Plant Barry - Citronelle Field Project Southeast Regional Carbon Sequestration Partnership (SECARB)

Prepared for:

Carbon Storage R&D Project Review Meeting

Pittsburgh, PA

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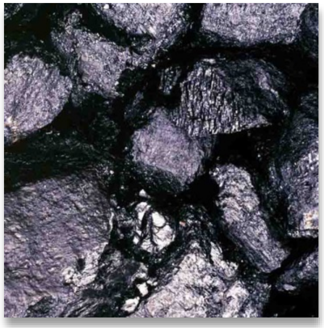

Topics of Discussion

1. Citronelle Field Project Overview
2. Surface and Shallow MVA
3. Deep MVA
4. Experimental MVA
5. Questions, Answers, Discussion

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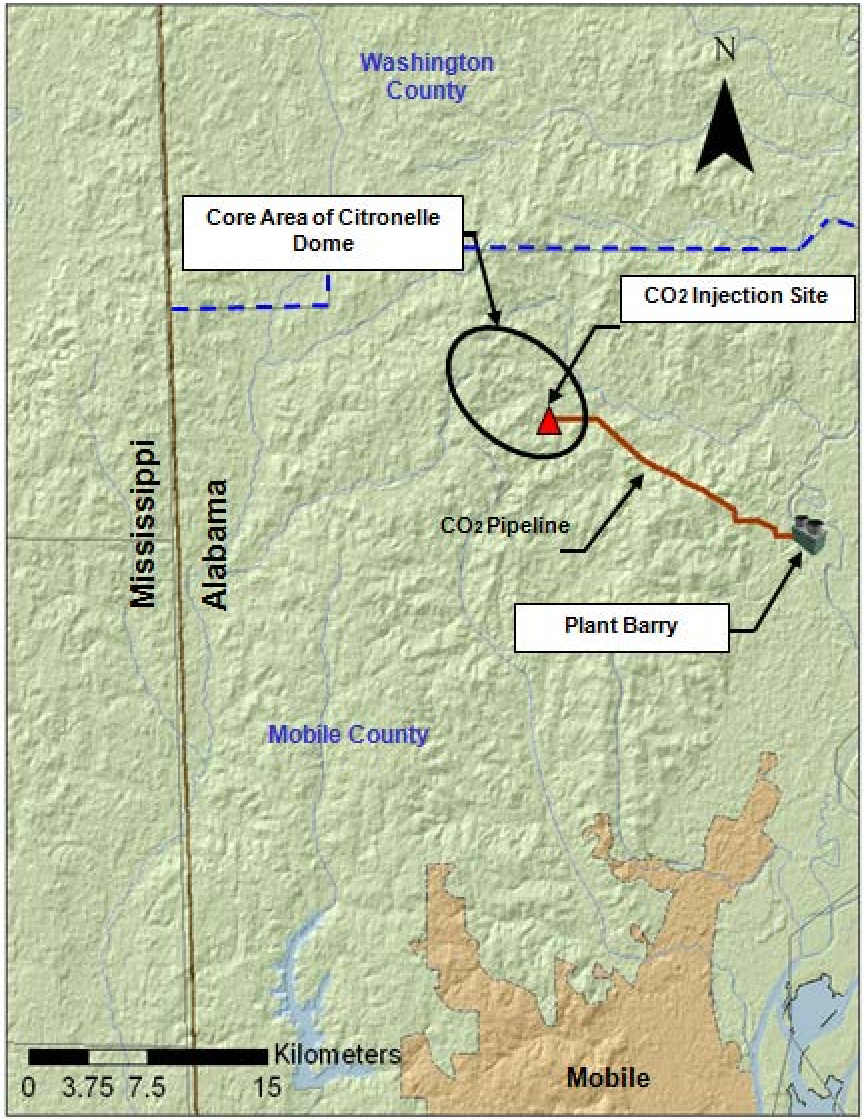
Project Objectives

Baseline 1 year	Injection 2 years	Post 3 years
APR 2011 to AUG 2012	SEPT 2012 to DEC 2014	JAN 2015 to SEPT 2017

1. *Support the United States' largest 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.*

Citronelle Storage Overview



Project Schedule and Milestones

*The CO_2 capture unit at Alabama Power's (Southern Co.) Plant Barry became **operational in 3Q 2011.***

*A newly built 12 mile CO_2 pipeline from Plant Barry to the Citronelle Dome **completed in 4Q 2011.***

*A characterization well was drilled in **1Q 2011 to confirm geology.***

*Injection wells were drilled in **4Q 2011**.*

*100k – 150k metric tons of CO_2 will be injected into a saline formation **beginning 3Q 2012.***

***3 years of post-injection monitoring**.*

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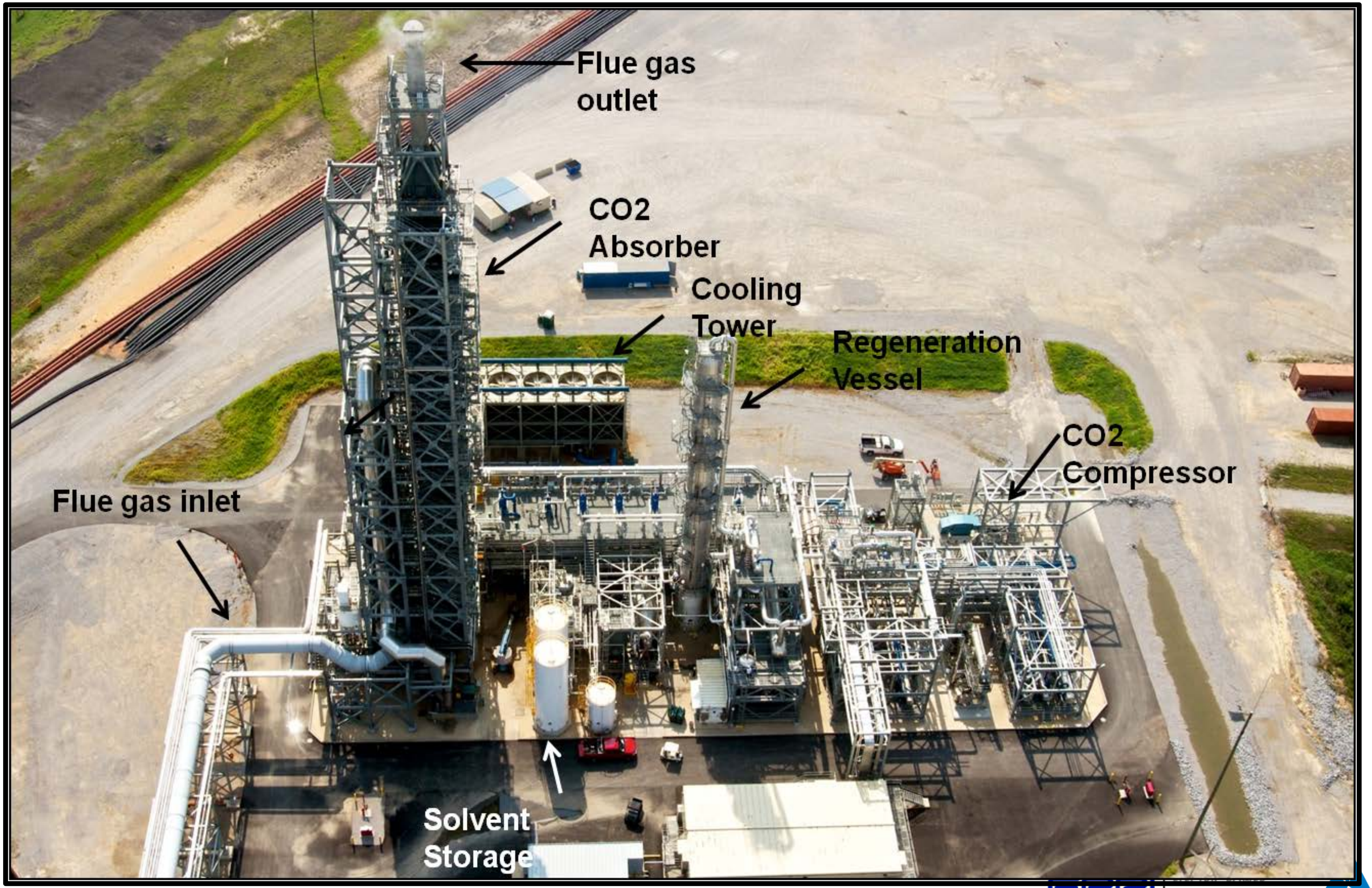
Barry Carbon Capture Project Overview

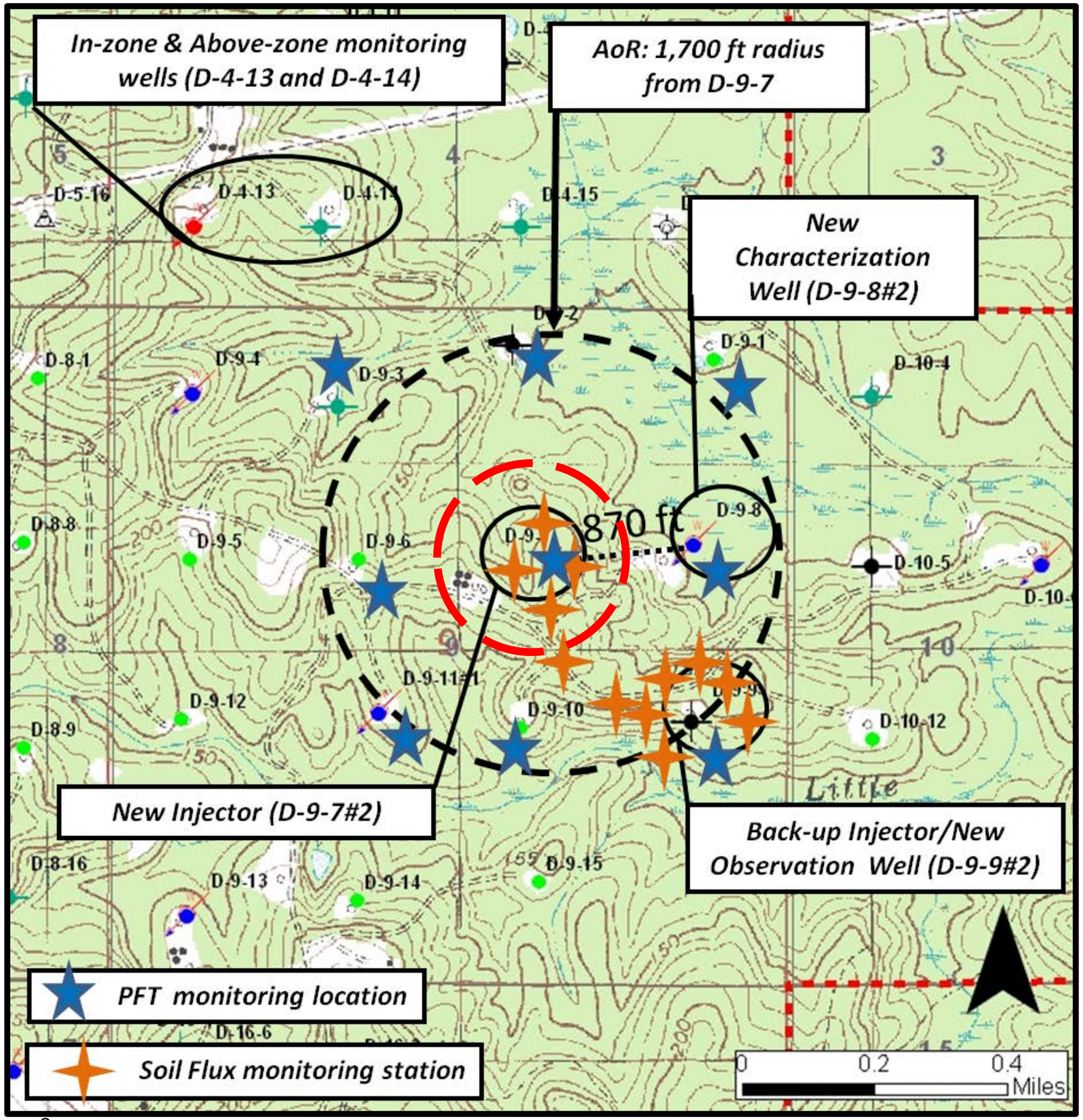


Geologic Overview

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	Wilcox Group	Hatchetigbee Sand Bashi Marl Salt Mountain LS	Saline Reservoir
Tertiary	Paleocene			
Tertiary	Paleocene			
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

- Proven four-way closure at Citronelle Dome
- Injection site located within Citronelle oilfield where existing well logs are available
- Deep injection interval (9,400 ft)
- Numerous confining units
- Base of USDWs ~1,400 feet
- Existing wells cemented through primary confining unit
- No evidence of faulting or fracturing, based on oilfield experience, new geologic mapping and reinterpretation of existing 2D seismic lines.

Field Overview



- *One Injector (D-9-7 #2)*
- *Two deep Observation wells (D-9-8 #2 & D-9-9 #2)*
- *Two in-zone & above zone Monitoring wells (D-4-13 & D-4-14)*
- *One PNC logging well (D-9-11)*
- *Four shallow groundwater monitoring wells*
- *Twelve soil flux monitoring stations*

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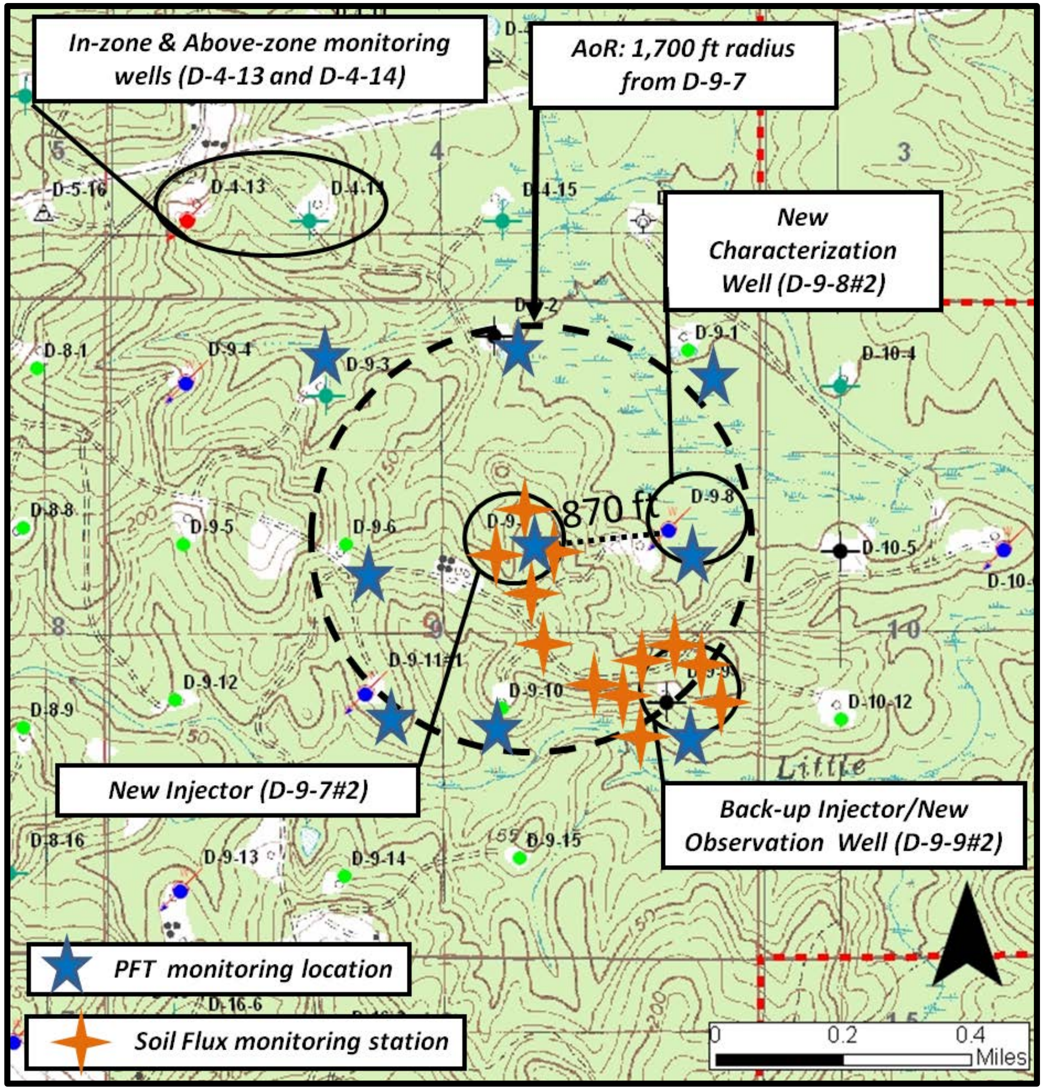
Surface and Shallow MVA



Goal #1: Operational monitoring

- *Injection rate and wellhead pressure*
- *CO_2 stream composition*

Goal #2: Identification of fast-flow pathways (nearby abandoned well)

- *Perfluorocarbon tracers*
- *Soil CO_2 flux measurements*
- *Groundwater sampling*

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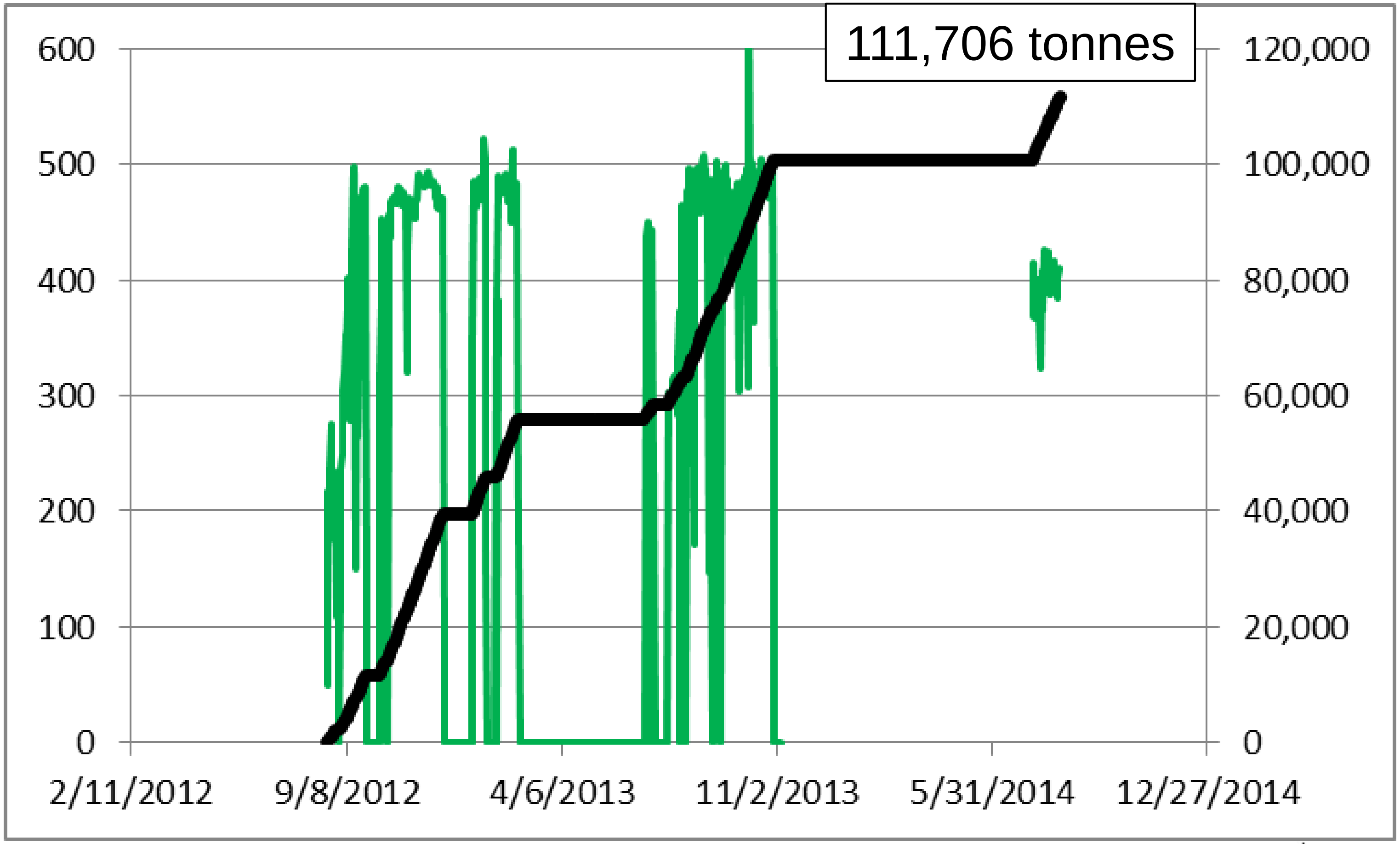
Injection Rate and CO_2 Composition Summary

- Average quality of the captured gas is 99.933% CO_2, 0.015% O_2 and 0.052% N_2.



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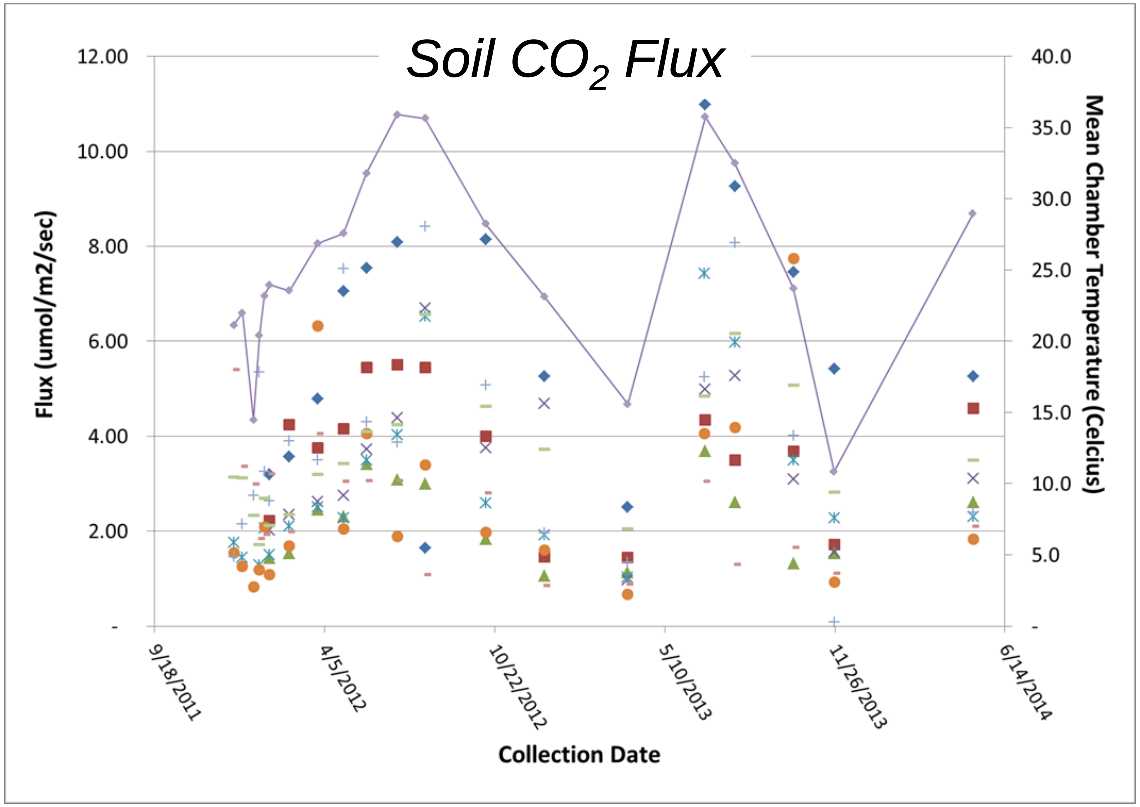
Shallow MVA-CO_2 Flux and Tracer Sampling



Tracer Results

	Inoculation	Testing	
Well/Sample	**AUG 2012**	**JUN 2013**	**NOV 2013**
D-9-1	ND	ND	ND
D-9-2	ND	ND	ND
D-9-3	ND	ND	ND
D-9-6	ND	ND	ND
D-9-7-1	ND	ND	ND
D-9-8	Invalid Data	ND	ND
D-9-9	ND	ND	ND
D-9-10	Invalid Data	ND	ND
D-9-11	ND	ND	ND
Air Blank 1	ND		
System Blank		ND	ND

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

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Shallow MVA - USDW Monitoring

3 - Background Monitoring Events:

- January 2012 (N=1) through July 2012 (N=3)

7 - Injection Period Monitoring Events:

- November 2012 (N=4) through May 2014 (N=10)

Background anomalies of Manganese, Iron, and Chloride above UIC permit. To evaluate the potential exceedance of regulatory standard (*e.g.*, UIC permit discharge limit), the EPA GW Unified Guidance recommends the collection of >4 data points before performing statistical comparisons (*e.g.* confidence limit determinations)

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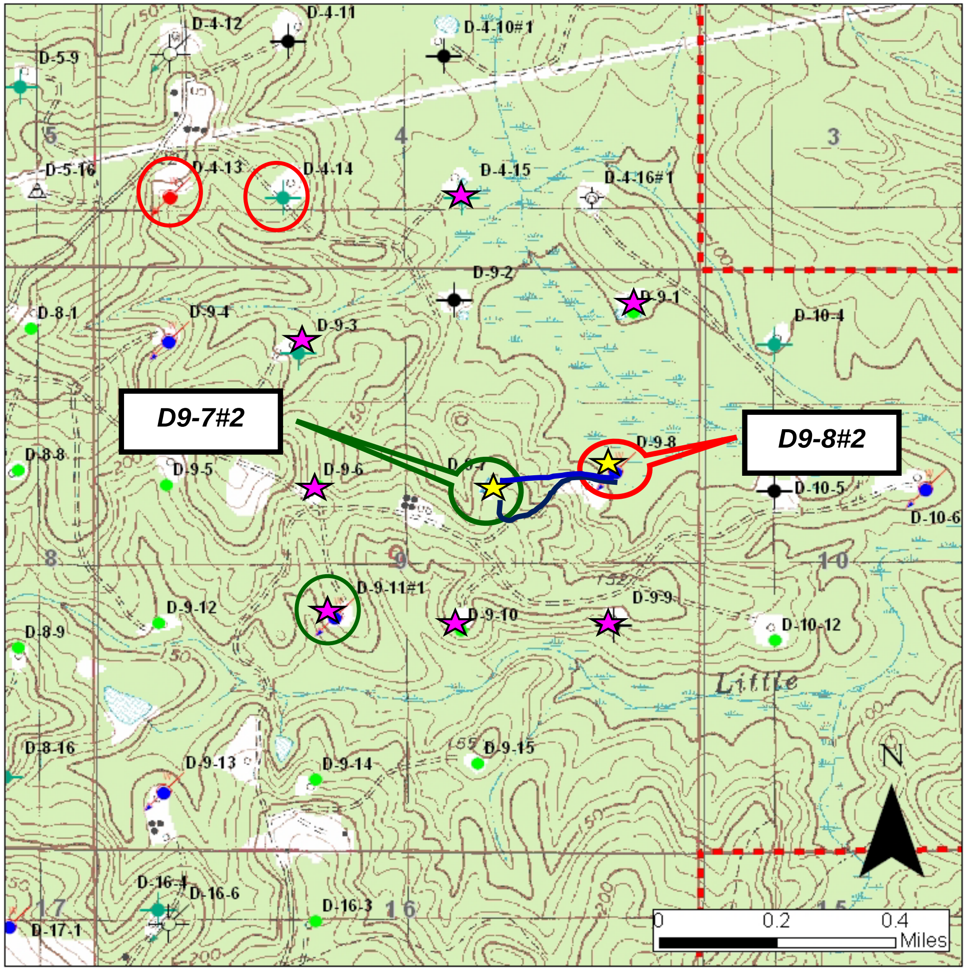
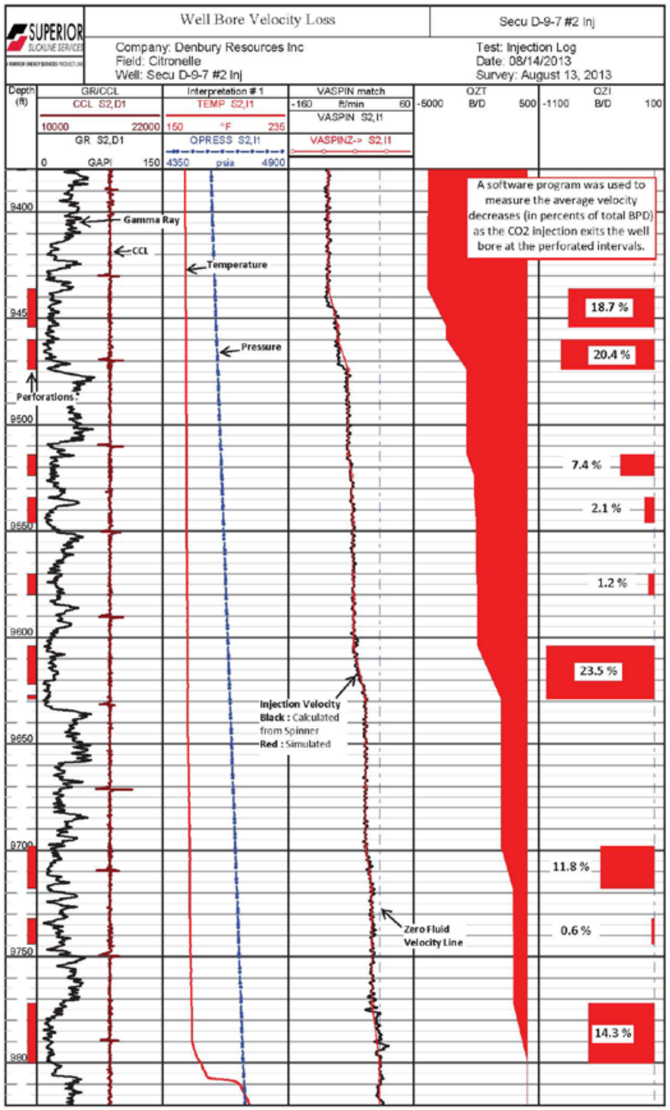
Deep MVA



VSP source offset locations (stars), receiver locations (D9-7#2 and D9-8#2), and walk-away lines (blue and red lines)

- *Goal #1: Operational monitoring*
  - Well logging (PNC and spinner surveys)
- Goal #2: In-zone CO_2 migration, leak detection and pressure monitoring
  - Downhole pressure monitoring
  - Cross-well seismic surveys
  - Offset vertical seismic profile (VSP) surveys
  - Walkaway VSP

Deep MVA-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)

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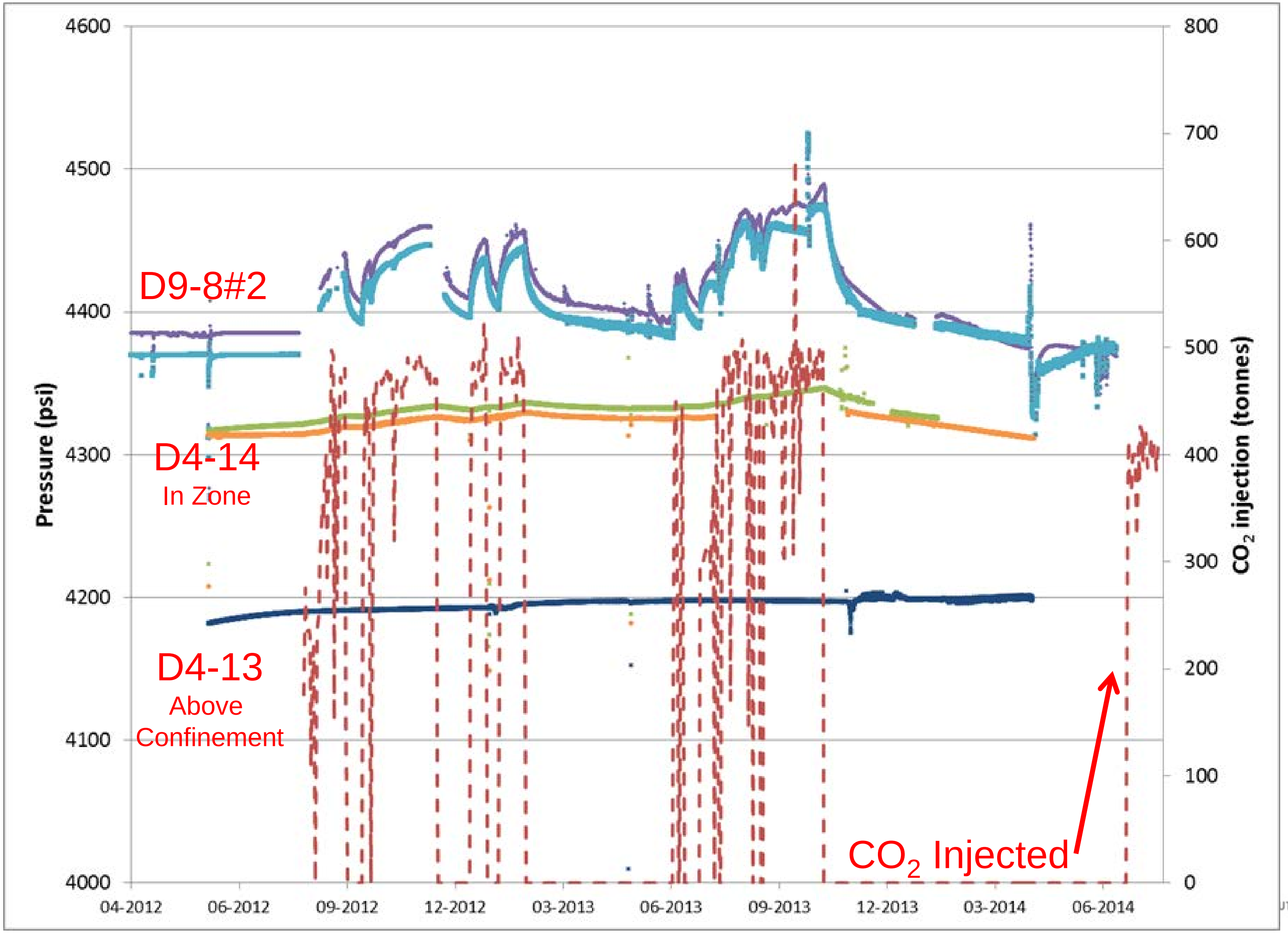
Deep MVA - Pressure Response



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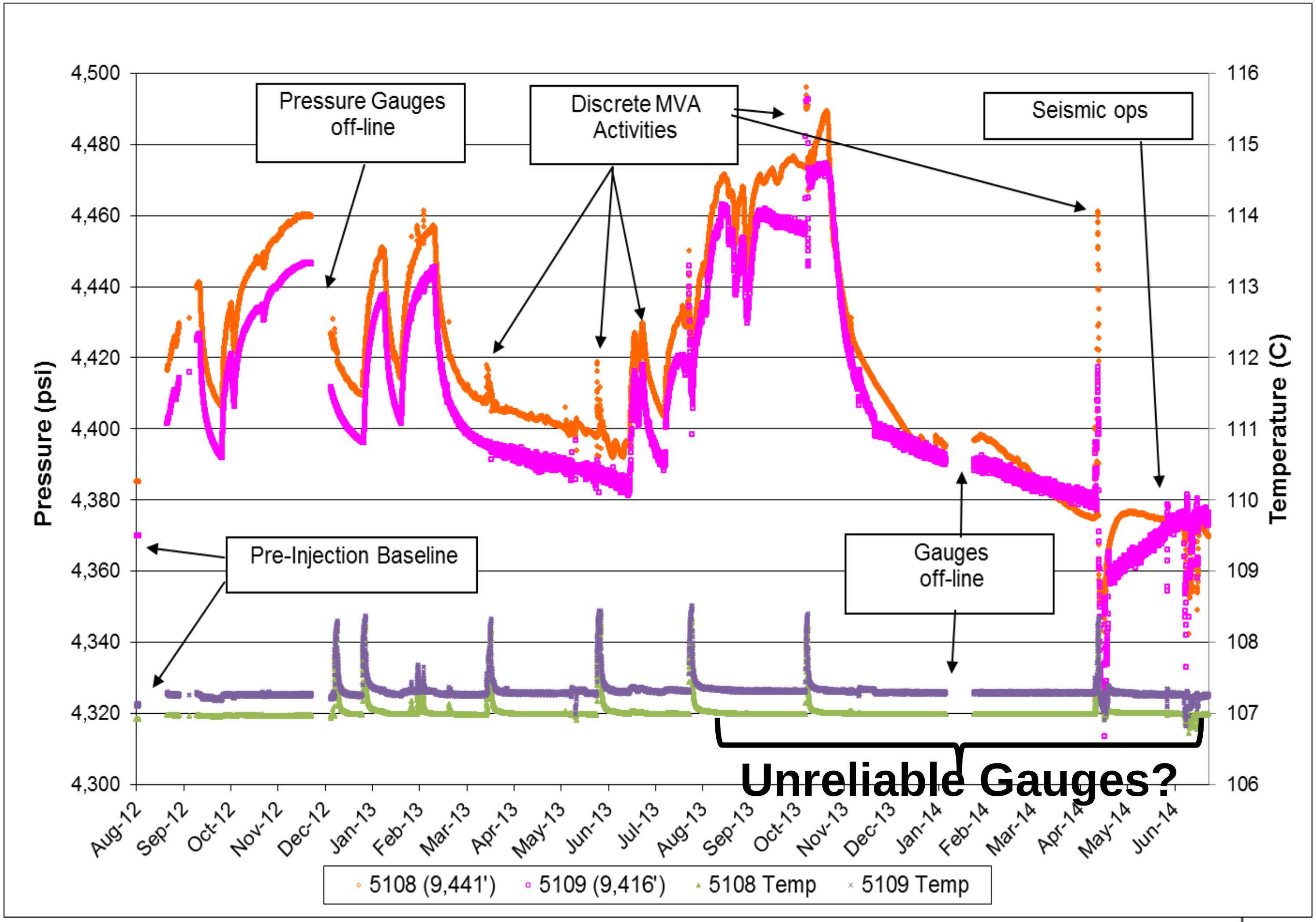
Deep MVA – Pressure Response



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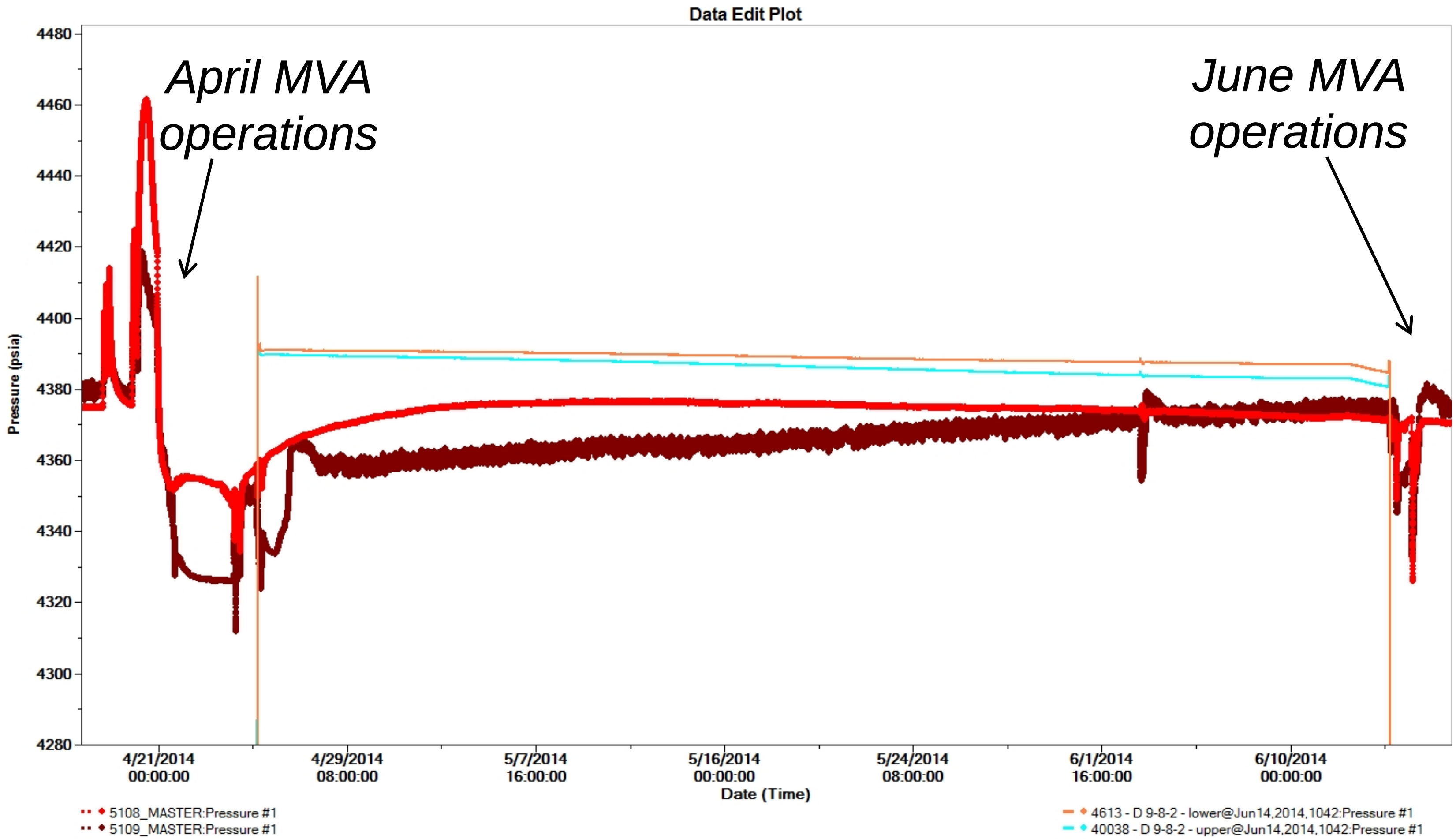
Permanent MBM vs Removable Memory Gauge



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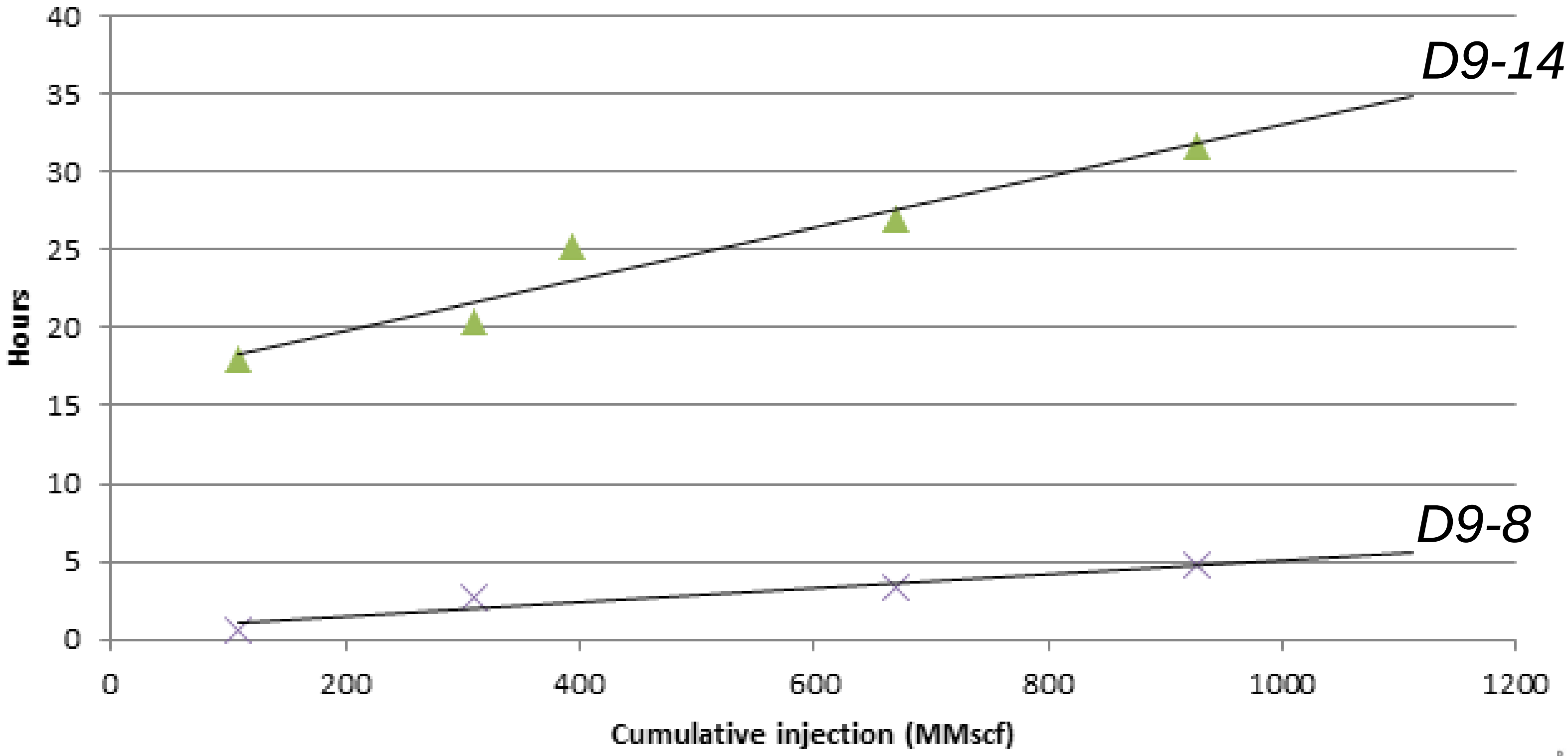
Deep MVA – Pressure Response

- The system, as expected, is getting more compressible with continued injection. As a result, the response time (observed initiation of injection) at the offset observation wells continues to grow. This tells us something about the saturation between the wells, when calibrated to reservoir models.



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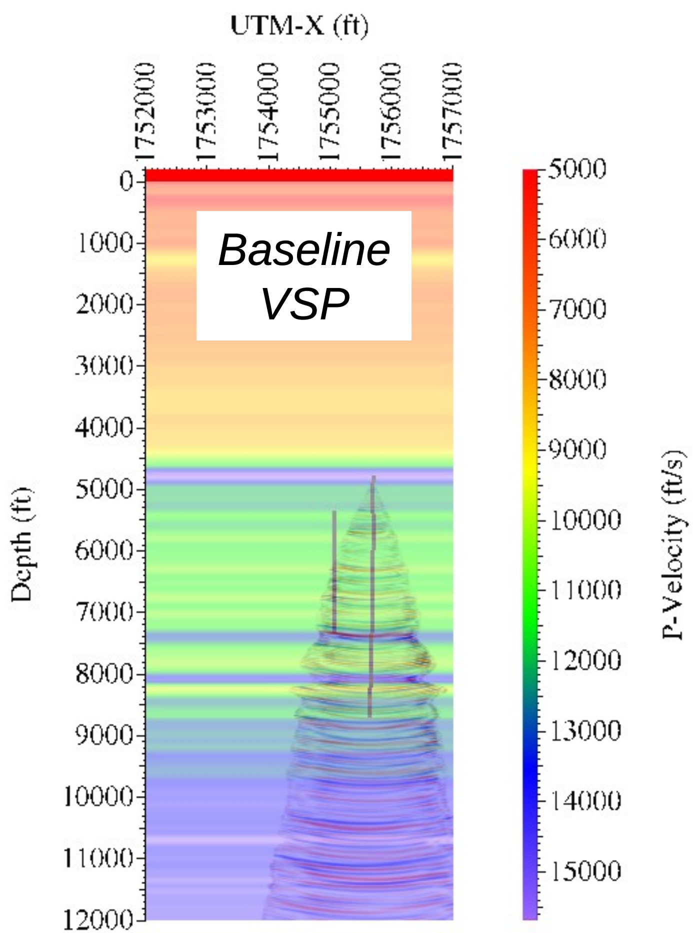
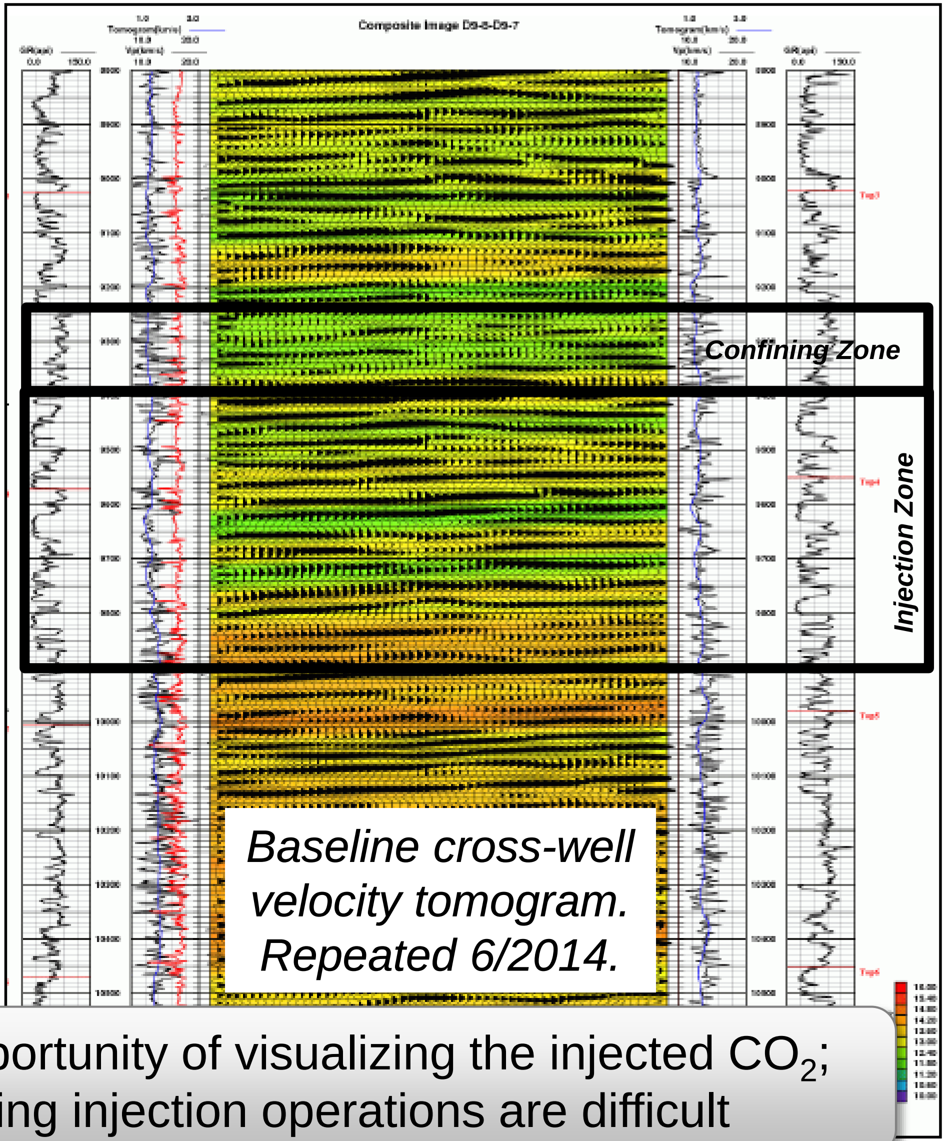
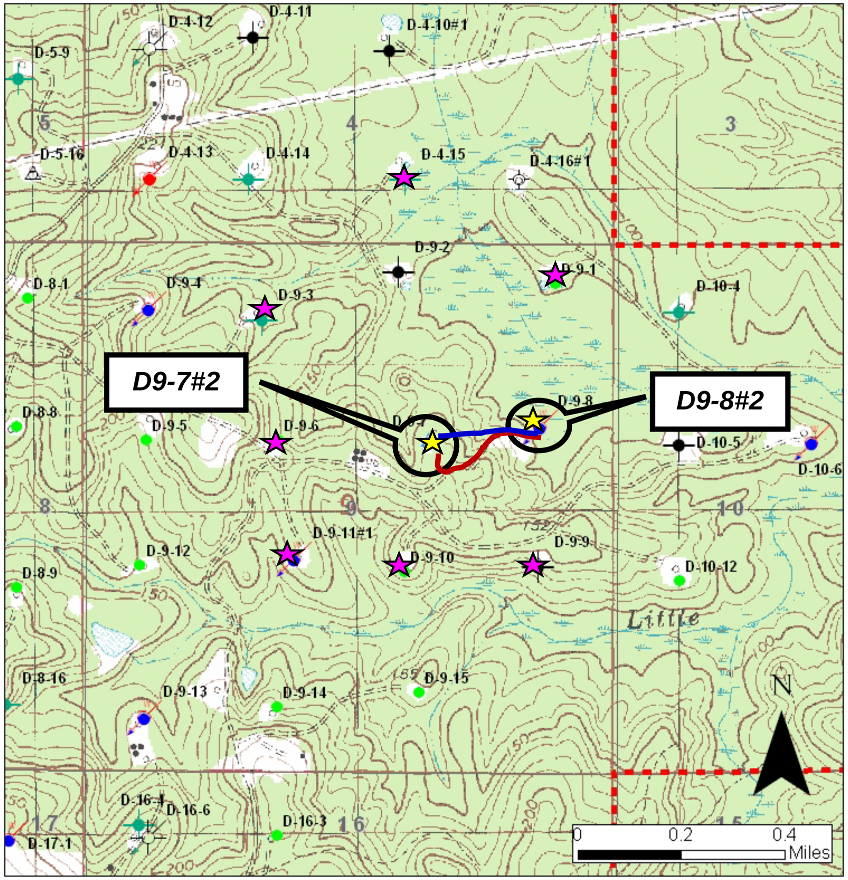
Deep MVA - Seismic Operations





Crosswell seismic may hold the best opportunity of visualizing the injected CO_2; however, time-lapse acquisition during injection operations are difficult

Experimental MVA-Modular Borehole Monitoring (MBM) System



VSP source offset locations (stars), receiver locations (D9-7#2 and D9-8#2), and walk-away lines (blue and red lines)

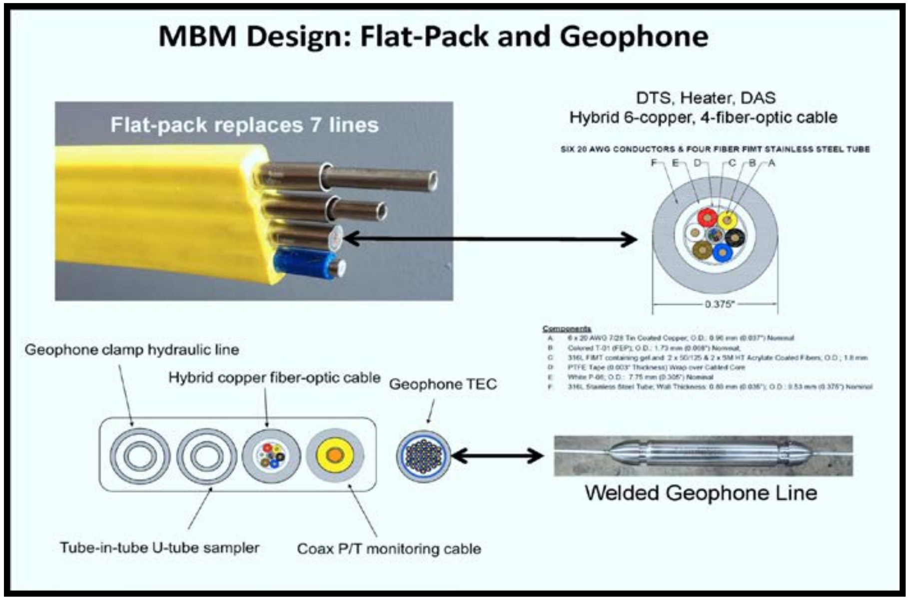
- *Motivation: Deep monitoring wells are expensive to drill and complete and have limited space available for instrumentation*
- ✓ *Monitor CO_2 plume location*
- ✓ *Reservoir pressure and temperature*
- ✓ *Fluid sampling*
- ✓ *Leak detection*
- ✓ *CO_2 saturations*
- An experimental, semi-permanent geophone deployment was desired to act as a “fence-post” during time-lapse VSP acquisition

SECARB Southeast Regional Carbon Sequestration Partnership

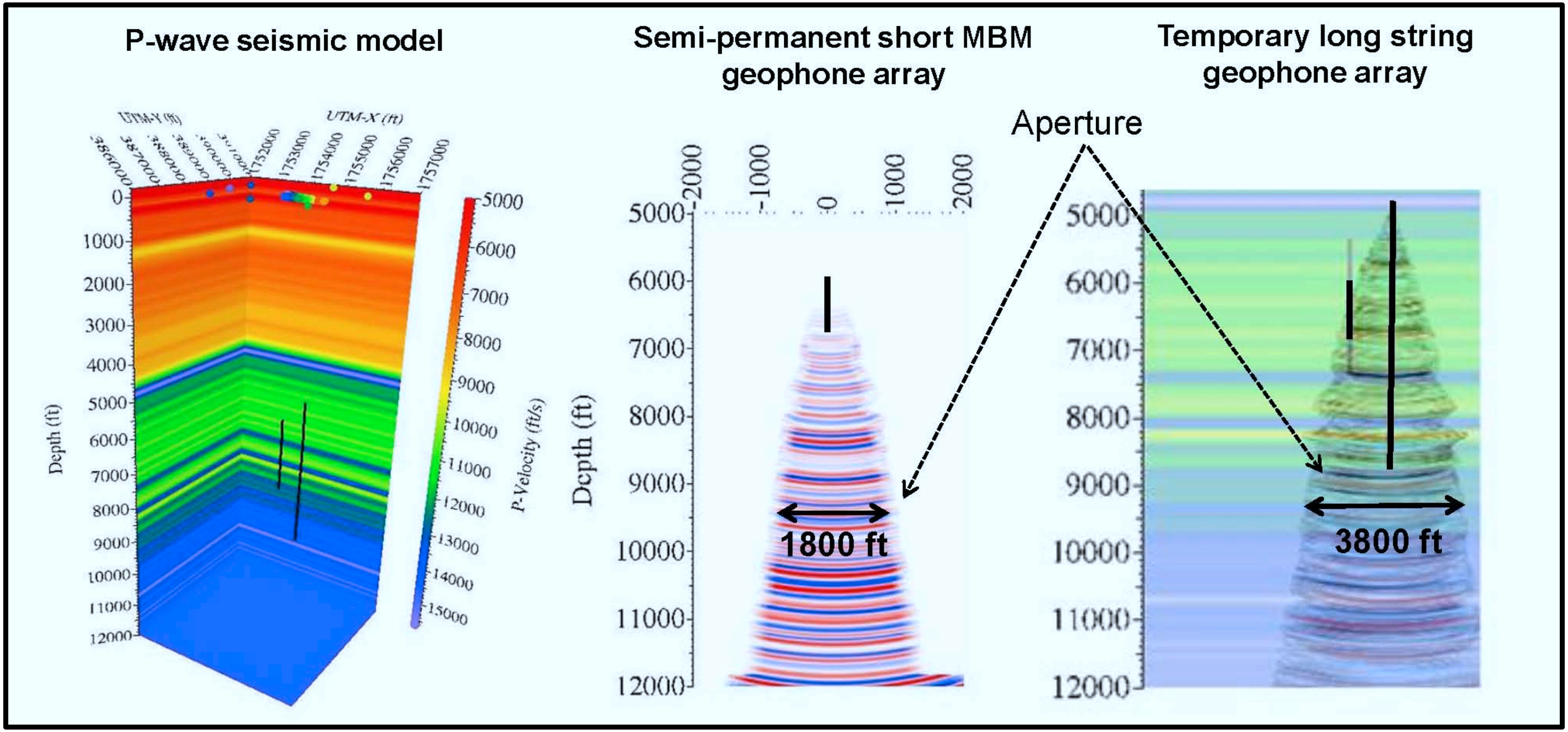
CO_2 Capture Project

MBM Design and Monitoring Capabilities

- 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 cable for distributed temperature and acoustic measurements
    - Heat-pulse monitoring for CO_2 leak detection
    - Acoustic array for CO_2
- 2 7/8” production tubing open for logging

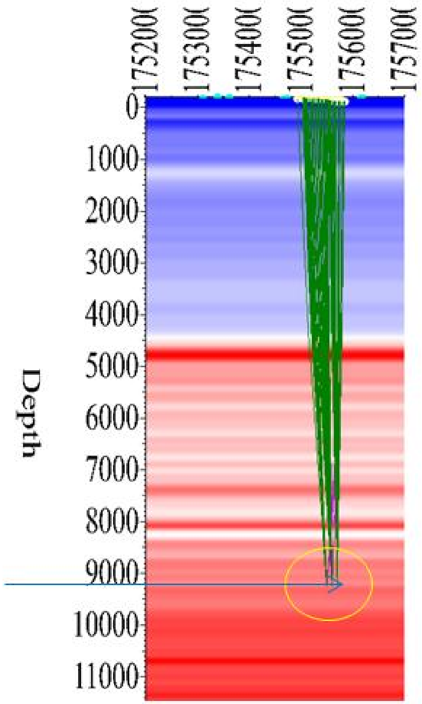


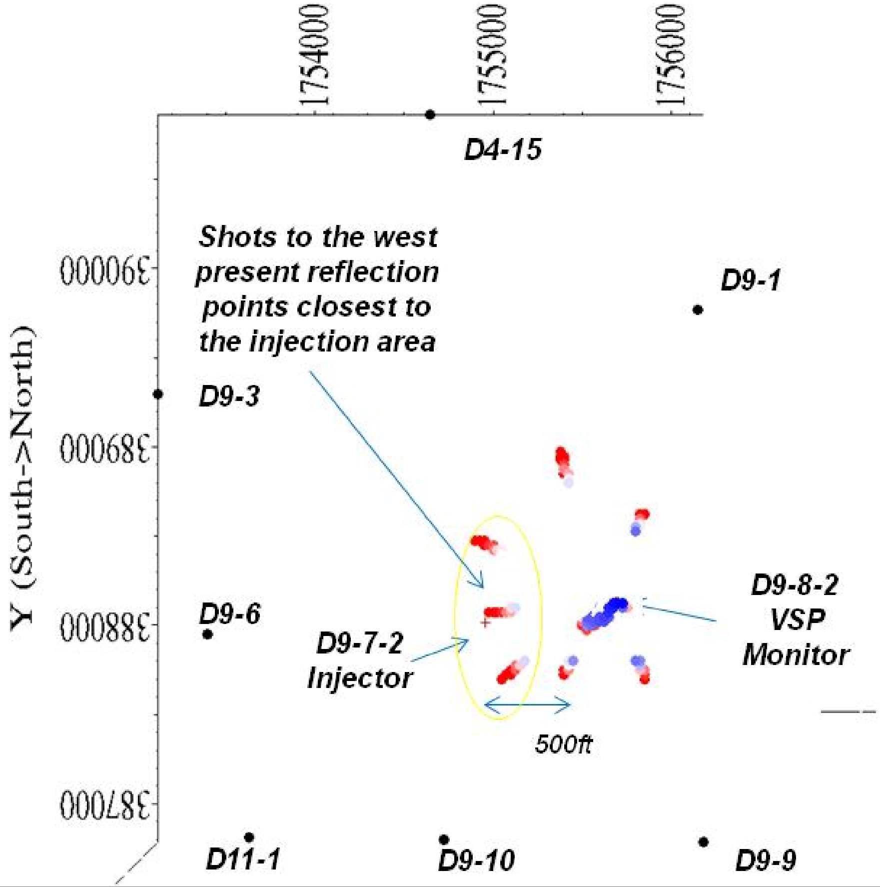
Time-Lapse Difference, MBM, VSP



Shorter MBM array has an lateral image area that is smaller, but it should be able to see changes in the gather response and images over time due to CO_2 injection

DEEP MVA – MBM VSP





Difference between the monitor and baseline surveys reveal subtle changes in the amplitudes at depth; however the changes may not be significant because of noise

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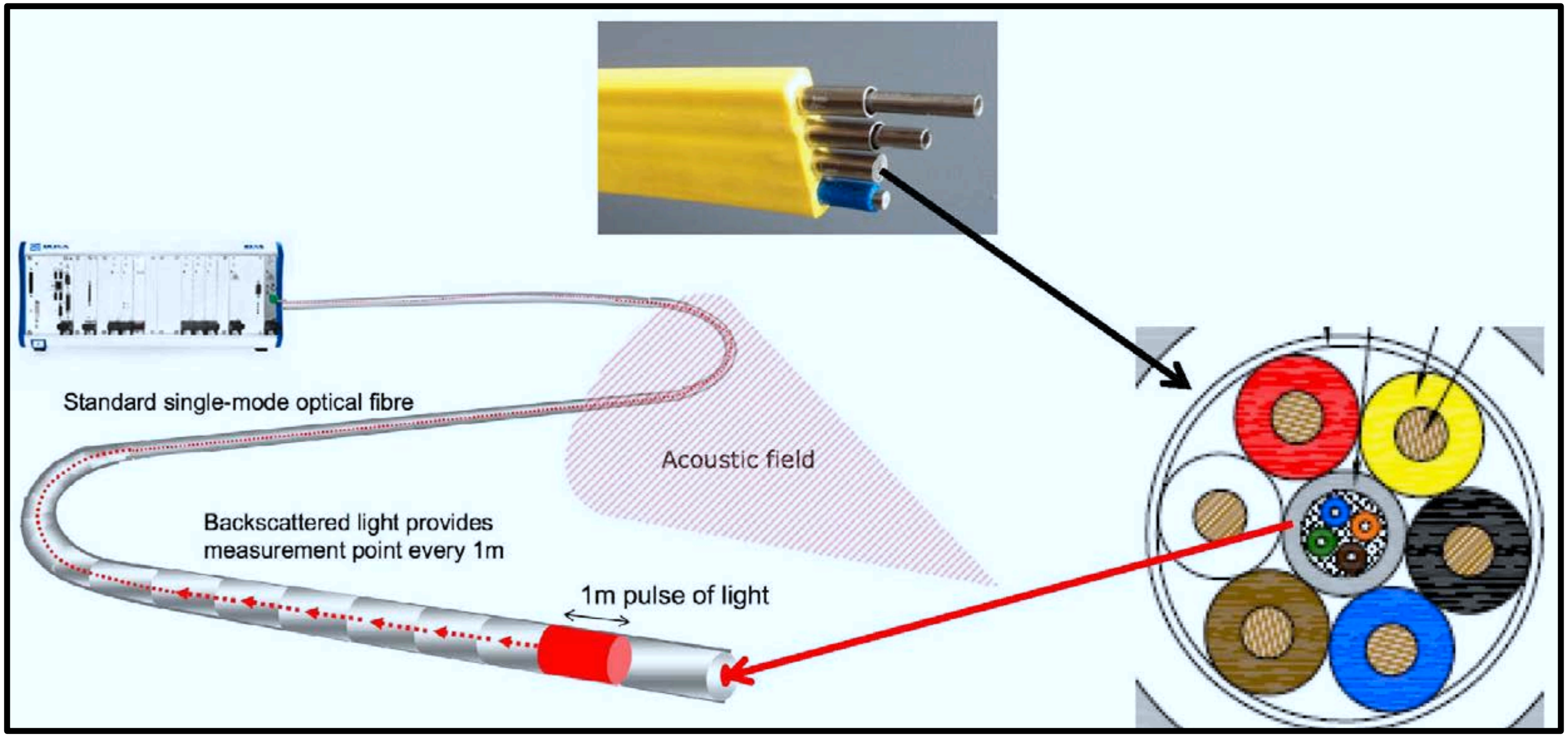
Distributed Acoustic Sensing (DAS)

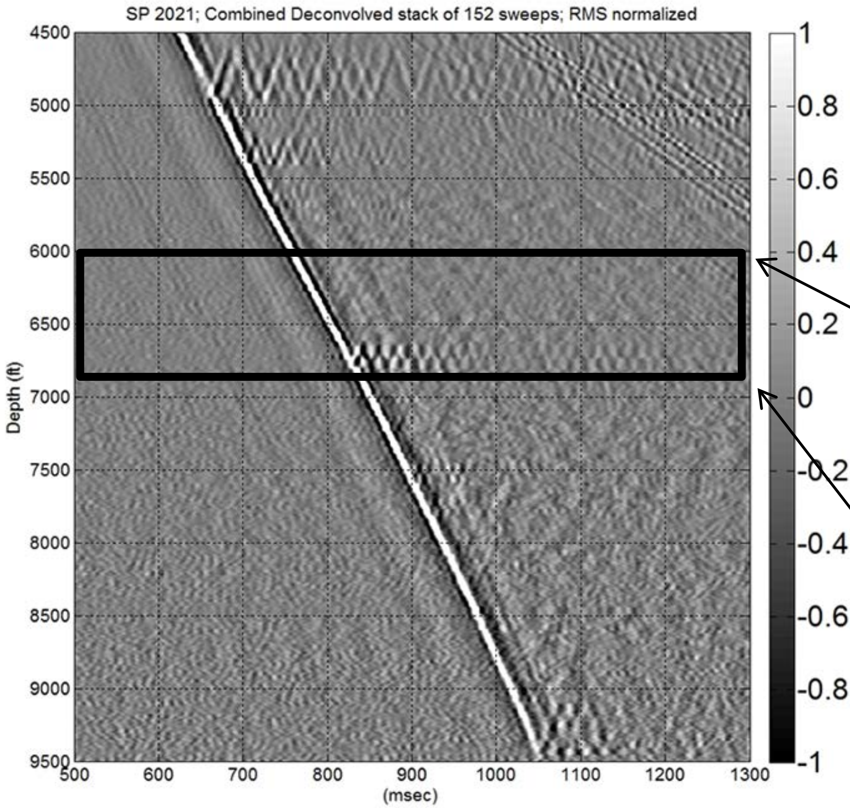
DAS allows seismic monitoring with fiber optics

- Sensitivity less than standard geophone, but 3000 sensors versus 18
- Spatial sampling and ease of deployment much greater



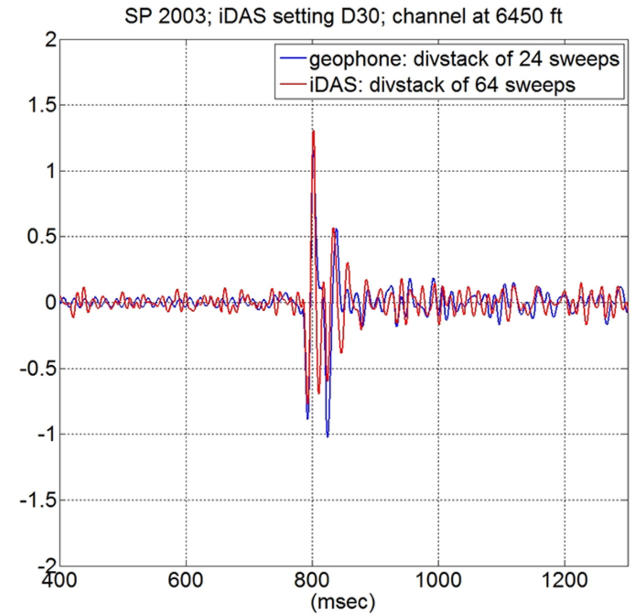
Citronelle DAS-Geophone Comparison from Walkaway

DAS Data

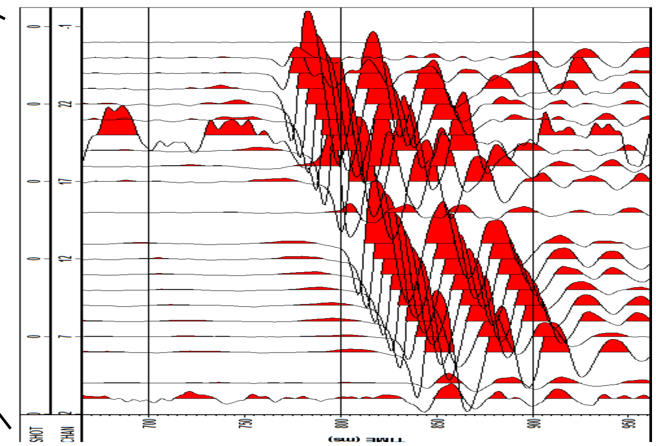


Processed by D. Miller, Silixa

DAS vs. Geophone



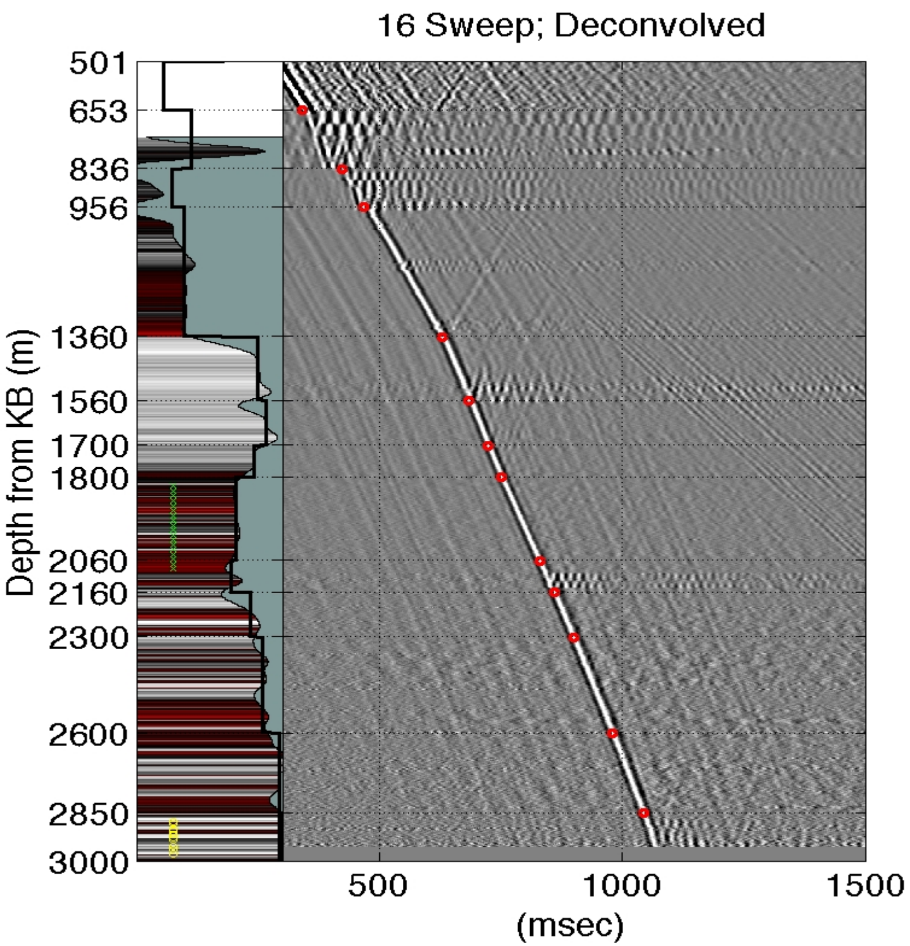
Geophone Data



Acquisition of stacked source sweeps improved DAS data signal to noise ratio, producing traces that match those from more sensitive geophones

Improved DAS VSP Processing

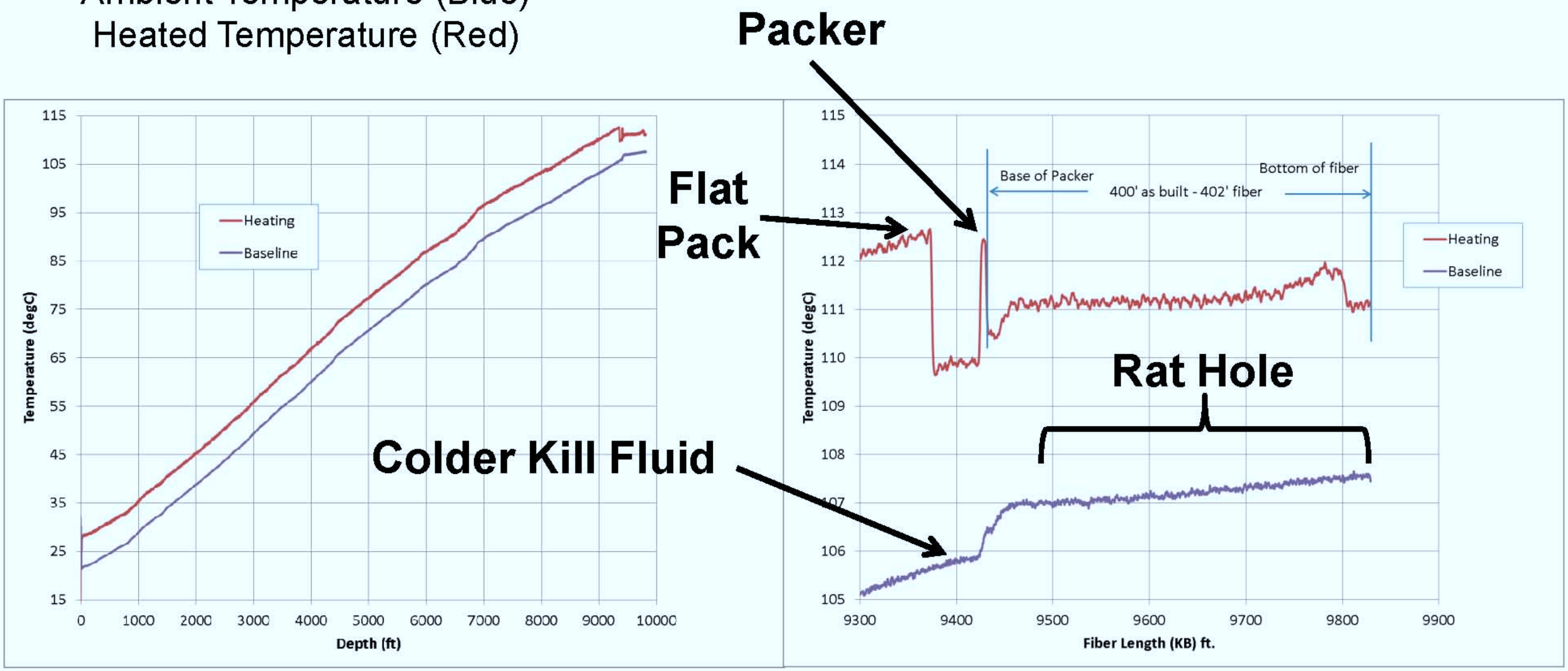
- Downgoing Deconvolution
- Travel Time Picks
- Velocity Model
- Comparison to Well Logs (Sonic, Gamma)



- *Good tie to logs*
- *Reflections clear*
- *Strong 'ringing' in some zones*

Heat Pulse Testing and Fiber Optic Distributed Temperature Sensing (DTS)

Ambient Temperature (Blue)
Heated Temperature (Red)



Temperature Profile along Entire Cable (0 – 9,800 ft +/-)

Temperature Profile Across Bottomhole Assembly (9,300-9,900 ft)

Deep Groundwater Sampling

- In- and above-zone monitoring may be used as a compliance tool to detect CO_2 leakage
- Samples undergo geo-chemical transformation when collected from deep wells, e.g.,
  - Exsolution of dissolved gases
  - Changes in dissolved CO_2 concentrations that control pH and alkalinity
  - Exposure to the atmosphere causes changes in redox conditions

USGS photo: Fluid Sampling during Pumping at D9-8#2

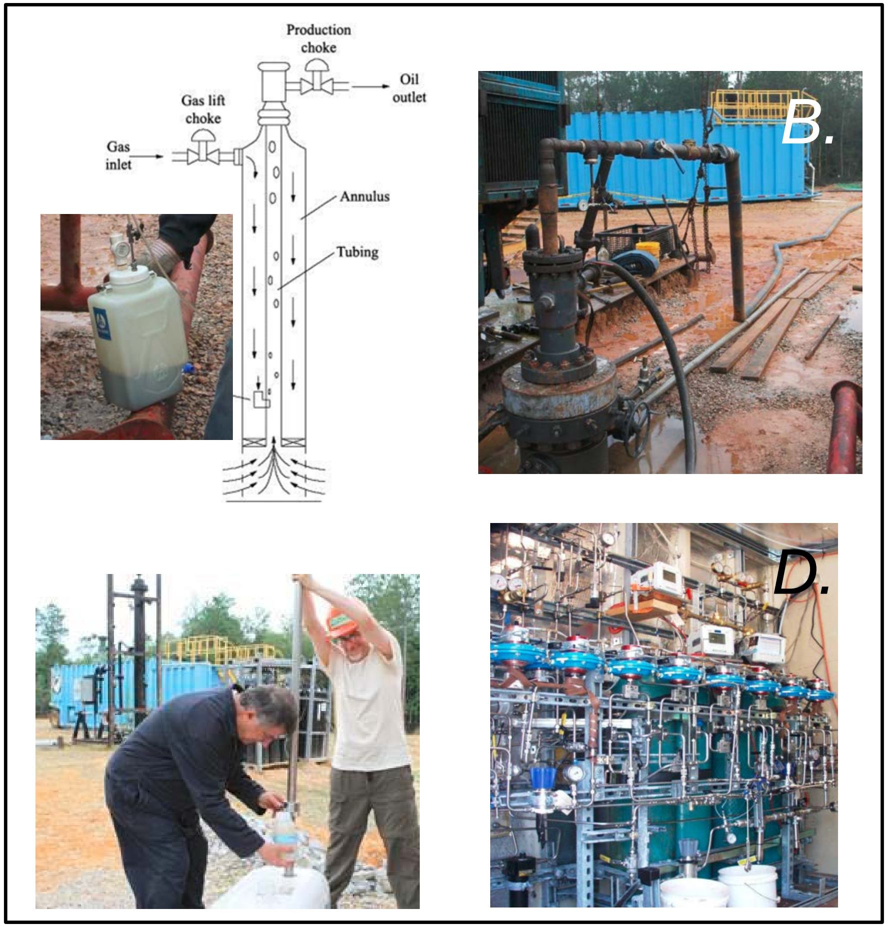
Testing & Monitoring: In-zone Comparison Deep Groundwater Sampling Methodologies

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

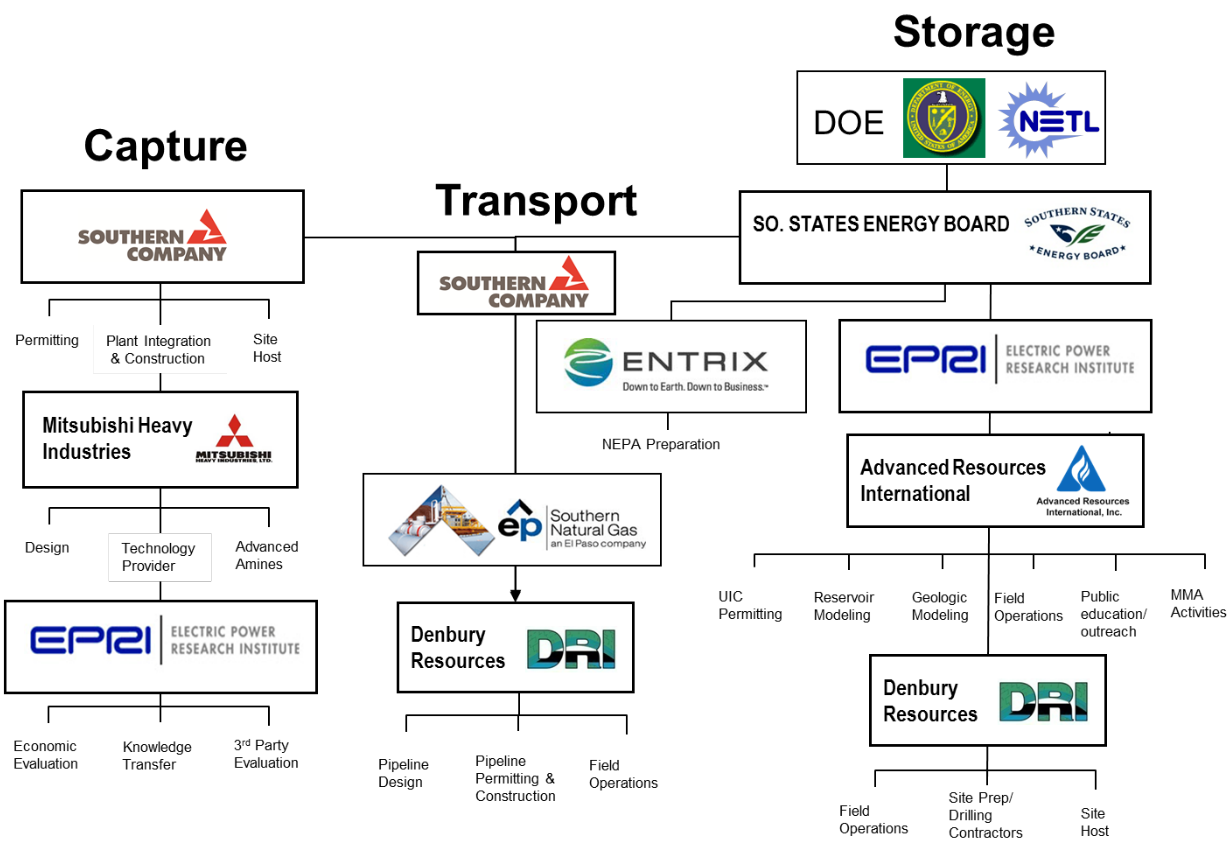


USGS collecting in-zone groundwater samples using: A. gas-lift; B. electric submersible pump; C. Kuster sampler; and D. u-tube sampler

Accomplishments

- Injected over 110,000 metric tons to date from the world's largest CO_2 capture system using advanced amines on a coal-fired unit
- Fully integrated carbon capture, transportation and storage project
- Demonstrating monitoring technologies at a commercial-scale (i.e., oil field setting) within the regionally extensive Paluxy saline formation
- Unique opportunity to evaluate performance of different seismic survey configurations and sensors
- Research effort is focused on developing, testing and validating borehole-based monitoring technologies and methods

Thank You from the SECARB Team



- Questions
- Comments
- Discussion

6