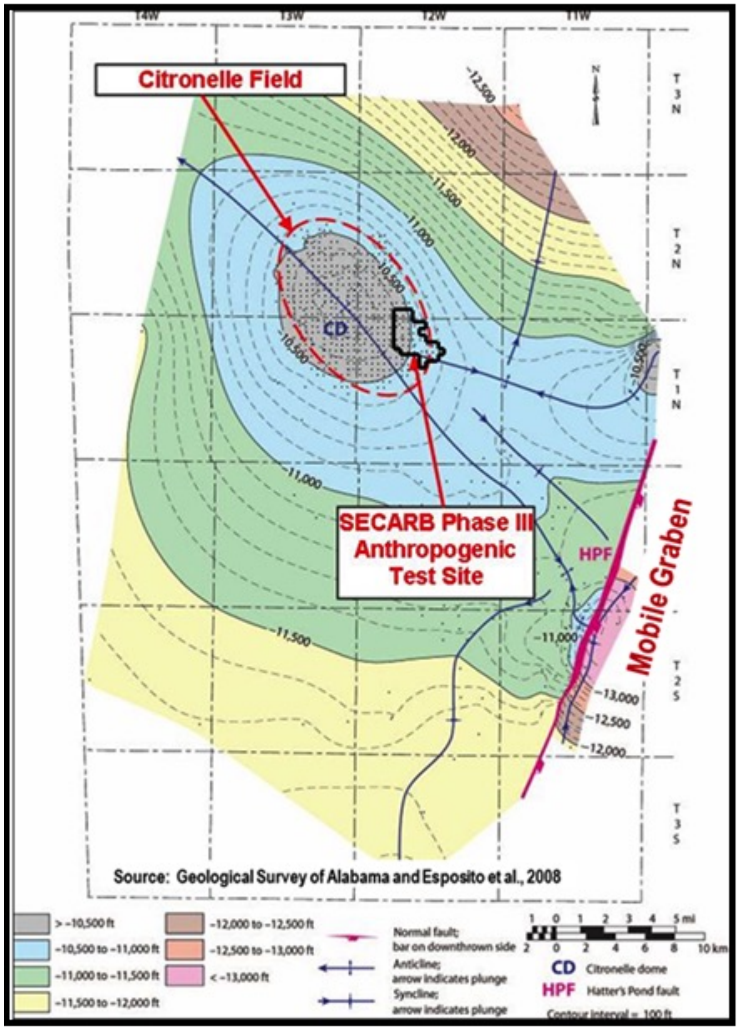
Storage Project Objectives



1. Test the CO_2 flow, trapping and storage mechanisms of the Paluxy Formation
2. 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
3. Test the adaptation of commercially available oil field tools and techniques for monitoring CO_2 storage
4. Test experimental CO_2 monitoring activities, where such technologies hold promise for future commercialization
5. Begin to understand the coordination required to successfully integrate all four components (capture, transport, injection and monitoring) of the project
6. Document the permitting process for all aspects of a CCS project

Largest demonstration of CO_2 capture, transportation, injection, monitoring and storage from a coal-fired electric generating unit in the United States

Storage Site Overview—Citronelle Oilfield



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	Saline Reservoir
			Basal Shale	Primary Confining Unit
		Paluxy Formation	'Upper' 'Middle' 'Lower'	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

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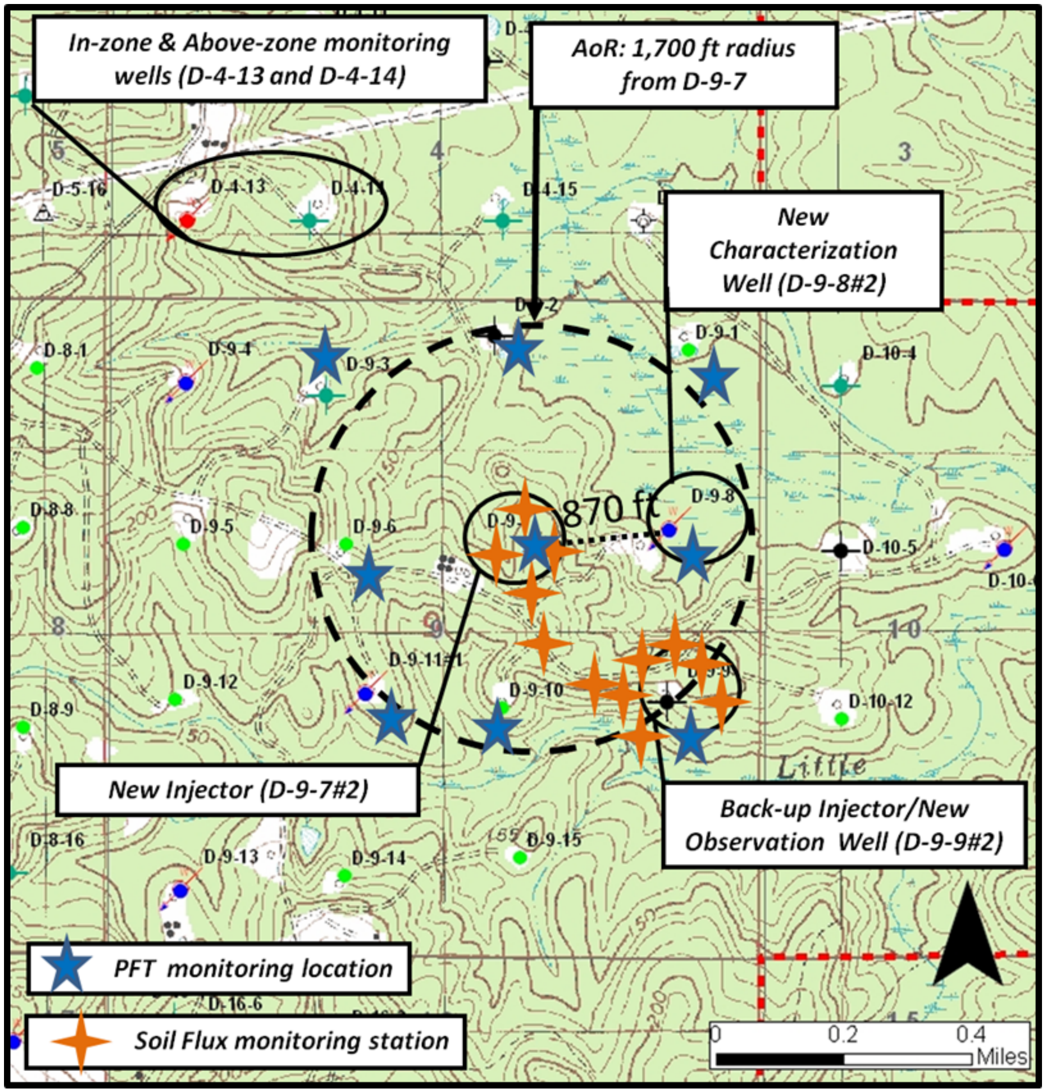
Storage Project Status

- Alabama Department of Environmental Management (ADEM) issued Class V permit, Nov. 2011
- ADEM granted permission to inject on August 8, 2012
  - Injection commenced on August 20, 2012
- Injection ended September 1, 2014
  - Approximately 114,104 metric tons of CO_2 injected
- A crosswell seismic survey acquired in June, 2014 captured a time-lapse image of the CO_2 plume
- Other testing and monitoring activities have indicated containment
- The project entered the *Post-Injection Site Care Period* on September 2, 2014
- *Site closure based on* ***demonstration of CO_2 containment and non-endangerment of USDW***

1. Monitoring & Modeling Lines of Evidence

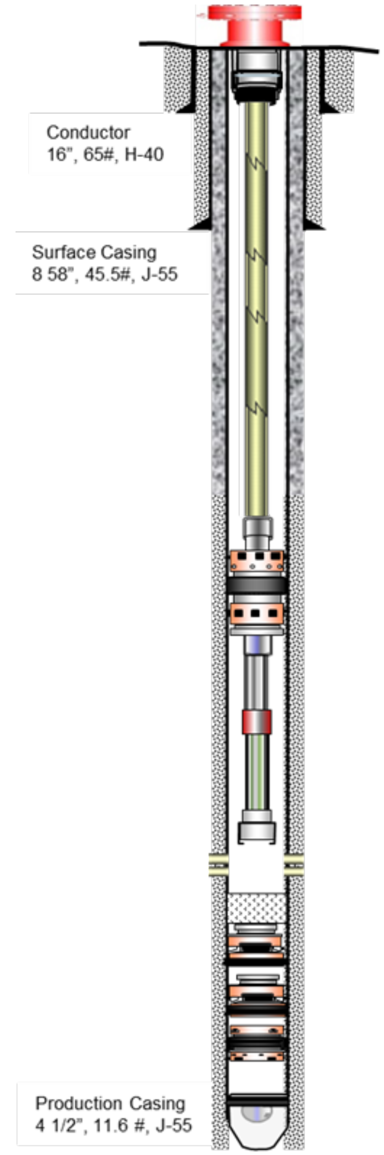
Anthropogenic Test MVA Program



- Multiple lines of evidence to confirm CO_2 containment include:
  - Soil CO_2 flux
  - PFT monitoring
  - Crosswell Seismic and VSP surveys
  - PNC logging (above zone saturation)
  - Pressure monitoring
- Assure non-endangerment of USDWs
  - Monitoring geochemistry of multiple aquifers
- Monitoring results are used to inform the reservoir simulation

MVA Elements and Frequency

MVA Method	Frequency				
	Continuous	Monthly	Quarterly	Annual	Milestone *(Baseline, Injection, Post)*
Shallow					
Soil flux		■			
Groundwater sampling (USDW)			■		
PFT survey				■	
Deep					
CO2 volume, pressure & composition	■				
Reservoir fluid sampling				■	
Injection, temperature & spinner logs				■	
Pulse neutron logs				■	
Crosswell seismic					■
Vertical seismic profile (VSP)					■
Experimental					
Distributed Temperature Sensing (DTS)		■			
Comparative fluid sampling methods				■	
MBM VSP				■	
Distributed Acoustic Sensing (DAS)				■	
MBM VSP & OVSP Seismic				■	



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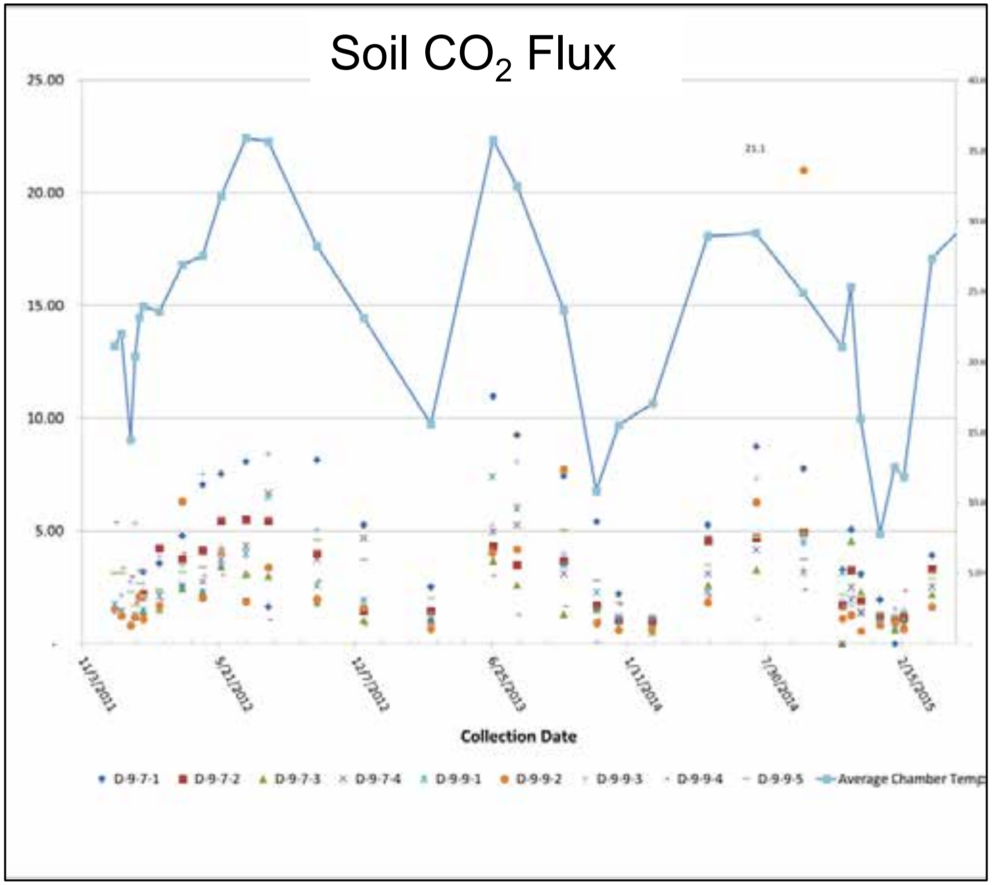
CO_2 Containment—Soil CO_2 Flux and Tracer Monitoring



Tracer Results

Well	Innoculation	Jun-13	Nov-13	Mar-15
D-9-1	ND	ND	ND	ND
D-9-2	ND	ND	ND	ND
D-9-3	ND	ND	ND	ND
D-9-6	ND	ND	ND	ND
D-9-7	ND	ND	ND	ND
D-9-8	*Invalid Data*	ND	ND	ND
D-9-9	ND	ND	ND	ND
D-9-9	ND	ND	ND	ND
D-9-10	*Invalid Data*	ND	ND	ND
D-9-11	ND	ND	ND	ND

PRAXAIR

Soil CO_2 results appear to vary as a function of mean temperature and tracer surveys have been non-detect

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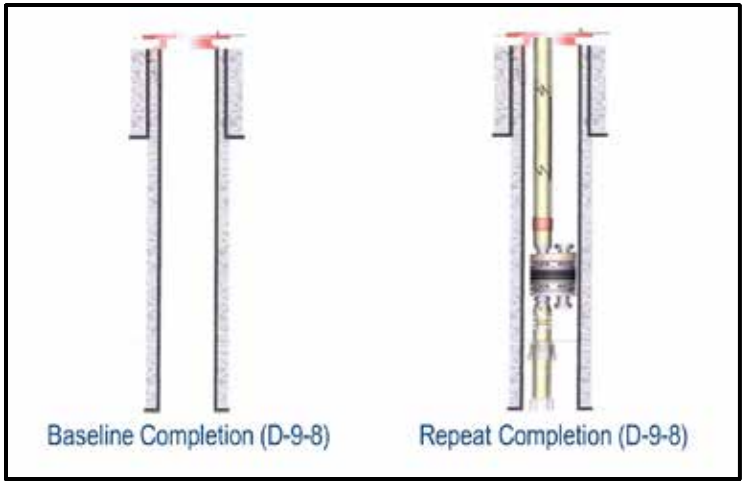
Deep Monitoring—Time-Lapse Crosswell Seismic

Schlumberger

- Crosswell seismic surveys allow for high-resolution mapping of the acoustic travel time (velocity) and seismic reflectors between a pair of wells
- When CO_2 displaces water in the formation, it changes the acoustic impedance of the rock
  - Acoustic wave decreases and its direct travel time increases
- Results from "repeat" surveys performed during or after CO_2 injection can be compared to a pre-injection "baseline" survey to image the extent of the CO_2 plume (referred to as "time-lapse imaging")
- Baseline and repeat 2-D crosswell seismic surveys were performed between the injection well and the observation well

Crosswell Survey Configuration and Parameters

- Pre-injection baseline survey acquired on January 19-26, 2012
- Repeat survey was acquired on June 14-23, 2014
- Source Type: Piezoelectric – deployed in D-9-7#2 well
- Receiver type: Hydrophone – 10 levels – deployed in D-9-8#2 well
- 842' between D-9-7#2 and D-9-8#2 at reservoir depth

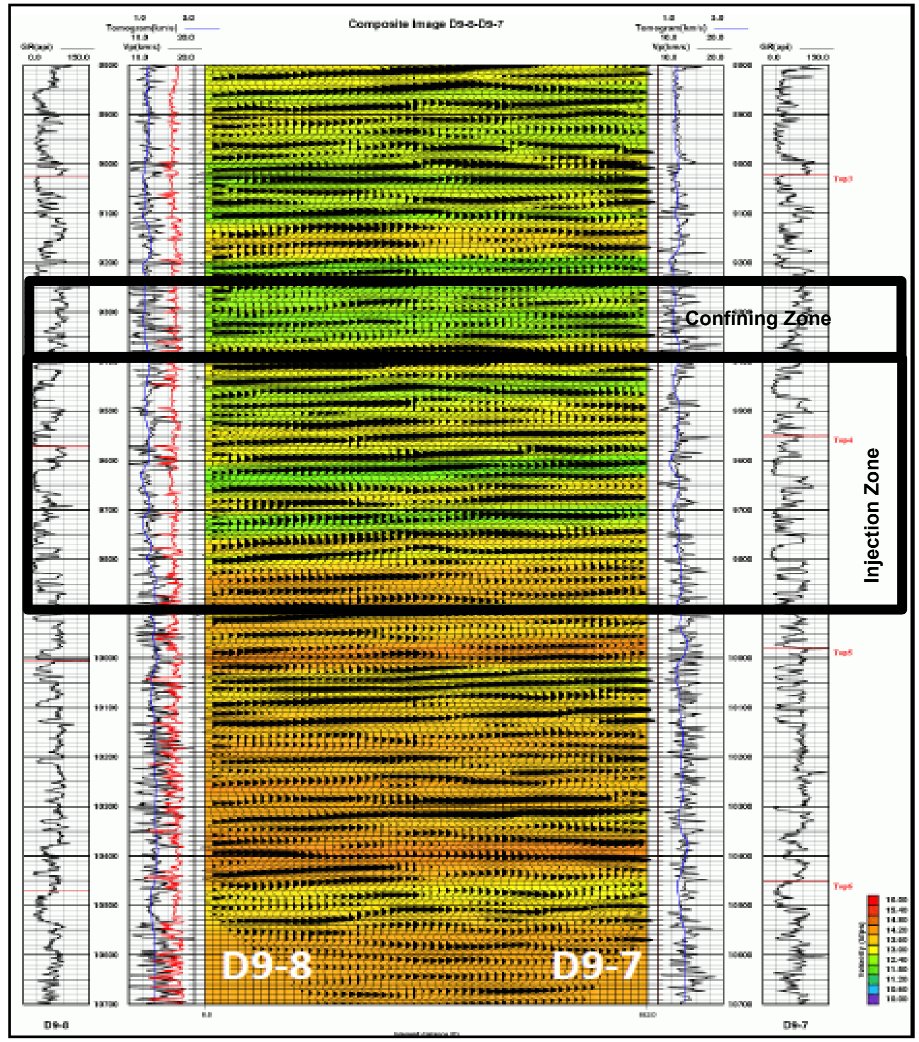


Schematic showing the open well completion in observation well D-9-8 during the baseline survey (left) and packer/tubing completion during the repeat (right)

Receivers were deployed in the open well during the baseline survey and inside the MBM tubing/packer assembly during the repeat survey, thus changing the data acquisition configuration

Baseline Survey Results

- Velocity tomograph and reflection image (right) provided a good representation of the reservoir and confining unit
  - ~10 feet vertical resolution
- No reservoir or confining unit discontinuities or small-scale faults were observed in the reflection data
- Layering observed in the Upper Paluxy will help disperse the CO_2 plume, thus minimizing its footprint
- Baseline velocity tomogram should be of sufficient quality for time-lapse CO_2 plume imaging



Composite image mapping the seismic reflections (squiggles) superimposed on top of the velocity tomogram (colored background)

Comparison of Baseline and Repeat Data Quality

- First arrivals and reflection data from the baseline survey have strong amplitudes and little noise, representing good quality data
- The first arrivals for the repeat survey are fairly "weak" probably due to signal attenuation caused by deploying the hydrophones inside the "stiff" production tubing and packer
- The reflection data that follow the first arrivals are noisy and of poor quality for the repeat survey

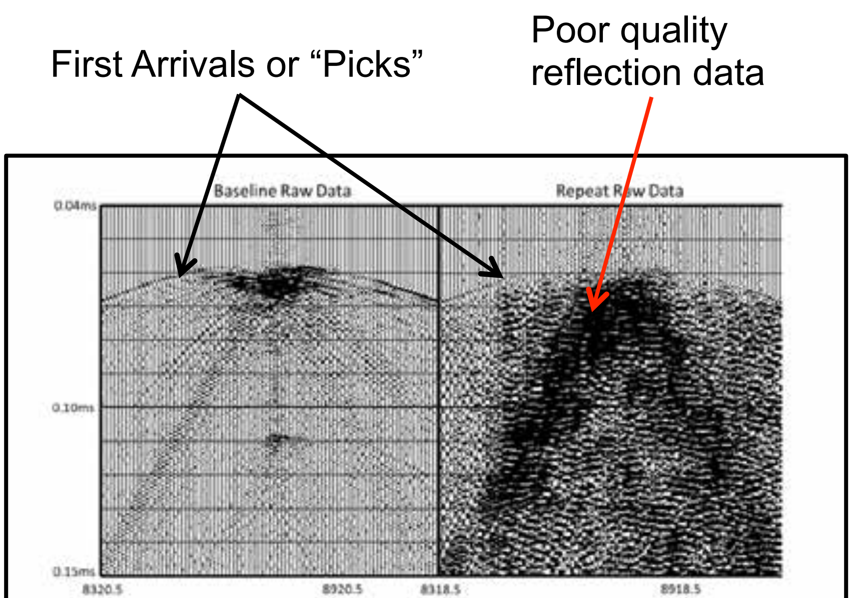


Figure I-3. Profile D-9-8 – D-9-7 baseline and monitor raw data comparison.

Side-by-side comparison of a baseline (left) and repeat (right) shot gather

There is a noticeable decrease in the signal-to-noise ratio (SNR) between the baseline and repeat surveys, which limits data interpretation

Comparison of Crosswell Reflectors

Baseline Tomogram

Strong, continuous reflectors

Repeat Tomogram

Weak and/or discontinuous reflectors

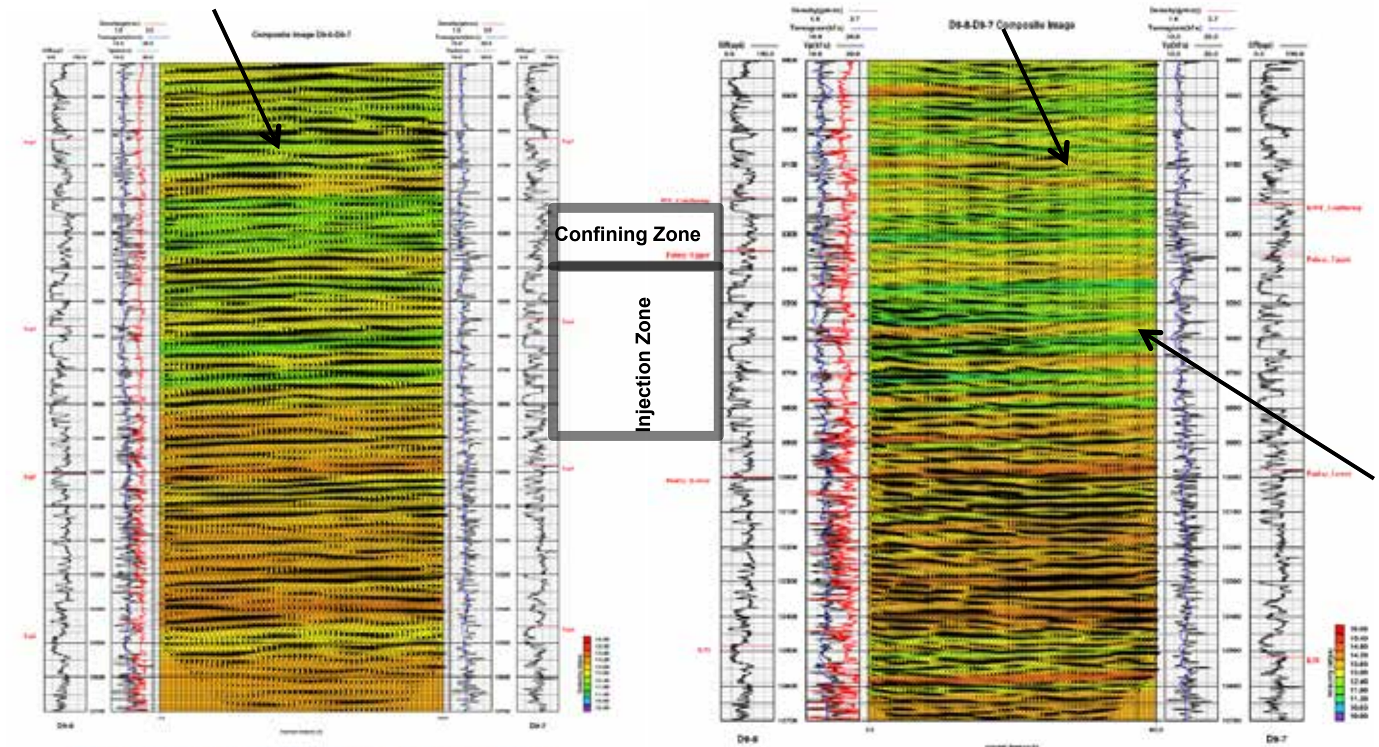


Figure I-4. Profile D-9-8 – D-9-7 baseline composite image

Figure I-5. Profile D-9-8 – D-9-7 monitor composite image

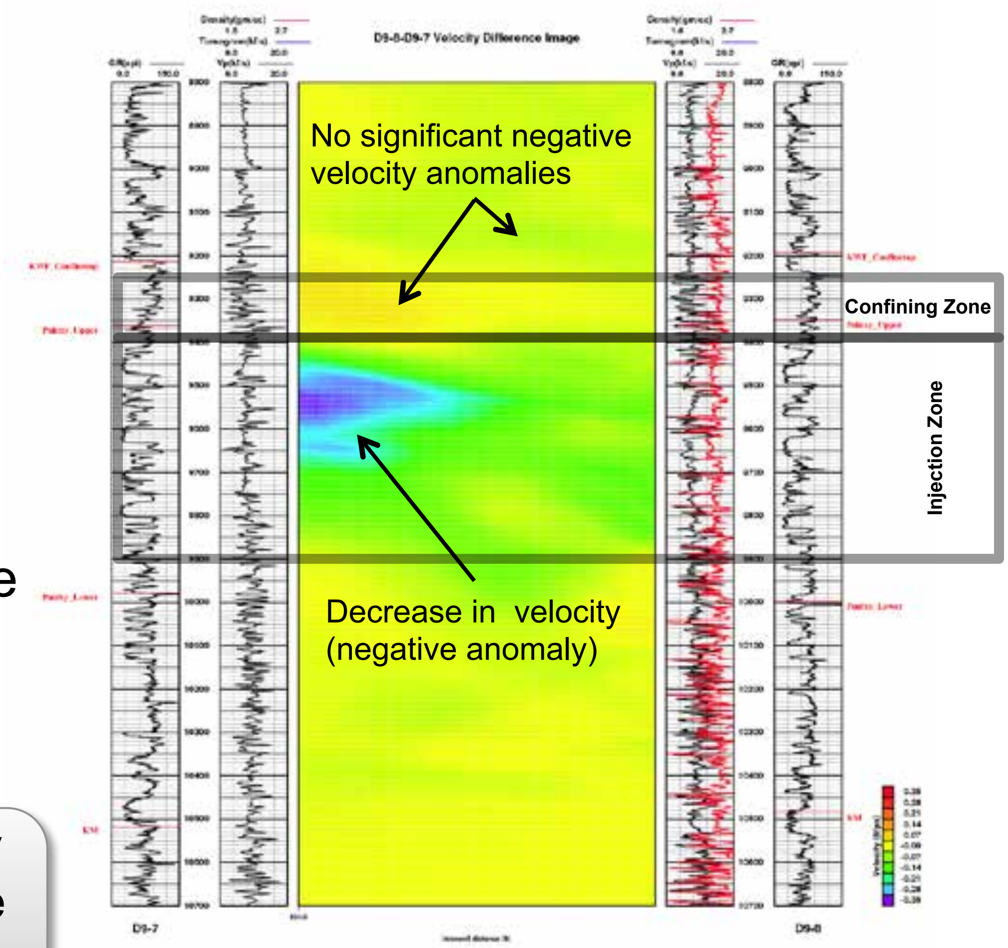
No reflector was detected at or near the top of the CO_2 where one should be present

Reflection data from the repeat survey are of poor quality and limited use. Likely cause is interference by tube waves moving up and down the well

Time-Lapse Differencing Using the Baseline and Repeat Velocity Tomograms

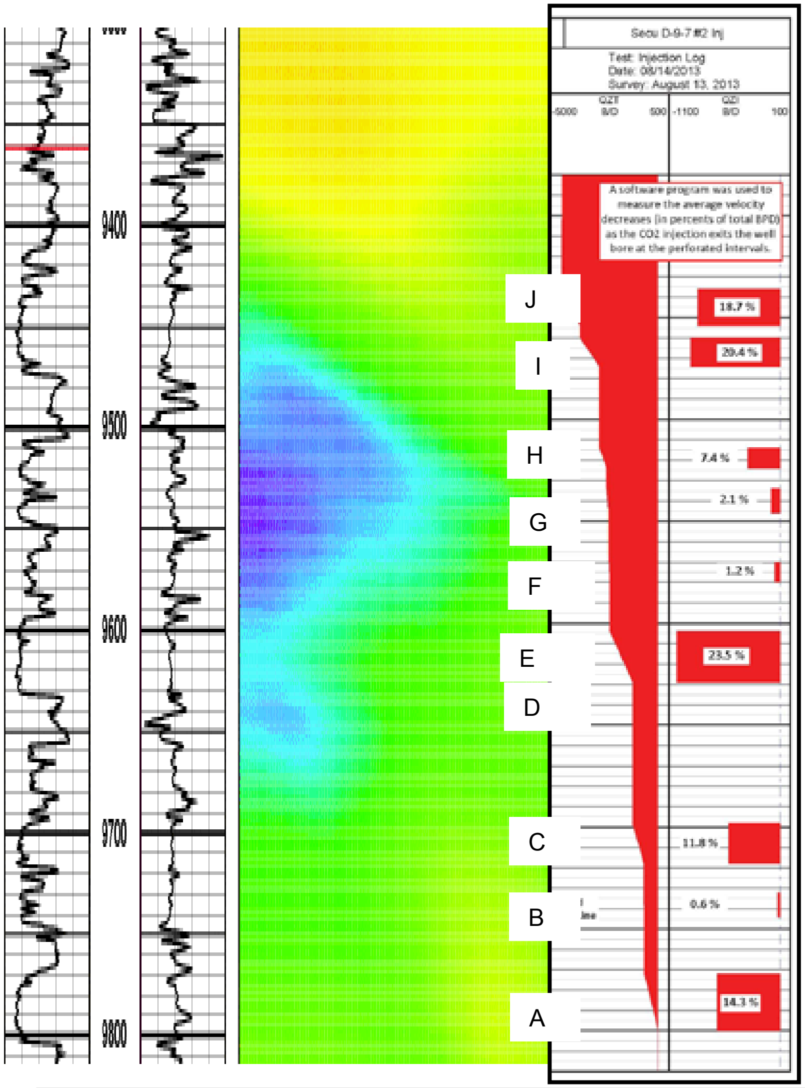
- First arrivals from repeat survey were of sufficient quality to produce a velocity difference image (right) showing regions where seismic velocity has changed over time
- Time-lapse difference image indicates a decrease in seismic velocity in the upper injection zone of up to 3%, suggesting an increase in CO_2 saturation

More importantly, no negative velocity anomalies are observed in or above the confining unit…implying no detectable leakage out of inj. zone



Pixelized difference tomography results without seismic reflection overlay showing positive velocity differences in warm colors and negative differences in cool colors

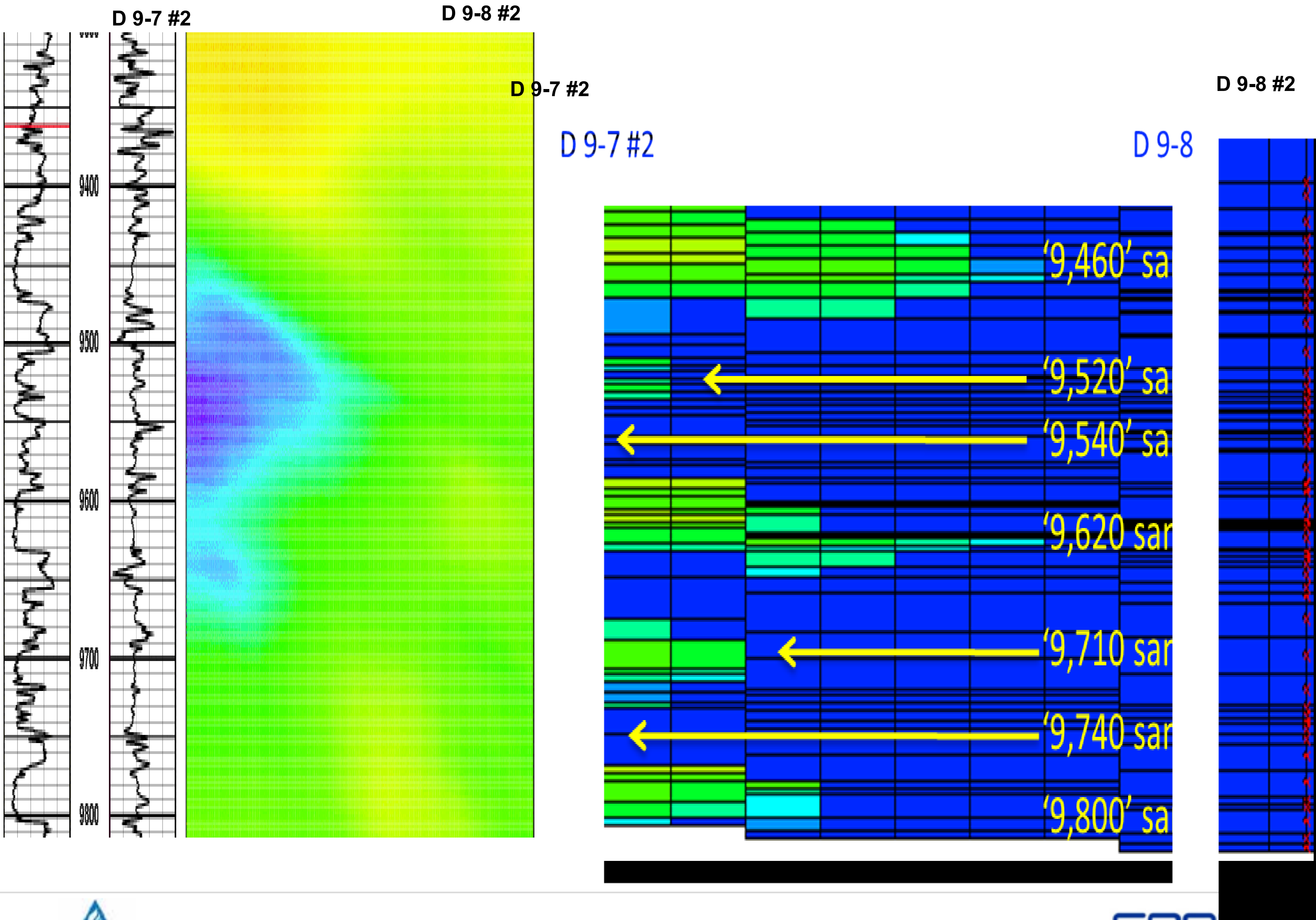
Plume Image Comparison with Spinner Surveys



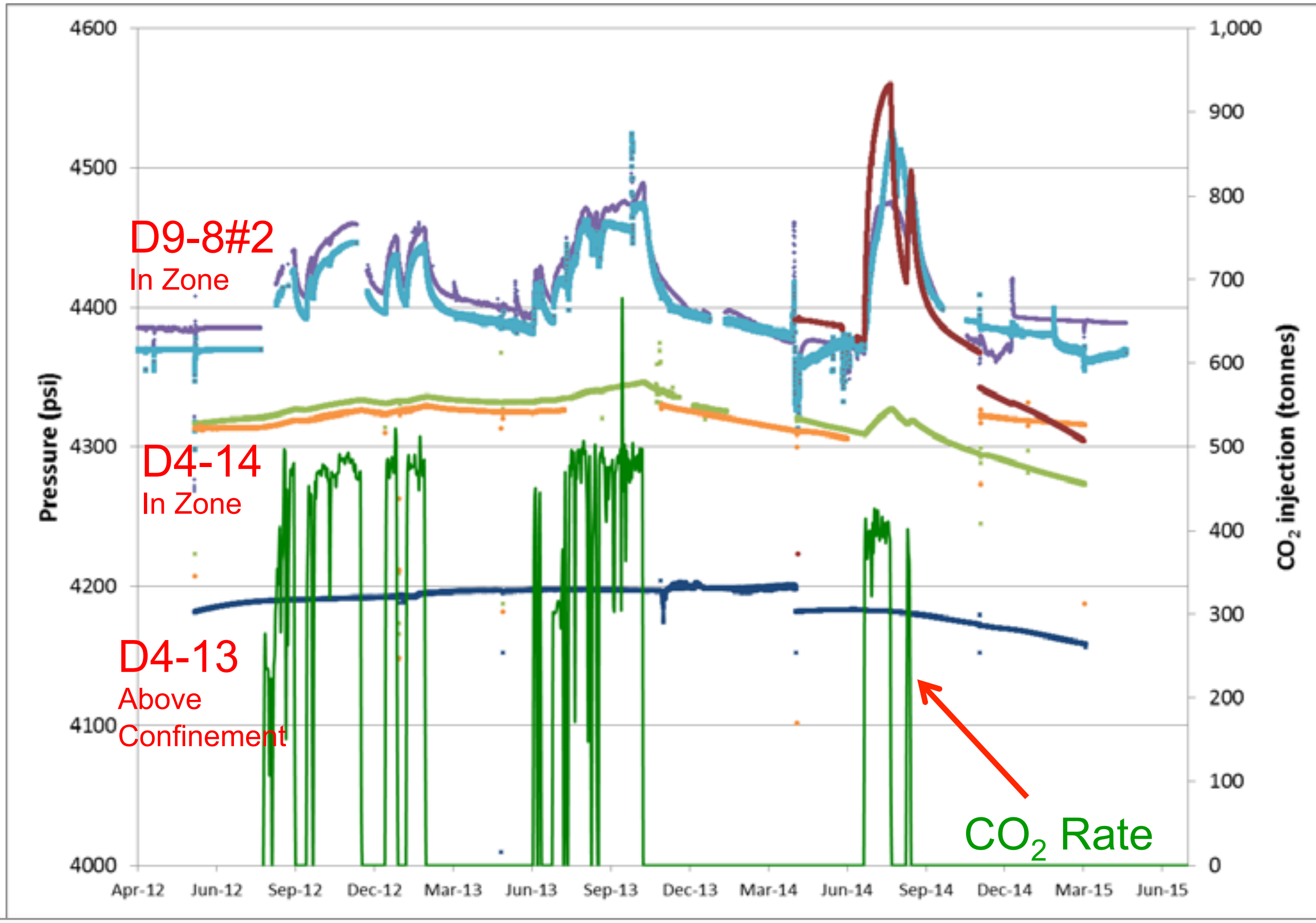
- Time-lapse image shows CO_2 plume located primarily in Paluxy sands F-H
- October 2013 spinner survey show these sands taking only 10% of the flow

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

Plume Image Comparison with Simulation



Deep MVA – Pressure Response



Downhole pressure data is a primary input to the history match and plume model

Plan Next Steps

- Continue to use multiple lines of evidence to demonstrate CO_2 containment and non-endangerment during PISC
  - Continue shallow subsurface and surface monitoring activities
  - Conduct full VSP and crosswell seismic repeats
  - Additional water injection tests to monitor pressure transient times
- Engage regulators throughout project closure process
- Permit closure

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QUESTIONS

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