SECARB's AnthropogenicTest: Phase III Update

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Southeast Regional Carbon Sequestration Partnership's (SECARB) 5th Annual Stakeholders' Briefing

March 9, 2010
Atlanta, Georgia

Anthropogenic Test — Scope and Goals

- **Scope:** Post-combustion capture with CO_2 transport and storage
- **Goals:**
  - Demonstrate integrated CO_2 capture-storage under realistic operating conditions typical of a coal-fired plant
  - Establish realistic values for the energy penalty and implementation costs
  - Test reliability of solvent-based capture
  - Prove the viability of secure, CO_2 storage
  - Build industry, regulatory and public acceptance for CO_2 capture and storage

Example: Integrated CO_2 capture, transport and EOR storage facility, Natural Gas Processing Facility, Gaylord MI

Project Overview
Integrated Capture, Transport and Storage

- MHI Capture equipment to be installed at Plant Barry, AL
  - 1st Quarter 2011
  - 25 Mw equivalent slipstream
  - 100-150kt CO_2/yr x 4 yr
- ~15 mile CO_2 pipeline to Citronelle Dome (AL)
- CO_2 injection into Paluxy Formation (saline reservoir)

  > 9,400 ft deep
- Permitting and NEPA process are well underway

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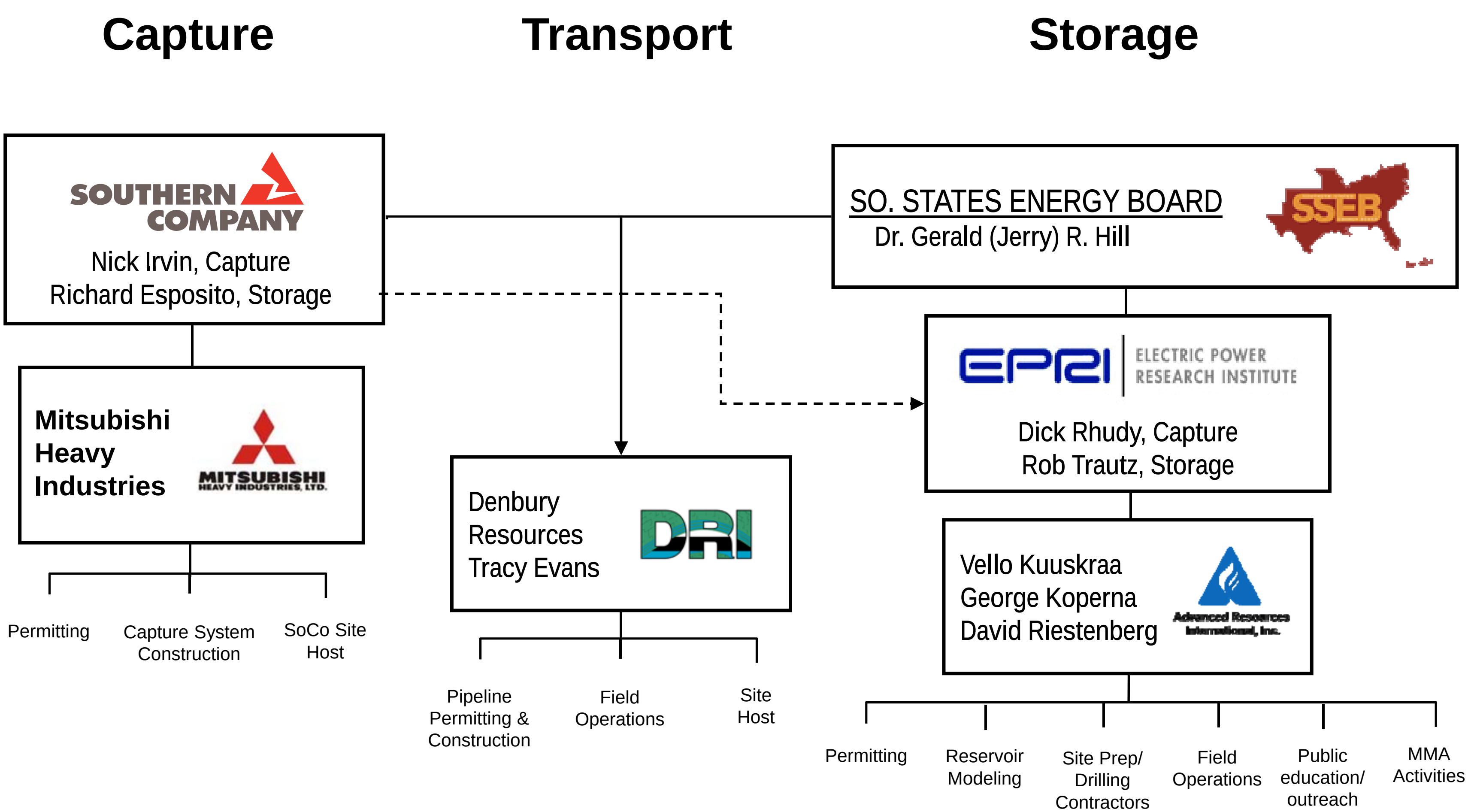
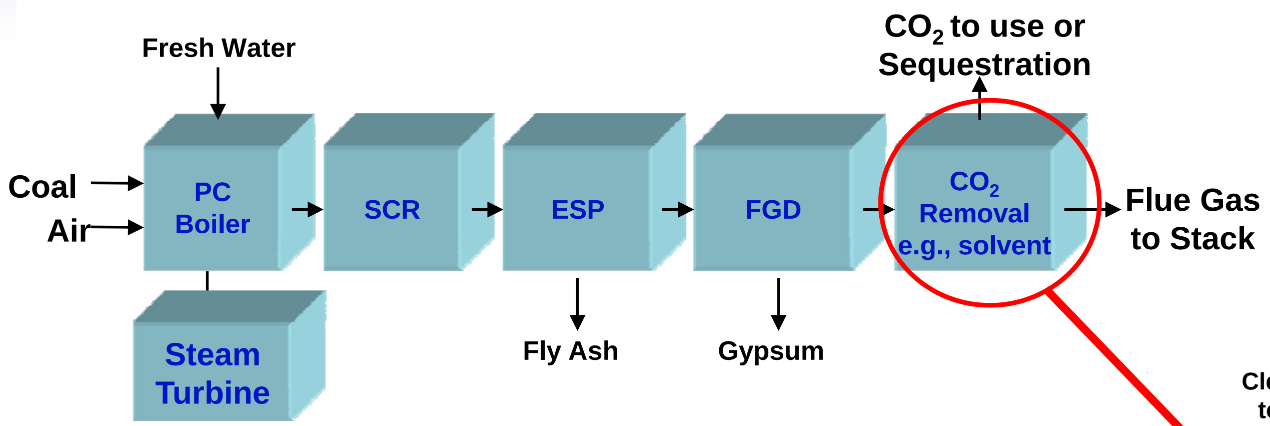
Key Organizations

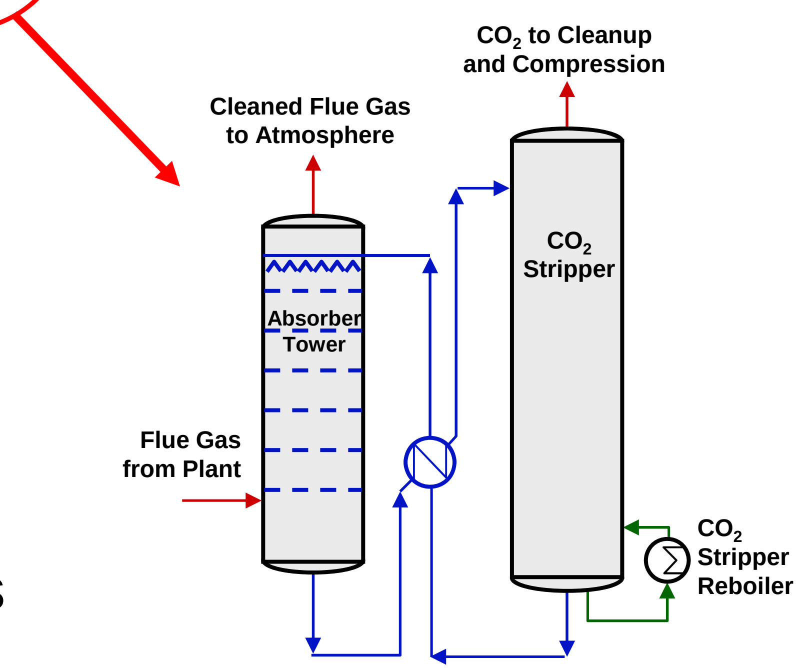


Challenges for CO_2 Capture on Pulverized Coal



Output Penalty: Up to 30% *Today*

- CO_2 capture needs
  - Ultra-low SO_2, NO_2, PM
  - Much energy for stripper
  - Large space
- Maximizing MW, efficiency requires optimal thermal integration



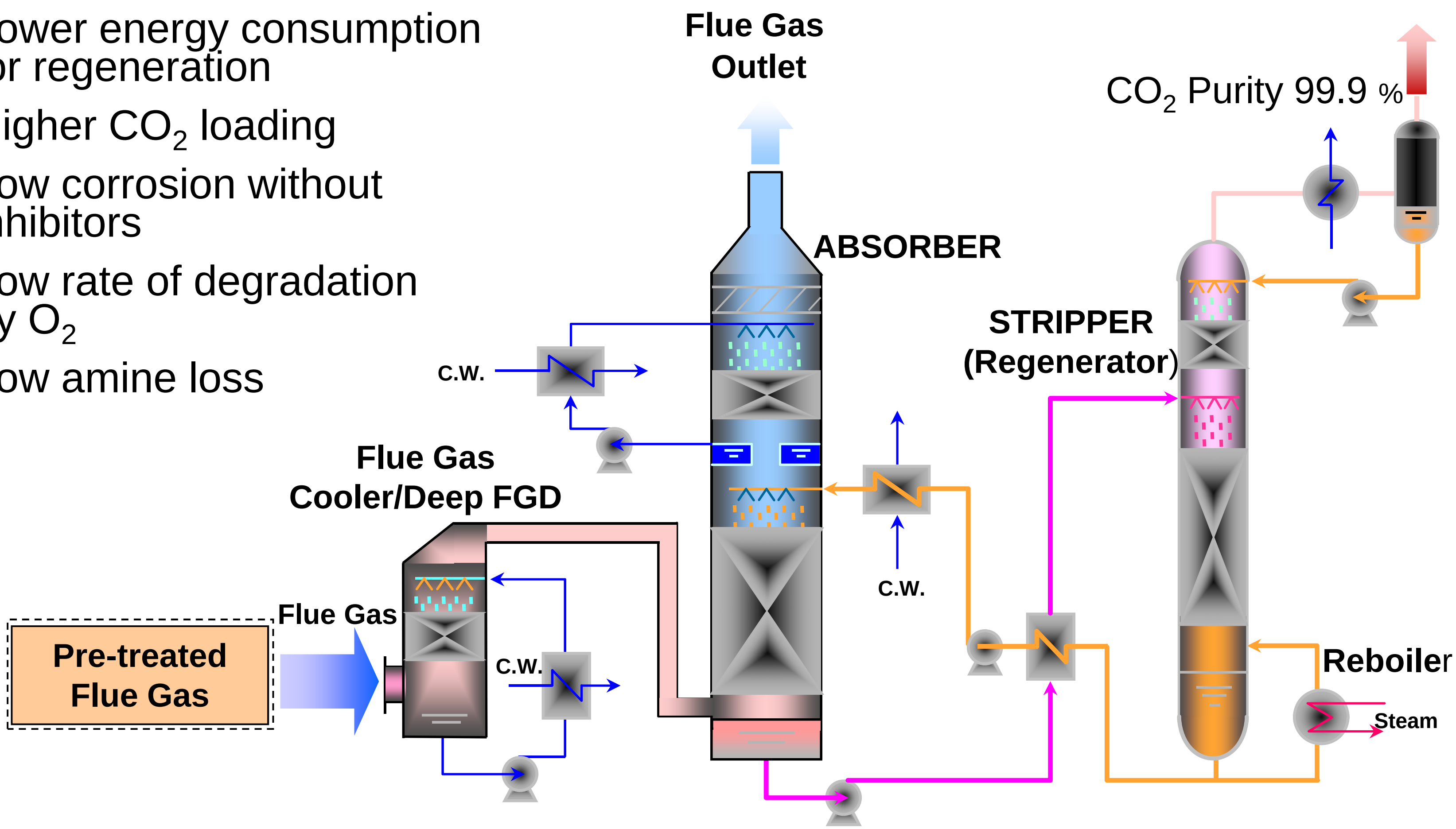
Typical sorption/desorption process

MHI's Advanced Amine Solvent Process

MITSUBISHI HEAVY INDUSTRIES, LTD.

Benefits

- Lower energy consumption for regeneration
- Higher CO_2 loading
- Low corrosion without inhibitors
- Low rate of degradation by O_2
- Low amine loss



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CO_2 Capture System Fabrication Underway!

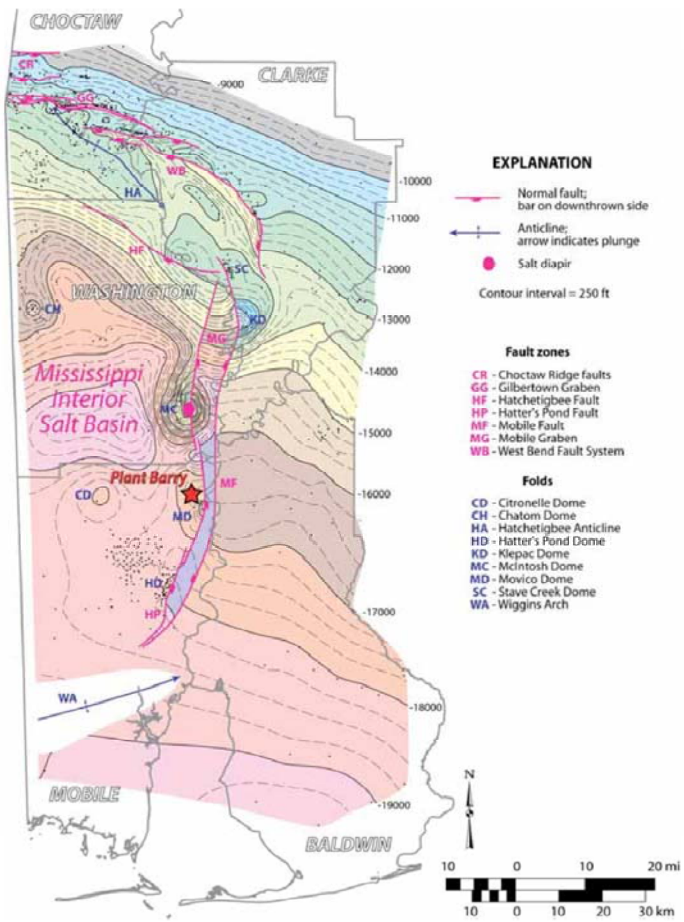
Courtesy of Southern Company

Shows the structure that will contain the cooler and absorber

Transport and Storage Activities

- Site characterization under way
- NEPA Underway
  - Complete for characterization well
  - Environmental Impact Volume (EIV) drafted for injection well
- Underground Injection control (UIC) permit drafted
- Pipeline evaluation under way

Geologic Overview



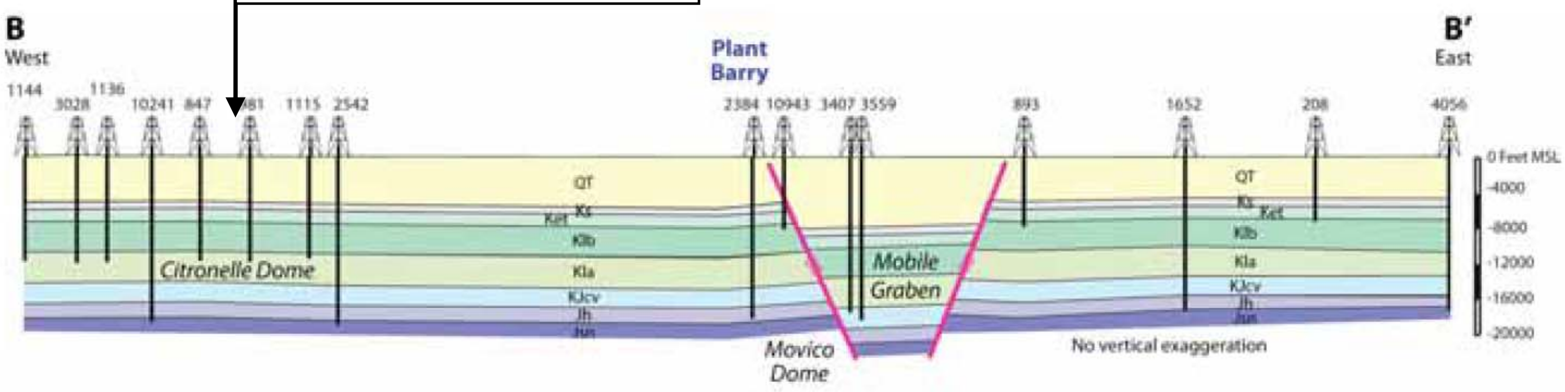
Structural contour map of the top of the Smackover Formation (Upper Jurassic) in southwest Alabama (GSA 2008)

Proposed sequestration site is on the southeast flank of the Citronelle Dome

- Within the southeast unit of the Citronelle oilfield
- Proven four-way closure
- No evidence of faulting or fracturing
- Multiple confining units between potential injection targets and base of USDW
- Existing well log data allow for detailed characterization of subsurface

Regional Structure Showing Shallow Dip

proposed injection area

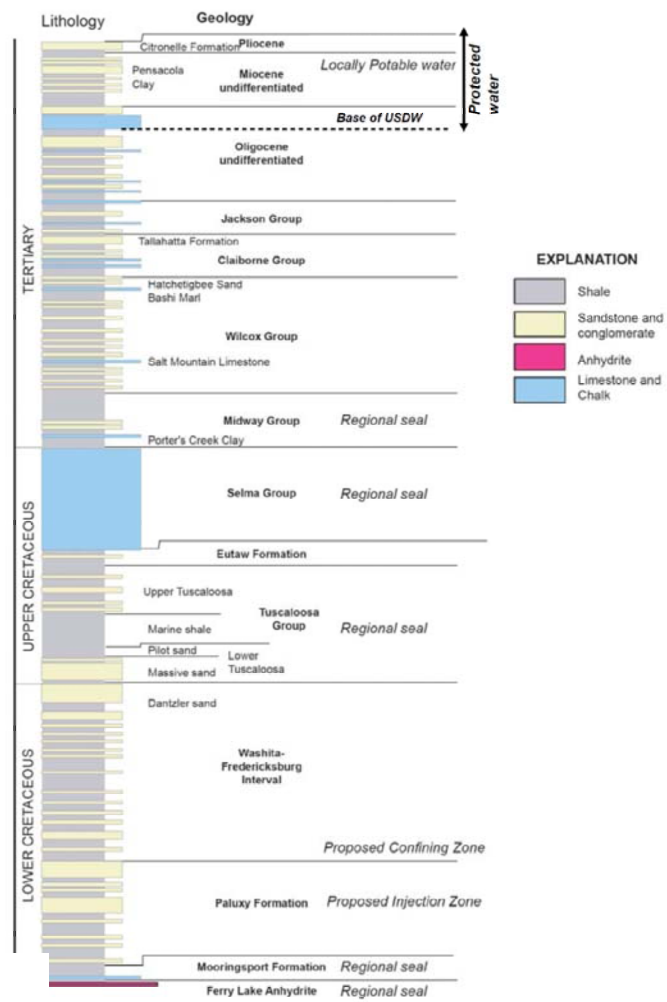


Courtesy of Alabama Geological Survey

The Citronelle Dome is a gently dipping (1–2°) salt pillow structure

Paluxy Formation is the Storage Reservoir Depths at Citronelle

Formation Tops	Depth (ft bgs)	Interval Thickness (ft)
Bottom of Fresh Water (<1,000 mg/l)	~1,000	
Base of USDW (<10,000 mg/l)	~1,200	
Selma Chalk Group (seal)	4,560	1,310
Eutaw	5,870	150
Tuscaloosa Group		
Upper Tuscaloosa	6,020	720
Middle Tuscaloosa (seal)	6,740	210
Lower Tuscaloosa	6,950	410
Washita-Fredericksburg (seal)	7,360	2,040
Paluxy Formation (target)	9,400	1,110
Mooringsport Formation	10,510	240
Ferry Lake Anhydrite	10,750	190
Rodessa Formation (oil reservoir)	10,940	-



Cross-section source: Pashin, J. C, McIntyre, M. R., Grace, R. L. B., Hills, D. J.; “Southeastern Regional Carbon Sequestration Partnership (SECARB) Phase III, Final Report”, 2008.

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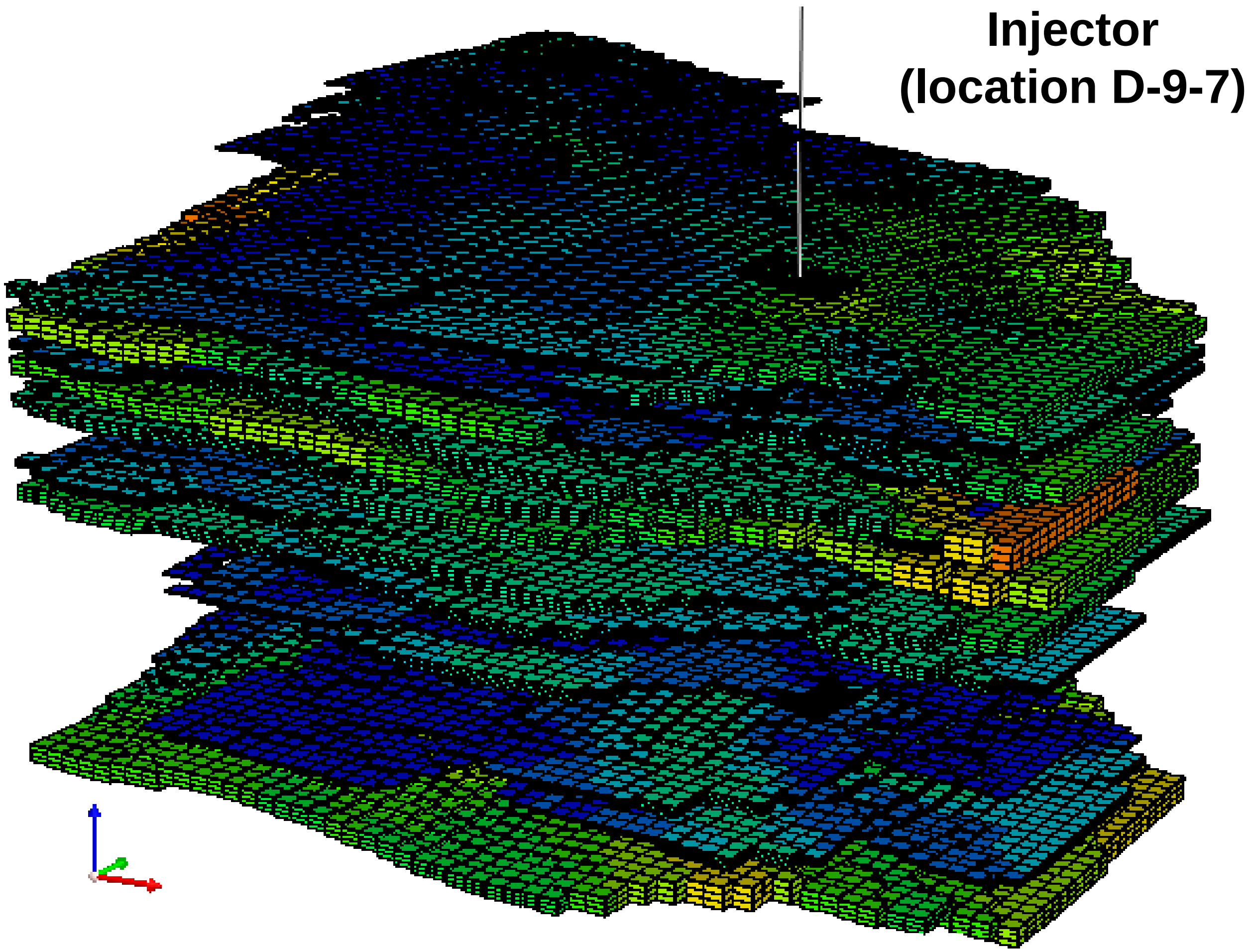
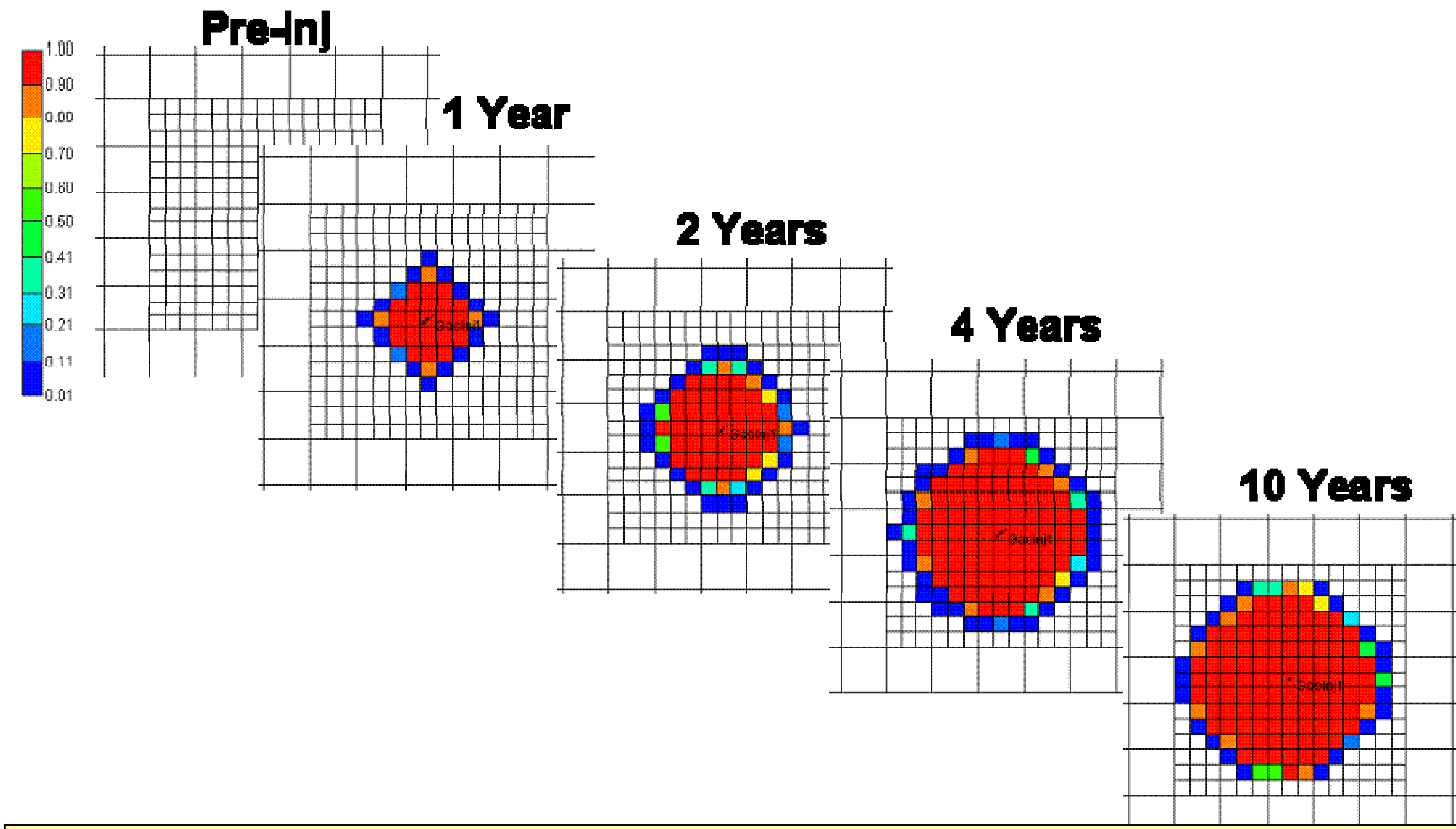
Paluxy Formation

- Paluxy formation represents a regressive ('infilling' or 'prograding') sequence
  - Approximately 1,100 ft thick in Southeast Unit
  - Individual sandstones are 10 to 80 ft thick
  - Paluxy resistivity derived porosities range from 17 to 22% (ave. 19%)
  - Permeability ranges from 28 to 246 mD (ave. 88 mD)
- Confining zone = basal shale of the Washita-Fredericksburg (~150 ft thick)

Paluxy Geologic Reservoir Model

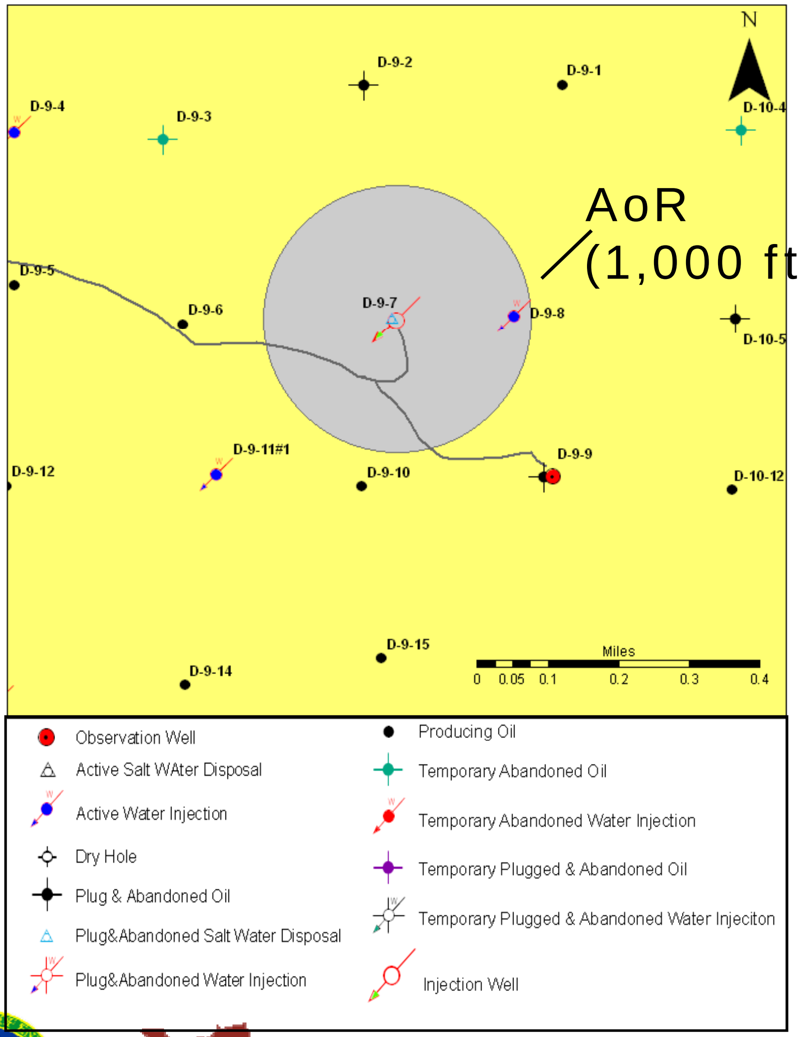


Permitting: Modeled Plume Extent



The maximum movement of the CO_2 is about 1,000 ft toward the west

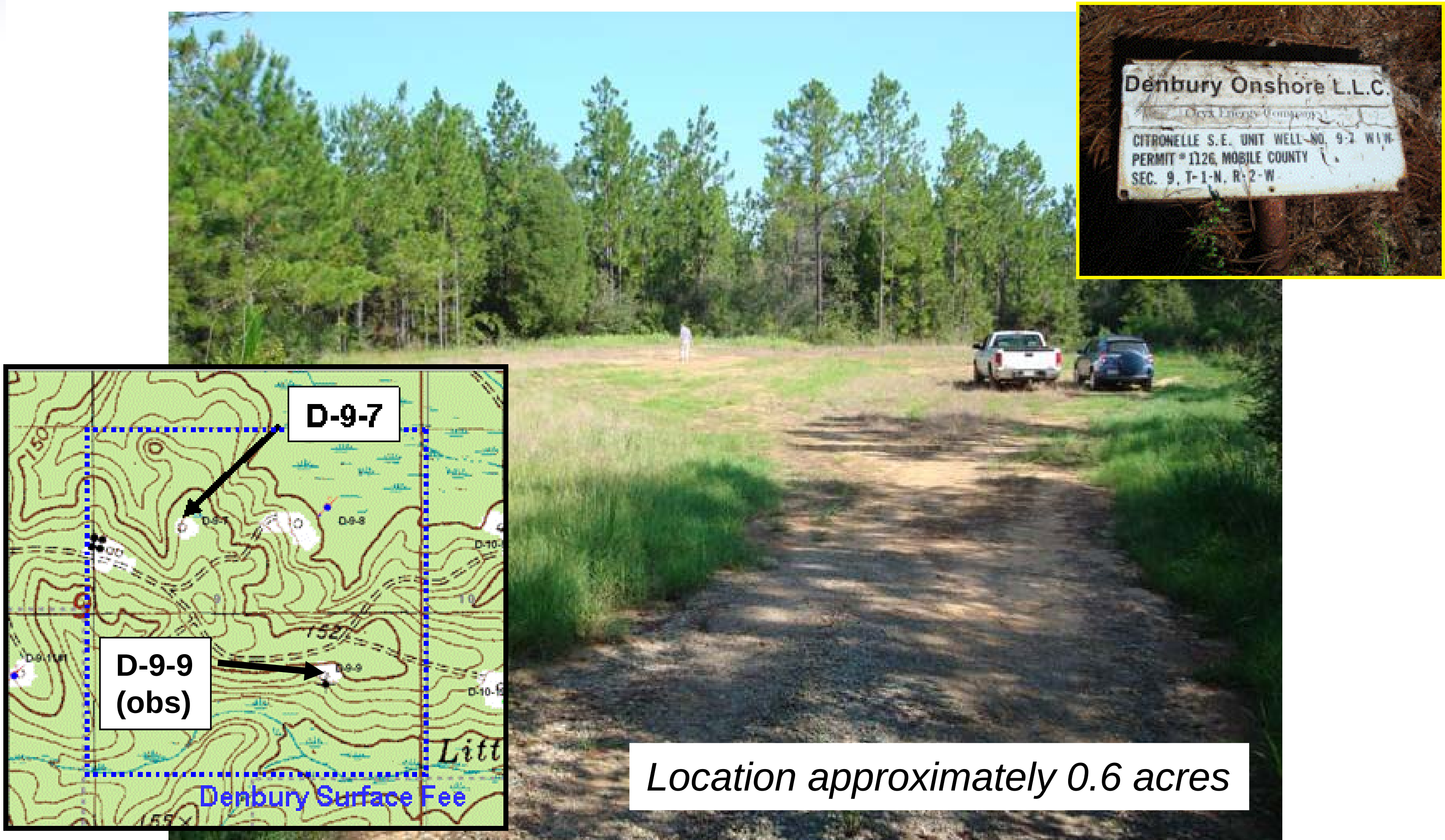
Wells Within the Area of Review (AoR)



- Two wells lie within the AoR: D-9-7 and D-9-8
  - ✓ D-9-7 has been abandoned per Alabama regulations
  - ✓ D-9-8 is an active secondary water injector
- No water supply wells within AoR

Well log review indicates existing wells should not be an issue

Proposed Injection Well Location (D-9-7 Pad)



Location approximately 0.6 acres

Outlook

- **Unique opportunity to demonstrate integrated CO_2 capture and storage at a coal coal-fired power plant**
- 2010
  - Permitting (UIC, EA, OGB)
  - Infrastructure Development (wells, pipeline, capture unit)
  - Site monitoring begins (baseline)
- 2011-2014
  - Injection Operations
- 2015-2017
  - Site Monitoring and Closure

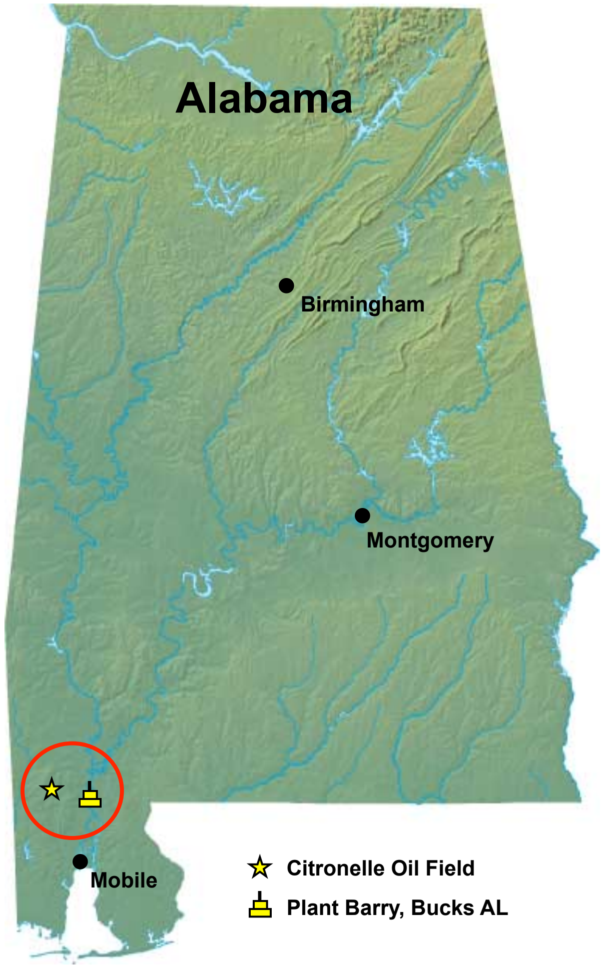
SECARB Anthropogenic Test Overview: Integrated CO_2 capture, transport and storage

Robert C. Trautz
Sr. Project Manager

SECARB 6th Annual Stakeholder's Meeting
March 10, 2011

Anthropogenic Test — Overview

- Fully integrated CO_2 capture, transport and storage project
- Construct and operate a 25 MW equivalent CO_2 capture unit at Alabama Power's (Southern Co.) Plant Barry
- Construct and operate a 12 mile CO_2 pipeline that will transport CO_2 from Plant Barry to the Citronelle Dome
- Inject 100,000–300,000 metric tons of CO_2 into the Paluxy Formation (saline) over 2 to 3 years
- Conduct 3 years of monitoring after CO_2 injection and then close the site



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CO_2 Source: James M. Barry Electric Generating Plant

- Owner/Operator
  - Alabama Power Company (A Southern Company)
- Located along the Mobile River in Bucks, AL
- Total nameplate generating capacity
  - 2,657,200 kW
- Generating units - 7
- Type of fuel
  - Coal and natural gas

Plant Barry, Bucks, AL

ALABAMA POWER A SOUTHERN COMPANY | Always on.℠

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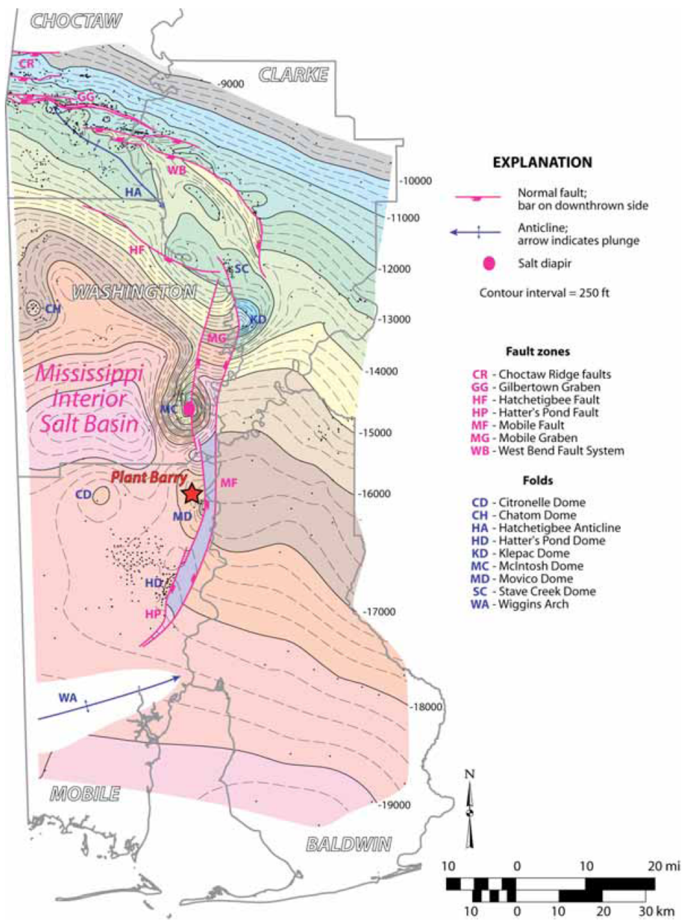
CO_2 Sink: Citronelle Oil Field



Structural contour map of the top of the Smackover Formation (Upper Jurassic) in southwest Alabama (GSA 2008)

- Located near the crest of a giant salt-cored anticline
- Discovered in 1955; Unitized beginning in 1961 for waterfloods
- Produced > 68 MMbbl of 42-46° gravity oil
- ~ 37% of the original oil in place has been recovered; CO_2-EOR potential up to 20%
- Unit Operator: Denbury Resources
- CO_2 project in SE Unit of field
- Paluxy Formation at 9,400 ft

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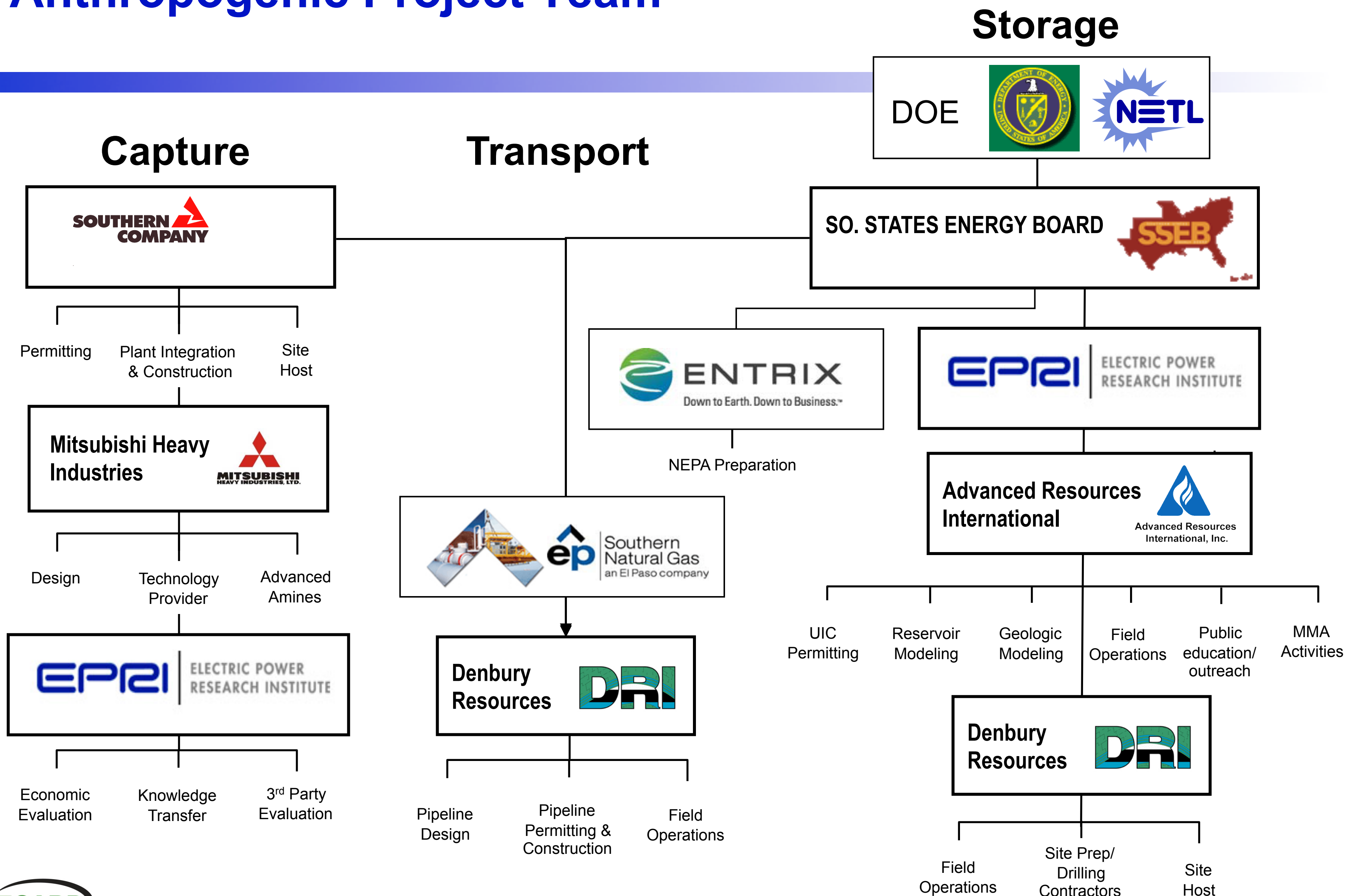
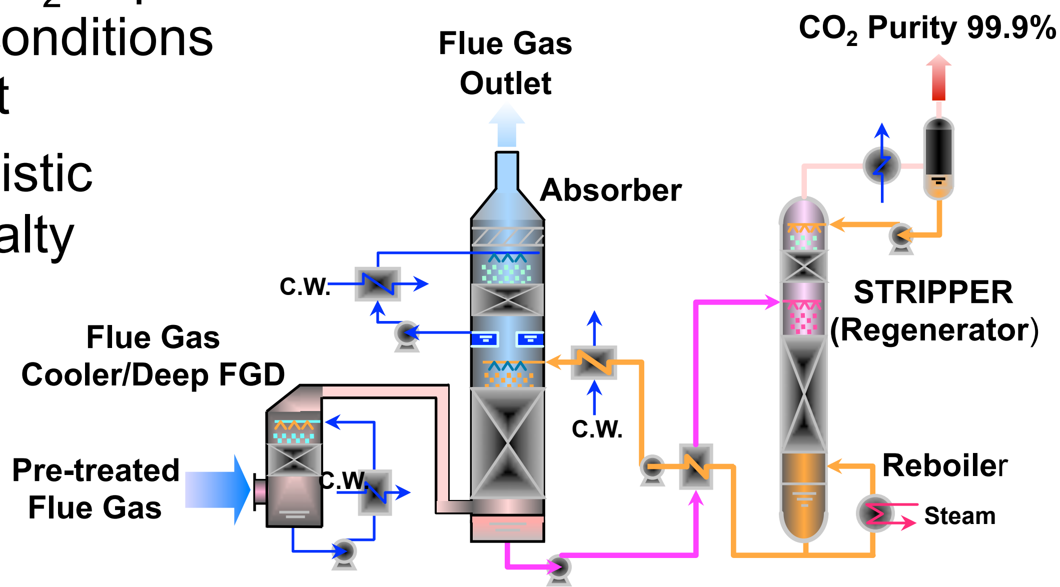
Anthropogenic Project Team



Capture Project Scope and Objectives

- Scope:
  - Demonstrate post-combustion capture of CO_2 from Plant Barry flue gas using MHI's advanced amine process
- Objectives:
  - Demonstrate integrated CO_2 capture under realistic operating conditions typical of a coal-fired plant
  - Economics: Establish realistic values for the energy penalty and implementation costs
  - Test reliability of solvent-based capture



Simplified schematic post-combustion solvent process

CO_2 Capture System Update

2010

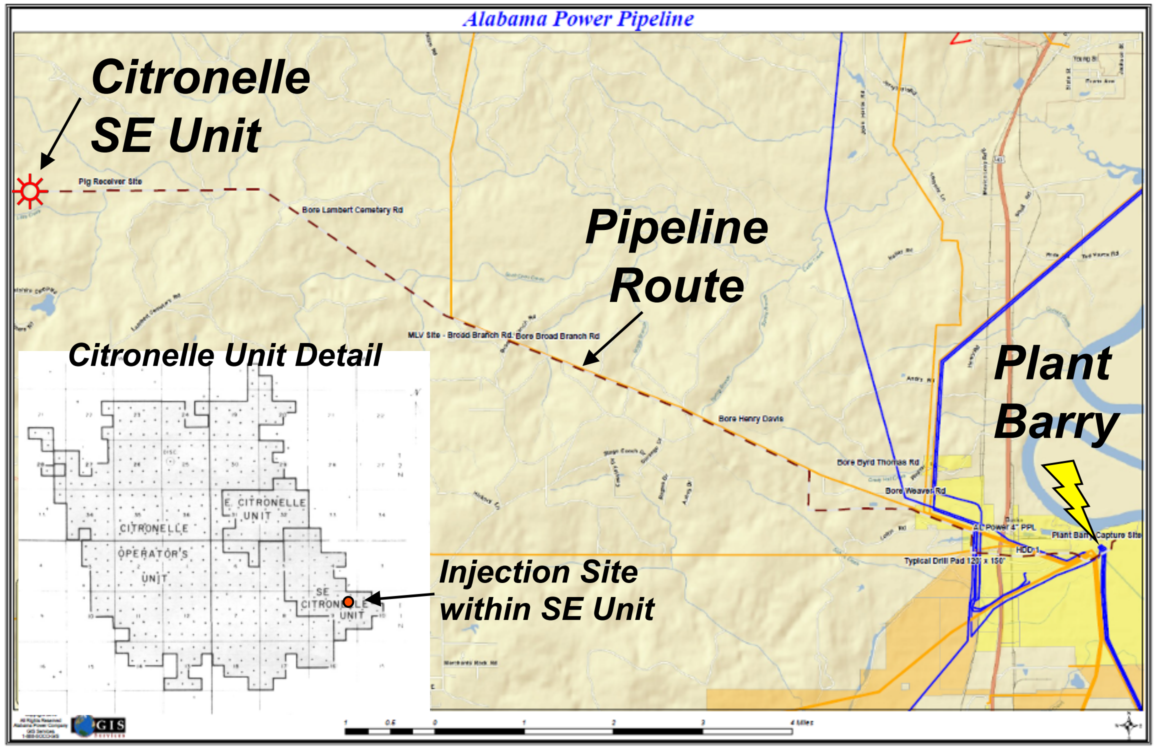
2011

Photos Courtesy of Southern Company

Capture plant & compressor will be operational by early July 2011

CO_2 Pipeline Overview

- Approx. 12 mi to the SE operators unit in Citronelle Field
- 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)



- Right-of-way habitat (pine forest in the Mobile River watershed; some wetlands)

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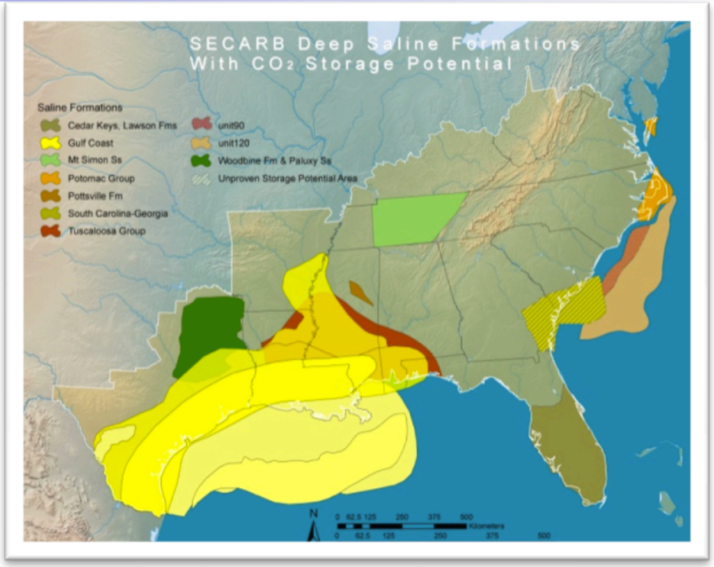
Geologic Project Scope and Objectives

- Scope:
  - Demonstrate safe, secure CO_2 injection and storage in regionally significant saline reservoirs in the SECARB region
- Objectives:
  - Identify and mitigate potential leakage risk
  - Evaluate local storage capacity, injectivity and trapping mechanisms for the Paluxy Formation
  - 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
  - Test the adaptation of commercially available oil field tools and techniques for monitoring CO_2 storage



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Geologic Storage Update

- Characterization Well D9-8#2 started 31-Dec-2010
  - 32 days to drill and install well
  - Total depth 11,817 ft (3,602 m)
  - 98 feet (30 m) of whole core
  - 45 percussion sidewall cores
  - Well logs (Triple Combo, MRI, Mineralogy, Dipole Sonic, CBL)
- Two injection wells to be installed upon receiving UIC permit (Q4 FY11)

Rig on location at well D9-8#2

Characterization well successfully completed January 31, 2011

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NEPA/Permitting Update

- UIC permit application
  - Submitted to Alabama Dept. of Env. Quality
  - Updated with new data
- Environmental Assessment (EA)
  - Mitigation
    - 3 mi of wetlands (wetland mitigation planned)
    - 23 gopher tortoise burrows
  - Permitting/consultation
    - Fish & wildlife service for the tortoise
    - Corp of Eng. for wetlands
    - SHPO (State cultural/archeological assets)
    - Storm-water construction (BMPs)

Gopher tortoise: Photo courtesy of Southern Company

Finding of No Significant Impact (FONSI) anticipated within days

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Transport and Storage Project Costs

Phase III Anthropogenic Test		
	Dollars	Percent
Storage		
DOE Share	$28,691,330	76.14%
Non-DOE Share	$8,990,057	23.86%
Total Value	$37,681,387*	
Expenditures (12/31/2010)	$2,274,513	
Transport	$8,000,000	

Project expenditures to date are within Budget
BP4 funding pending DOE approval

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Together…Shaping the Future of Electricity

SECARB Phase III ANTHROPOGENIC TEST:
Risk Management through Detailed Geologic Characterization and Modeling

Prepared by:
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SECARB Stakeholders' Briefing

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Acknowledgement

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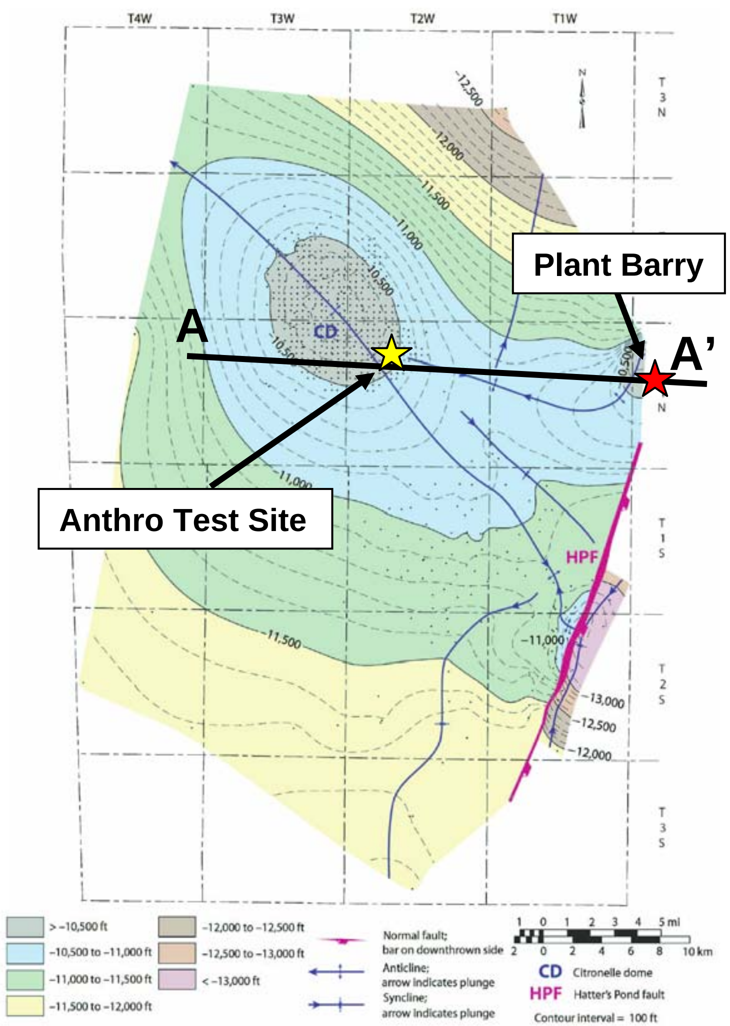
How Do We Address Storage Risks (prior to drilling a well)?

1. **Storage permanence**
   - Select a site with 4-way geologic closure (i.e. structural trap)
   - Multiple confining units and secondary storage compartments
2. **Adequate reservoir injectivity and storage capacity**
   - Conduct detailed reservoir characterization using existing log and core data
   - Reservoir simulation
3. **Existing wellbore leakage risk**
   - Survey of existing deep penetrations in the project area
   - Working relationship with existing well operator(s)
4. **New wellbore leakage risk**
   - Construct project wells to underground injection control (UIC) Class I non-hazardous standards

Structural Contour Map of the Top of the Rodessa Formation



Source: Esposito et al., 2008

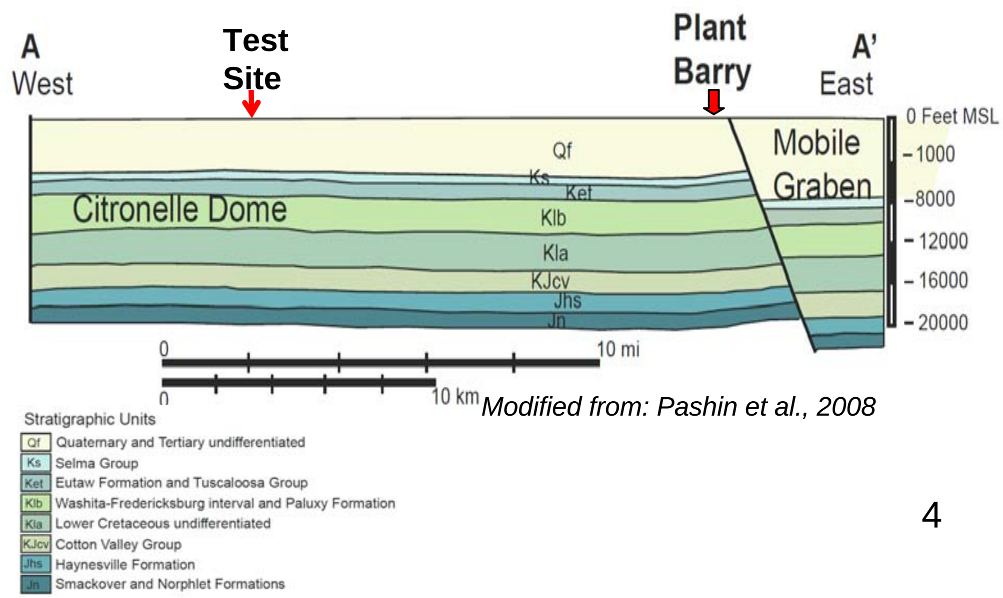
1. Storage Permanence

Regional data and studies show that the Citronelle Dome is:

- A subtle open fold
- Limbs dipping less than 1 degree
- Four-way structural closure

Sources: Pashin et al., 2008; Cottingham, 1988; Esposito and others, 2008

Cross Section from Plant Barry to Citronelle Dome



Modified from: Pashin et al., 2008

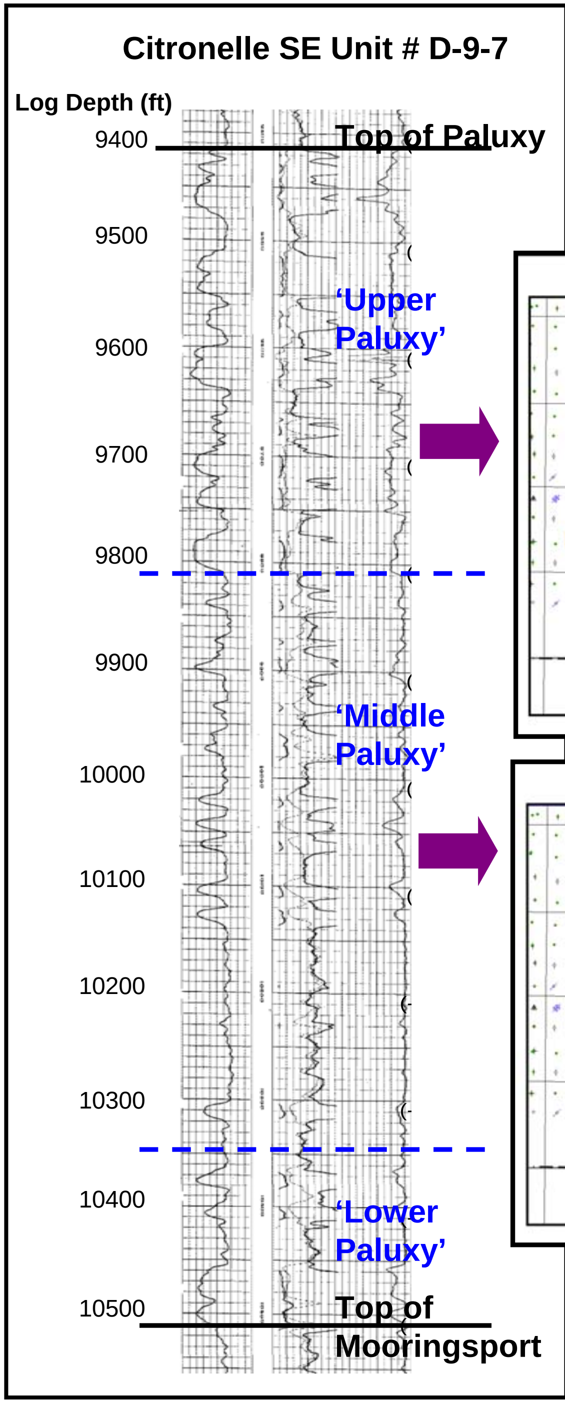
1. Storage Permanence (Cont.)

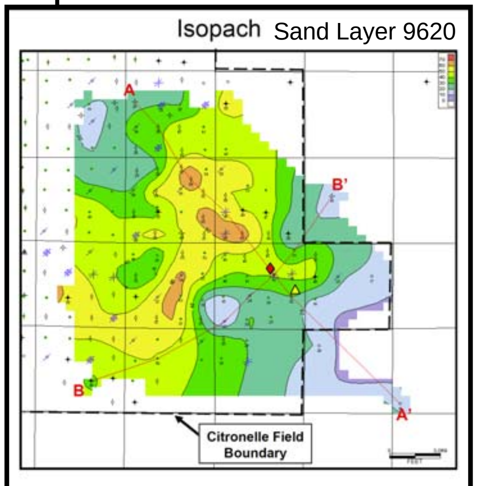
Southeast Alabama Saline Reservoirs and Seals

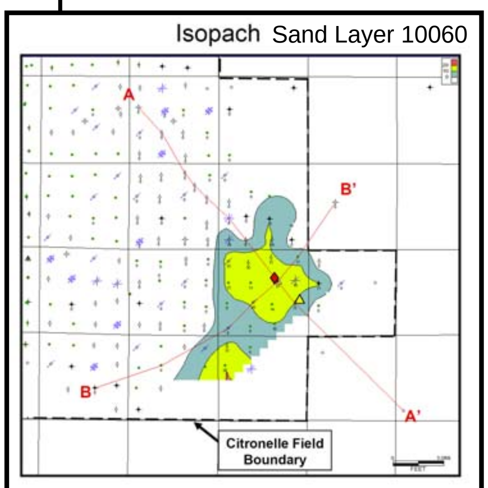
System	Series	Stratigraphic Unit	Major Sub Units	Potential Reservoirs and Confining Zones	
Tertiary	Plio-Pliocene		Citronelle Formation	Freshwater Aquifer	
Tertiary	Miocene	Undifferentiated		Freshwater Aquifer	
Tertiary	Oligocene		Chicasawhay Fm.	Base of USDW	
Tertiary	Oligocene	Vicksburg Group	Bucatunna 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	Confining Zone
Cretaceous	Lower	Paluxy Formation	'Upper' 'Middle' 'Lower'	Proposed Injection Zone	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	

The Anthropogenic Test's CO_2 Storage Site

- Target reservoir is the Lower Cretaceous Paluxy Fm (at 9,400').
- 1,100 foot interval of stacked sandstones and shales.
- Numerous reservoir seals and confining units (at least 5).
- No evidence of faulting or fracturing, based on reinterpretation of existing 2D seismic lines.







2. Injectivity and Capacity

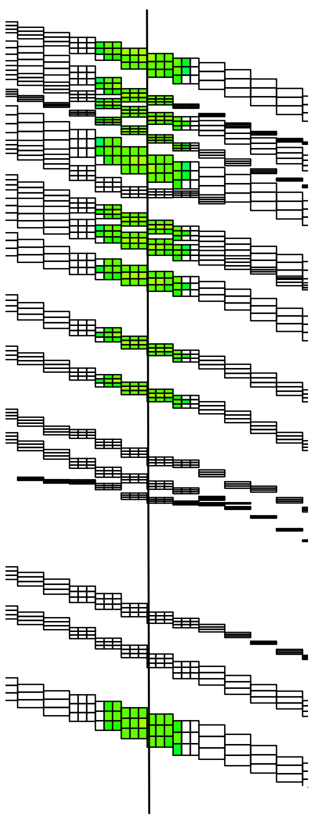
Establishing Reservoir Properties for Paluxy Saline Formation

- Sand continuity mapping to determine "open" or "closed" sand intervals.
- Detailed analysis of over 80 well logs for porosity and depositional style.
- Regional core data for porosity and permeability.
- 340 net feet of sand at injector
- Average porosity of 19%
- Average permeability of 90 md

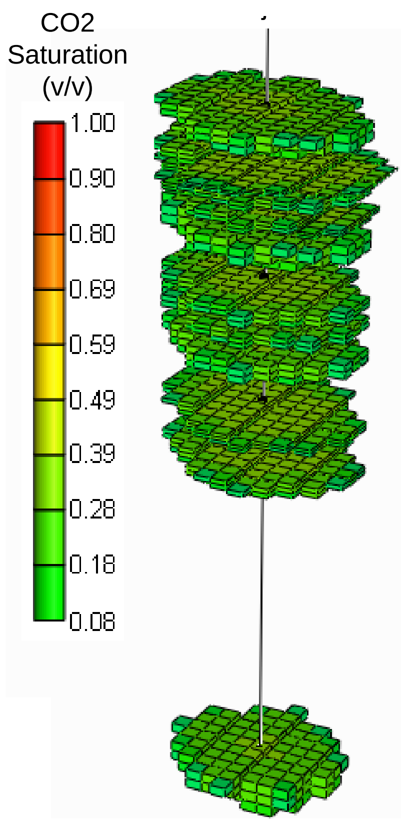
2. Injectivity and Capacity (Cont.)
Reservoir Simulation

Modeling the CO_2 Plume

X-Sectional View of CO_2 Plume CO2 Injection Well



3D View of CO_2 Plume CO2 Injection Well



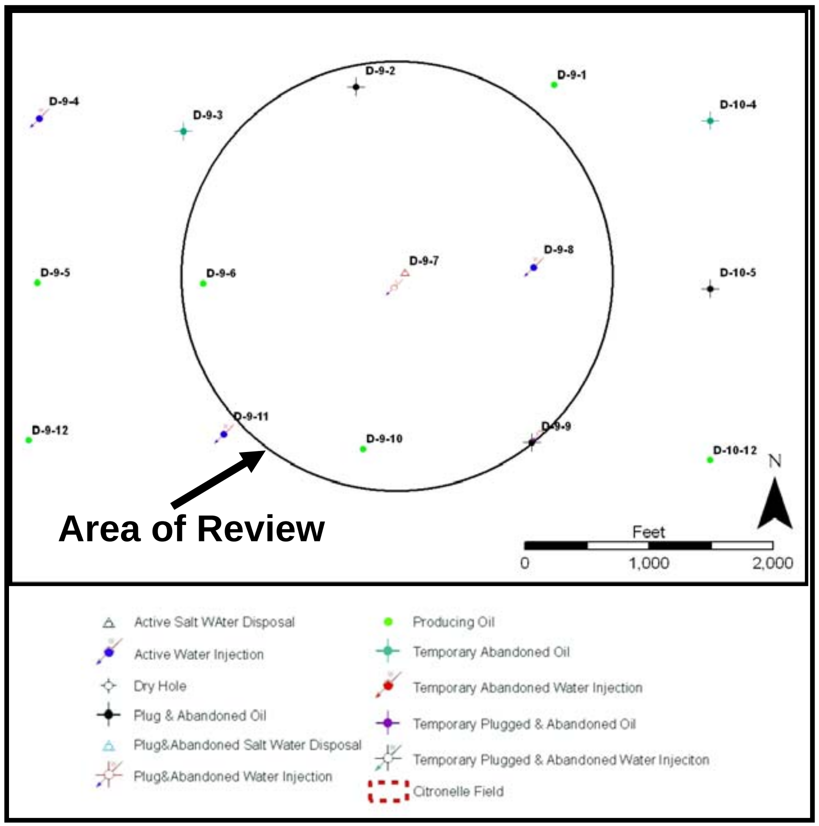
Understanding CO_2 Flow and Optimizing Storage Capacity

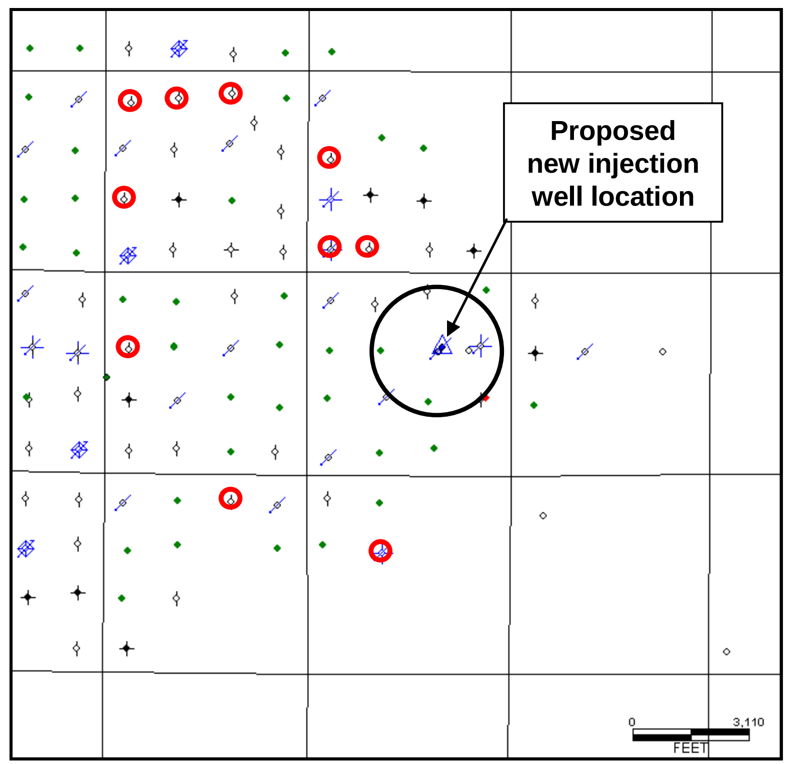
The information from detailed reservoir characterization was used to model and optimize the CO_2 plume:

- Areal extent of CO_2 will be limited (~1,000 ft) by injection into multiple sand layers.
- Low dip results in a near-circular plume and little post CO_2 injection up-dip migration.

3. Existing Wellbore Leakage Risk

- Catalog of data for wells within estimated plume area (Area of Review)
- Oil field operator maintains active MIT program for the field
- Ran cement bond logs on selected wells in the injection area (highlighted with red circles)
  - Adequate cement bonds observed across injection interval and confining unit in all wells
  - Average top of cement depth is at a depth of 6,800 ft (>2,000 ft above top of confining unit).





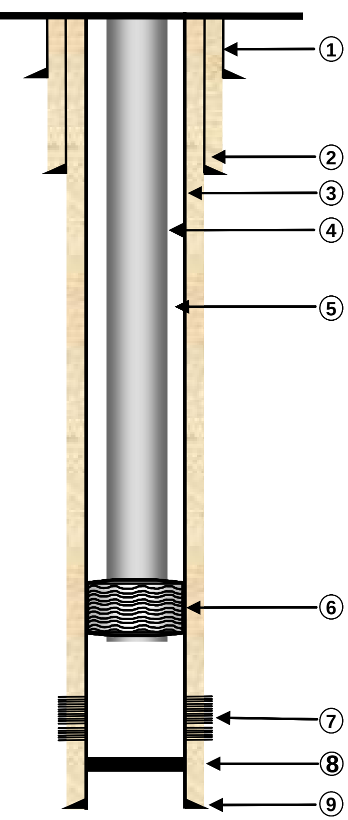
4. New wellbore leakage risk: Design for new Project Wells

- Using accepted UIC well construction standards (Class I non-hazardous) to construct all wells
- Surface casing run to below base of USDW and cemented to surface
- Long string casing to TD
- Cemented into surface casing
- Injection through tubing and packer
- Monitoring well-head and down-hole pressure throughout injection period

Completion Well Diagram

COMPLETION DETAIL

1. 16" Conductor Pipe set at 60'.
2. 10-3/4" Surface Casing @ 2,500', set in 13 1/2" hole; 45.5 lb/ft J-55 STC; Cemented to surface.
3. 7" Protection Casing @ 11,800', set in 9-7/8" hole; 26.0 lb/ft L-80 LTC; Cemented to surface (2 stage).
4. 2-7/8" Injection Tubing @ 9,300'; 6.5 lb/ft L-80 EUE 8rd.
5. Annular Fluid: 8.4 lb/gal inhibited fresh water.
6. Injection Packer @ 9,300'; 7" x 2 7/8" Ni-plated full-bore lockset packer
7. Perforations: 9,400' to 10,500'.
8. Cast Iron Bridge Plug and Cement Cap at Ferry Lake
9. Total Depth @ 11,800'.



How Does Drilling a Characterization Well Further Address These Risks?

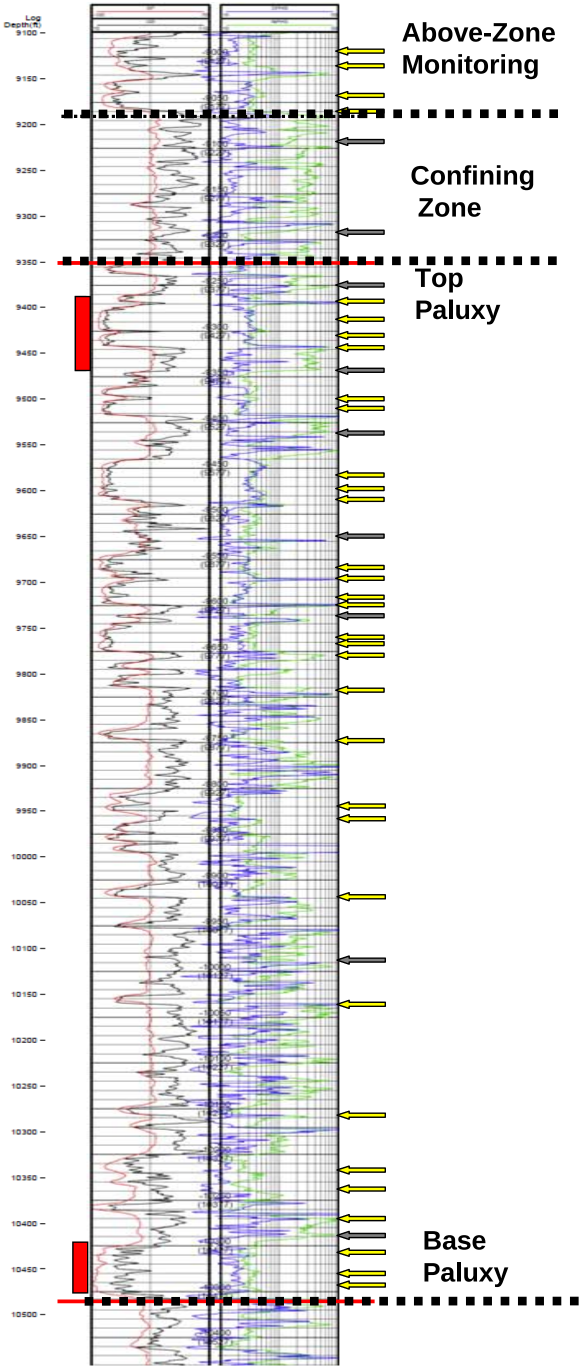
1. **Storage Permanence**
   - confirm properties of the confining units with core and log data
2. **Adequate reservoir injectivity and storage capacity**
   - confirm properties of the confining units with core, log and fluid data
3. **Existing wellbore leakage**
   - update reservoir simulation using new characterization data to reassess the project AoR
4. **New wellbore leakage risk**
   - Well construction requirements

Anthropogenic Test Characterization Well (D-9-8 #2)

At the end of December 2010, we began drilling the Anthropogenic Test characterization well

- Well drilled to 11,800’ TD (spud to TD) in 30 days and under budget.
- Well was cased and cemented in January 2011.
- Whole and sidewall cores, geophysical well logs
- Well will be used as an observation/monitoring well

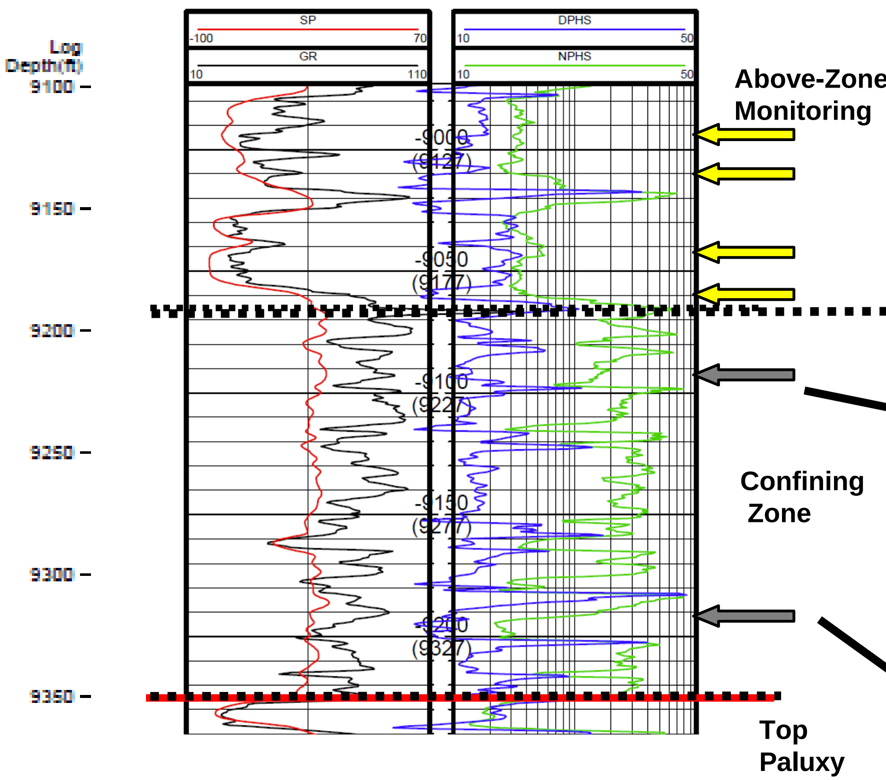
Data Collection at D-9-8#2



- Recovered extensive Paluxy Formation whole core (98 feet in two intervals)
- 62 Whole core plugs tested
- Recovered a total of 45 percussion sidewall cores from:
  - Overlying confining units,
  - Overlying saline reservoirs
  - Paluxy Formation
- Ran full set of well logs (quad combo, array gamma, MRI, mineralogy, dipole sonic, etc.).

D-9-8#2 Sidewall Core Data

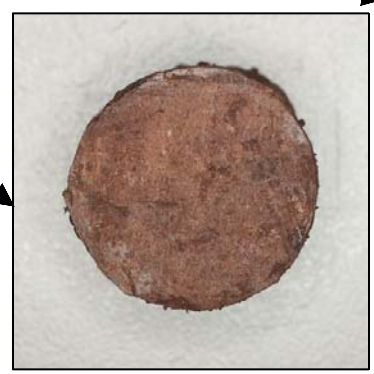
Sidewall cores can be used to acquire reasonable porosity values for sandstone intervals and confirm lithology for shales. Unreliable for permeability.



Above-Zone Monitoring Sand Properties

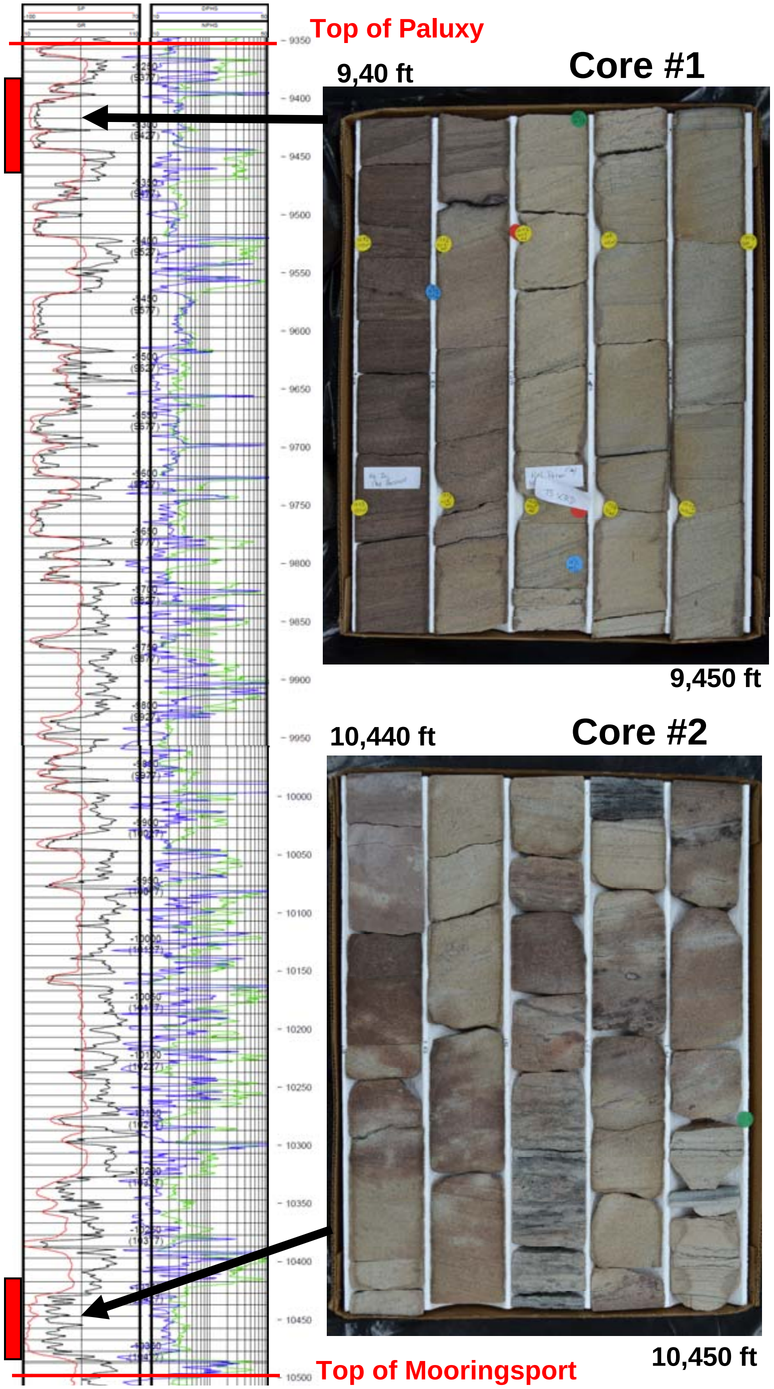
Sample Depth (ft)	Porosity (%)	Lithology
9,120	23.5	SS, fine-grained
9,160	21.0	SS, fine-grained
9,170	21.8	SS, fine-grained
9,180	23.4	SS, fine-grained

Confining Zone Lithology



9,318 ft
Siltstone-Shale

9,210 ft
Shale



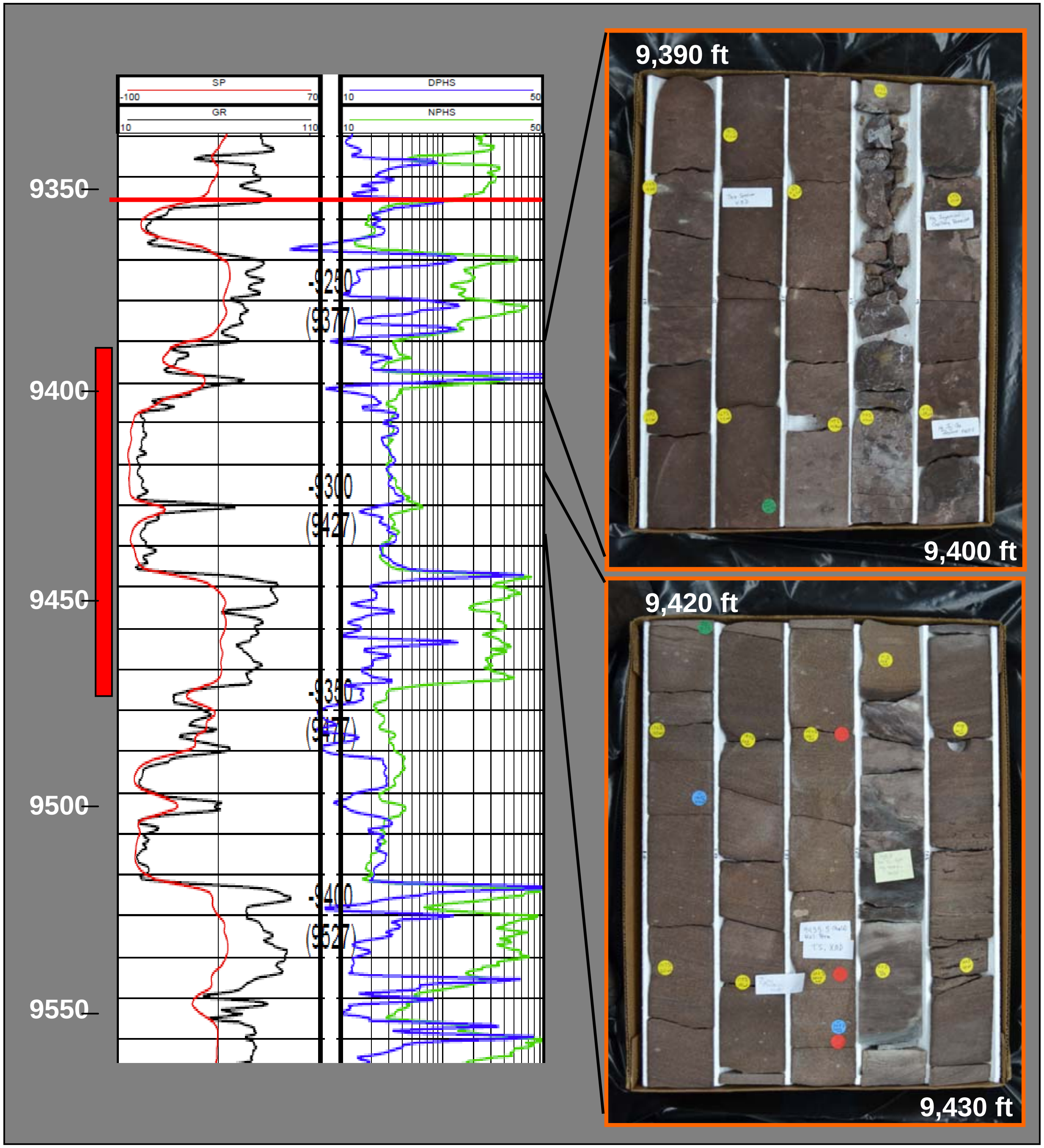
Paluxy Whole Core

Cored Top and Basal Paluxy Sands:

- Fluvial System: sand and shale sequence in both upper and lower core
- Fining upward units suggest channel fill
- ‘Sandy’ intervals are typically between ~ 2-10 ft
- Sharp base of medium- coarse grained sand grading upward to finer sand and then shale.

Prior to this project no core of the Paluxy Formation had been collected regionally

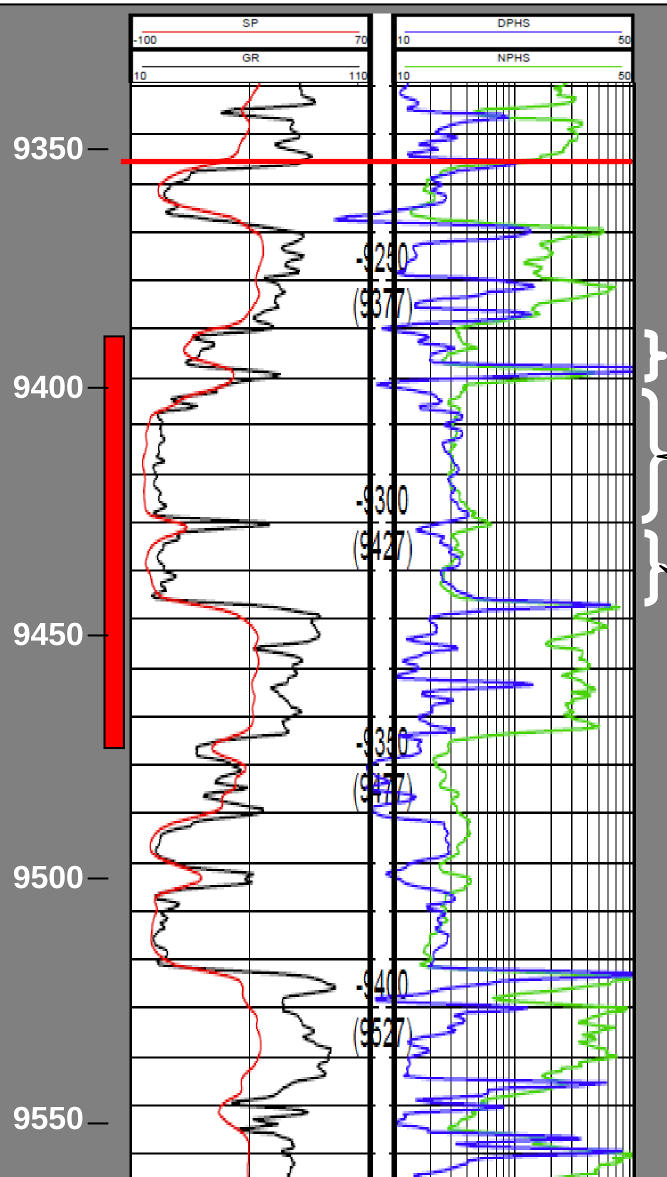
Paluxy Core #1



Notable Features:

- Heavily burrowed
- Rip-up clay pebbles
- Root zones
- Trough cross beds
- Multiple soil horizons
- Upper sands in Core # 1 were oxidized (red color)
- Lower sands are not oxidized

Porosity and Permeability Ranges, Core #1



Porosity Range: 6-18%
Permeability Range: 1 – 50 md

Porosity Average: 13 %
Permeability Average: 8 md

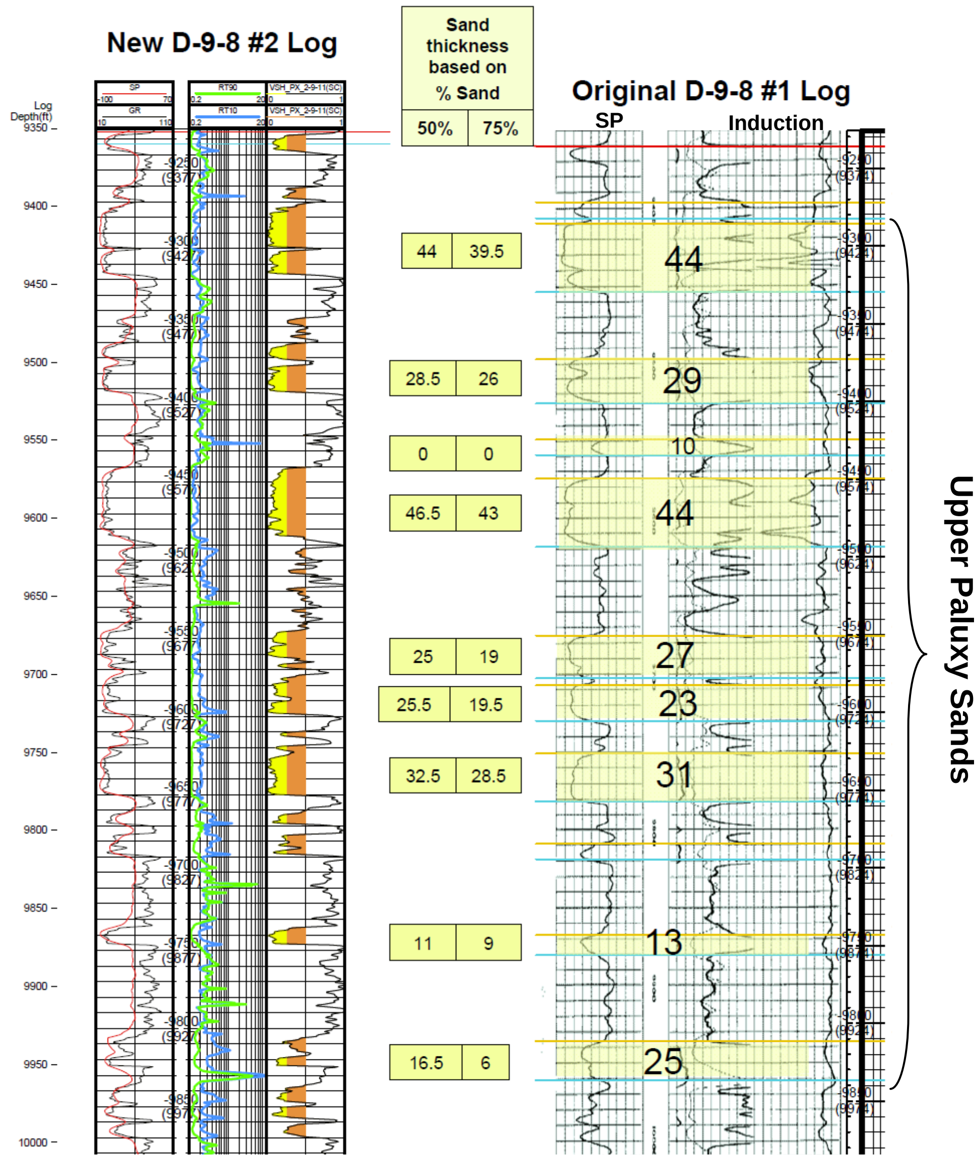
Porosity Range: 6-23%
Permeability Range: 1 – 3,800 md

Porosity Average: 18%
Permeability Average: 440 md

Porosity Range: 8-22%
Permeability Range: 1 – 1,900 md

Porosity Average: 18%
Permeability Average: 500 md

Confirming Storage Capacity (Thickness)



Note: thickness values are in feet

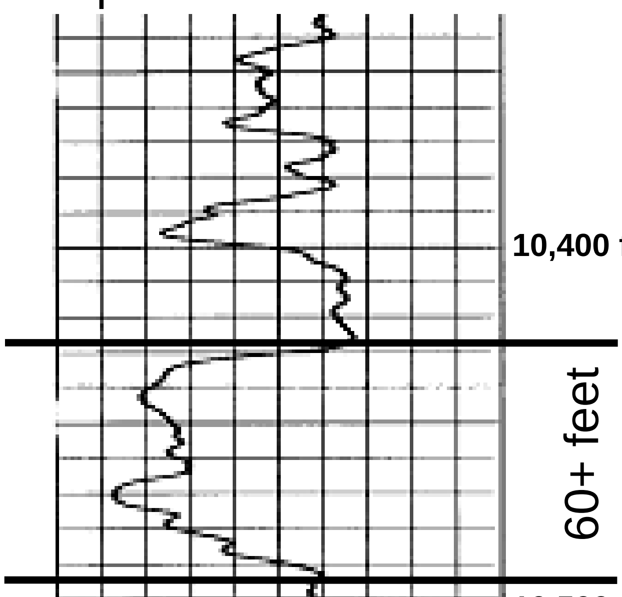
- Calculated sand thickness using new log data.
- New results suggest Paluxy reservoir thickness of:

  278.5 ft of **50%** clean sand
- Sand thickness estimates made using old logs (310 ft) appear to be acceptable
- However there were notable individual exceptions

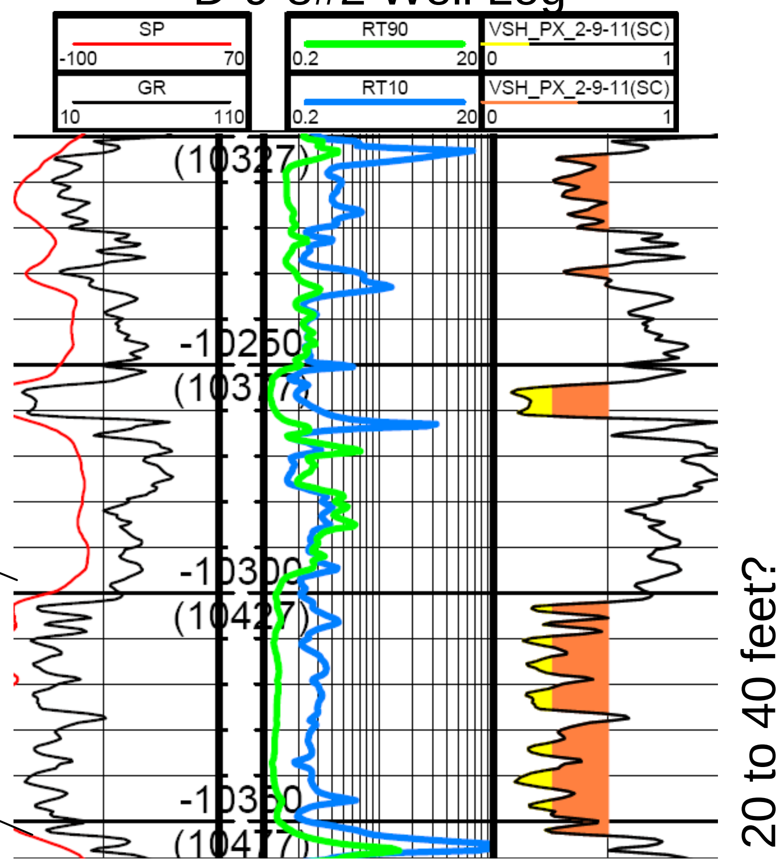
Confirming Storage Capacity (Thickness)

- Previous slide showed comparison of vintage and new logs for the Upper Paluxy
- The basal Paluxy sandstone (one of our whole core targets) appears to be of lower quality (thickness and vertical continuity) than the old log would indicate

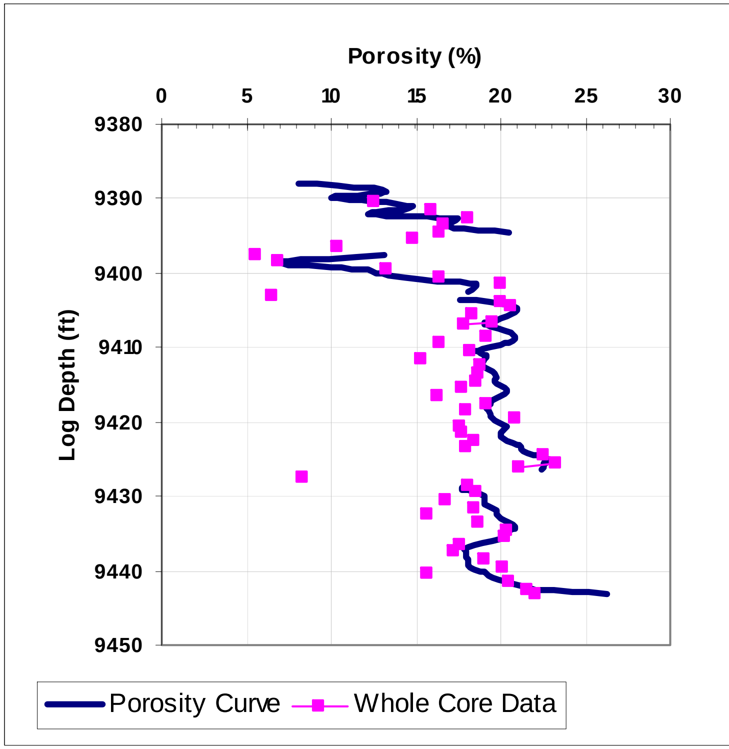
D-9-8#1 Vintage Spontaneous Potential

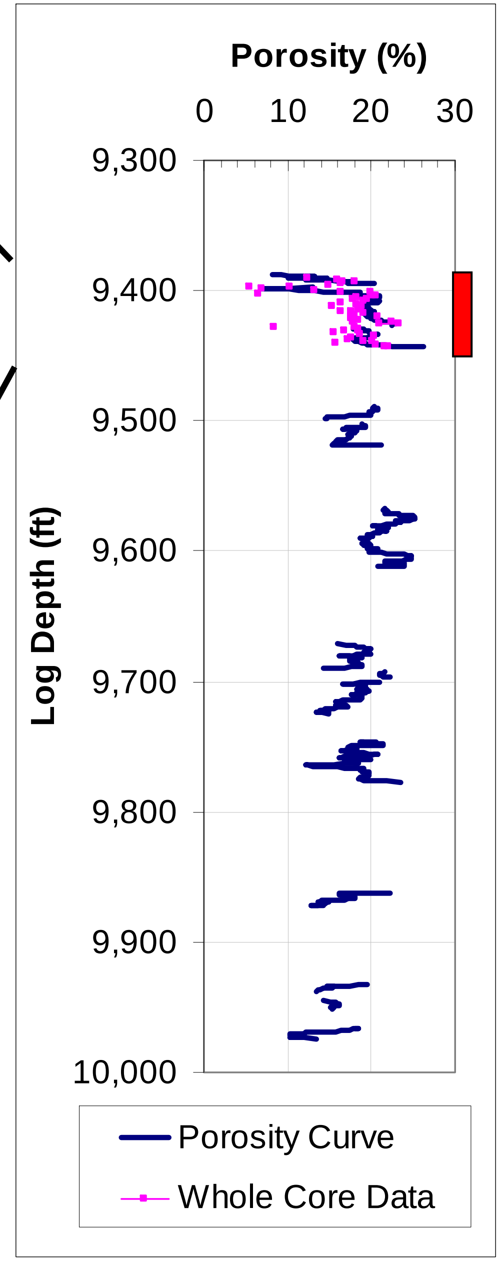


D-9-8#2 Well Log



Confirming Storage Capacity (Porosity)



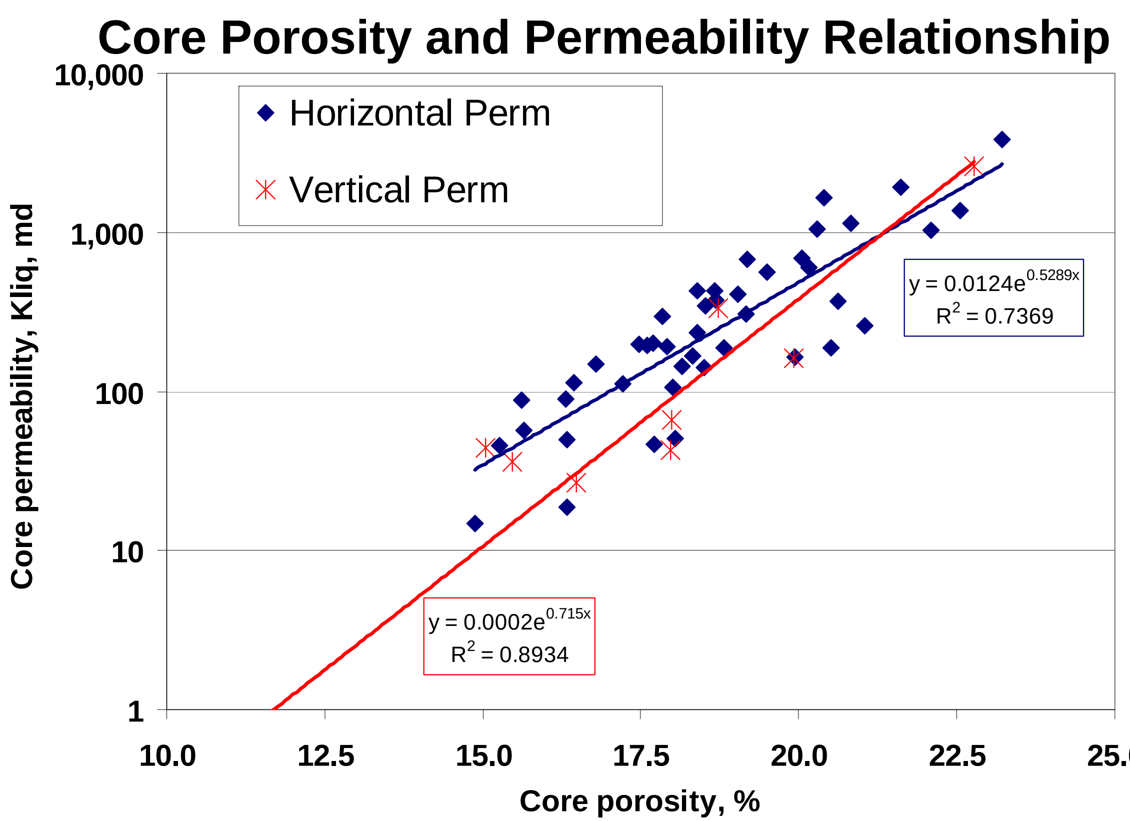


Porosity log data and core data were used to develop a Paluxy sandstone porosity curve

- Averaged porosity of the Paluxy Formation sandstones using this approach is 18.9 %
- This estimate compares quite well with the prior sandstone estimate of 19%

Confirming Reservoir Injectivity (Permeability)

Core tests demonstrated exceptional reservoir permeability

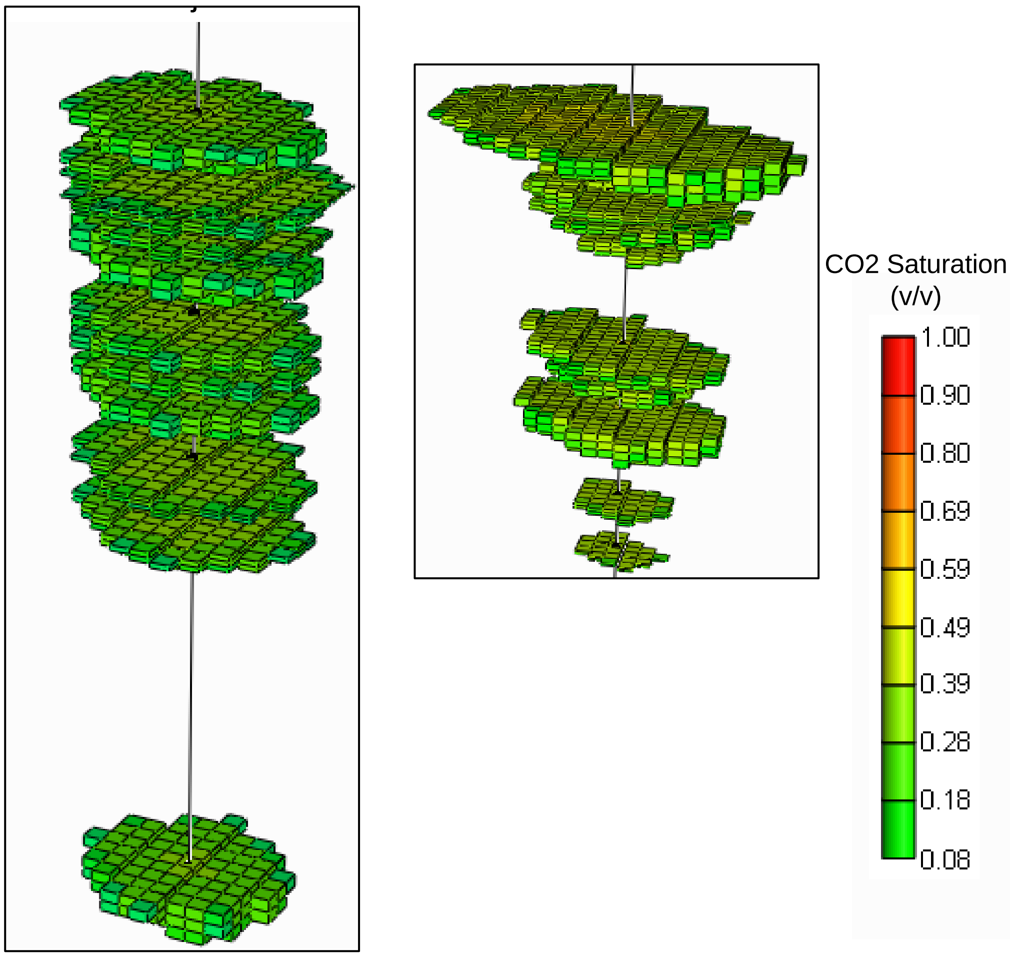


Phi (%)	Hz Perm (md)	Vt Perm (md)
24	4,040	5,670
22	1,400	1,360
20	490	320
18	170	80
16	60	20
14	20	4
12	7	1
10	2	0

Updating the Geocellular Model

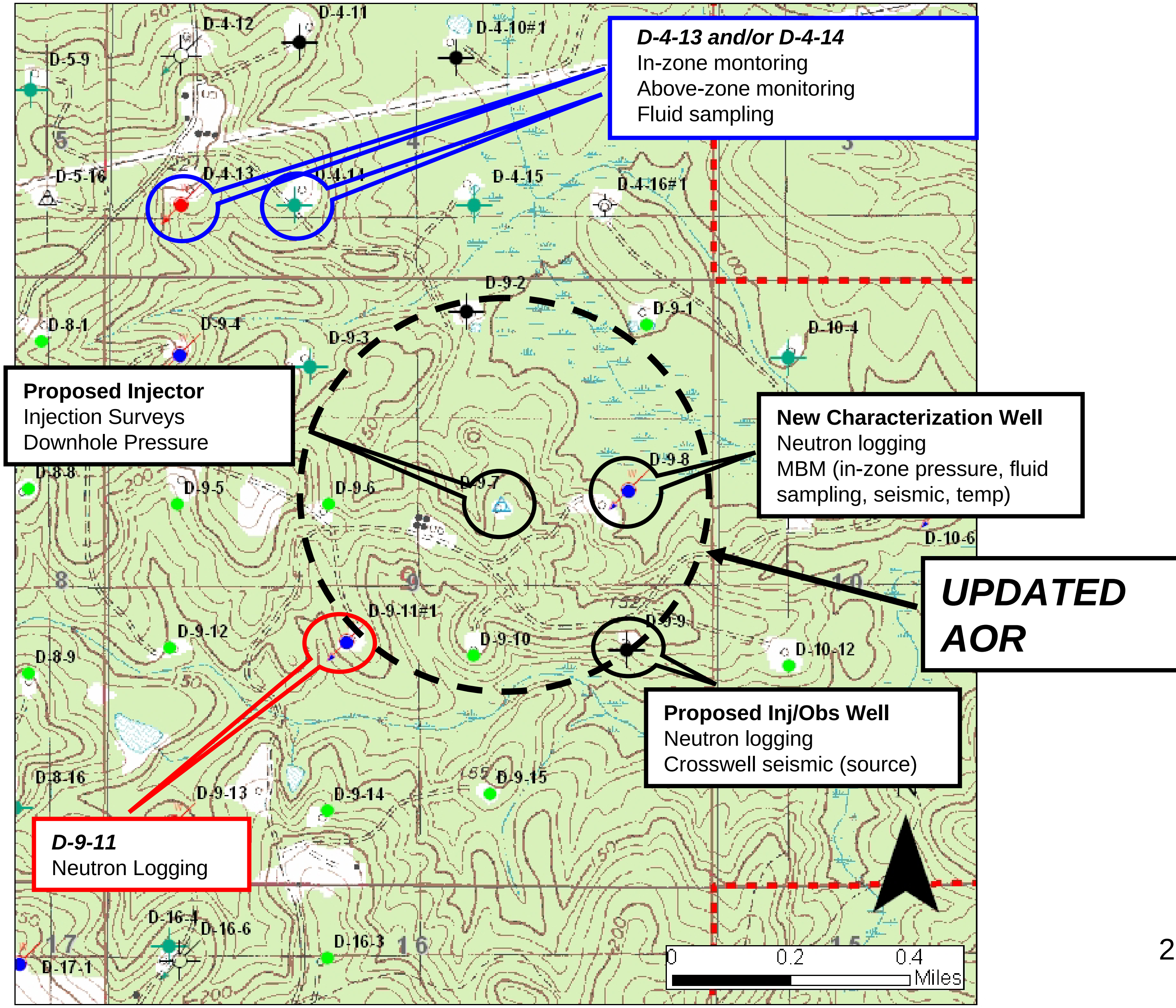
3D View of CO_2 Plume End of Injection

Original Model **Updated Model**



- Model plume extent was 1,000 ft radius in original model
- New model now shows plume extent nearly 1,700 ft
- Due to higher permeability in upper Paluxy sandstones
- Necessitates updated Area of Review
- MVA plan appears to be adequate
- Next step incorporate permeability variation within each sandstone – how does that affect the plume behavior?

Monitoring within and Beyond the Updated AoR



Conclusions (1)

Site characterization using existing geologic and well data defined project risks to an acceptable level to move forward with characterization well drilling

1. Storage permanence

- Geologic closure, no faults or major fracture zones.
- Confining units and seals.

2. Adequate reservoir injectivity and storage capacity

- Reservoir thickness, porosity and permeability appeared to be adequate to accept CO_2 volume.
- Stacked sand/shale package appears to confine plume extent.

3. Existing wellbore leakage risk

- Condition of deep penetrations in UPDATED project area appear to be adequate to prevent CO_2 leakage.

4. New wellbore leakage risk

- Wells constructed to UIC Class I standards.

Conclusions (2)

Data from the new characterization well further addresses these risks

1. Storage permanence

- Promising confining unit characteristics.
- Establish mechanical properties (work ongoing)

2. Adequate reservoir injectivity and storage capacity

- Reservoir thickness, porosity and permeability as good or better than preliminary estimates. More than adequate to accept CO_2 volume.
- Stacked sand/shale package still appears to confine plume extent.

3. Existing wellbore leakage risk

- Condition of deep penetrations in the updated project area appear to be adequate to prevent CO_2 leakage.

4. New wellbore leakage risk

- First project well drilled to UIC Class I standards.

SECARB Stakeholders Meeting Plant Barry CCS Demo

Michael Ivie

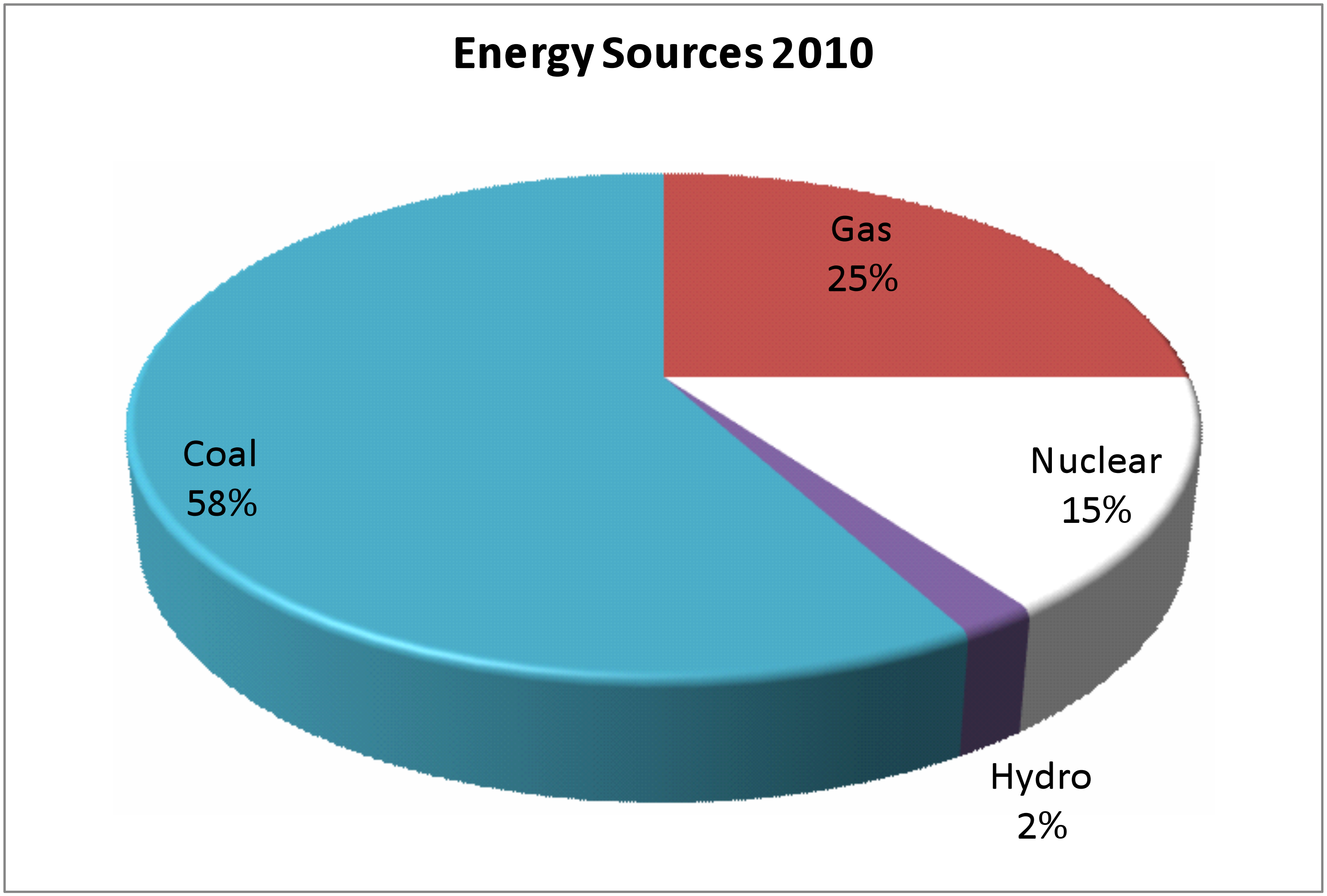
3-8-2012

SOUTHERN COMPANY

Southern Company: SO

- **Headquarters:** Atlanta, Georgia
- **2010 revenues:** $17.45 Billion
- **2010 net income:** $1.97 Billion
- **2010 total assets:** $55.0 Billion
- **Electric generating capacity:** 42,962 MW
- **Four regulated electric utilities:** APC, GPC, Gulf, MPC
- **One wholesale generator:** SPC

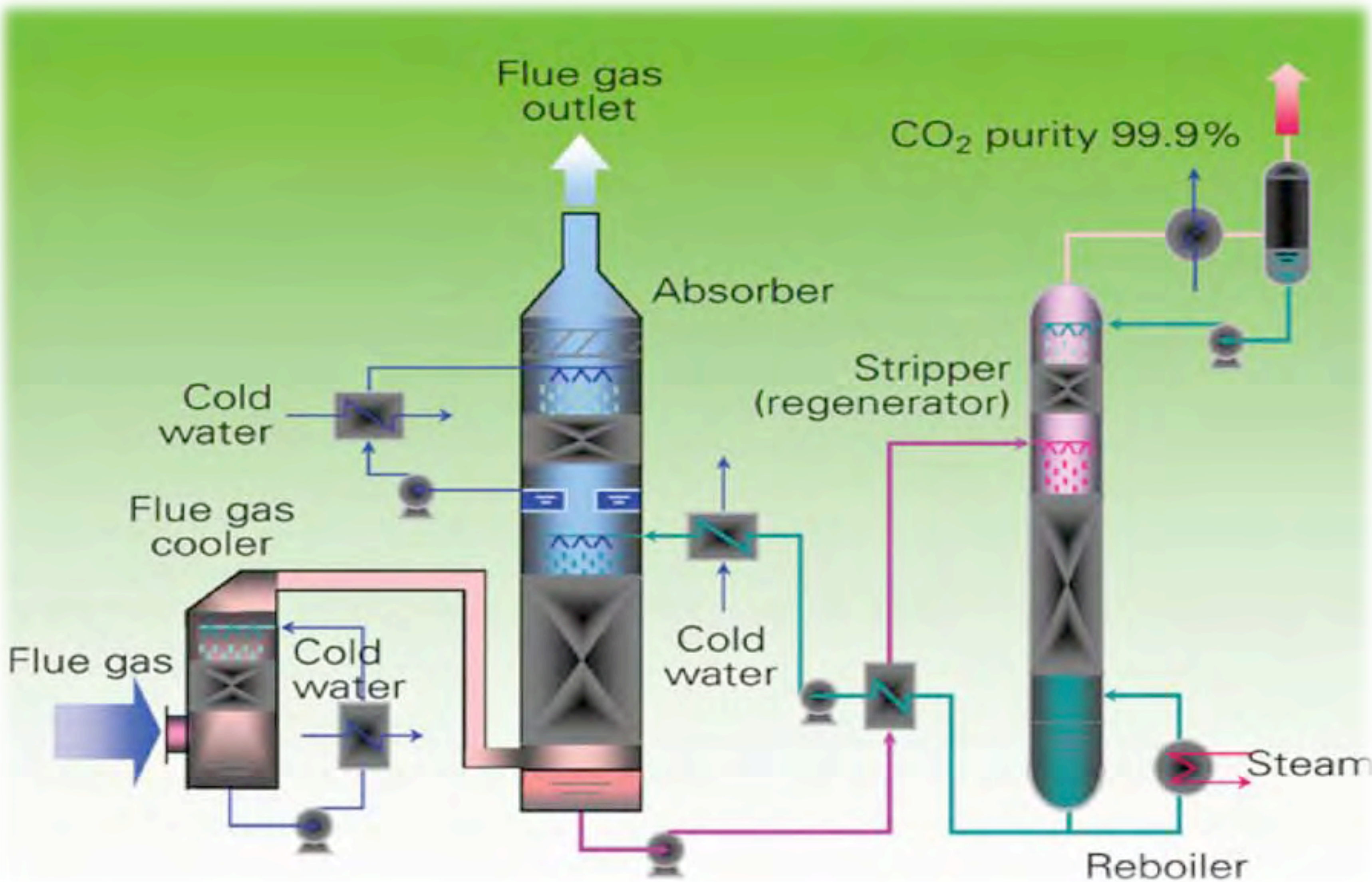
Diversified Energy Sources



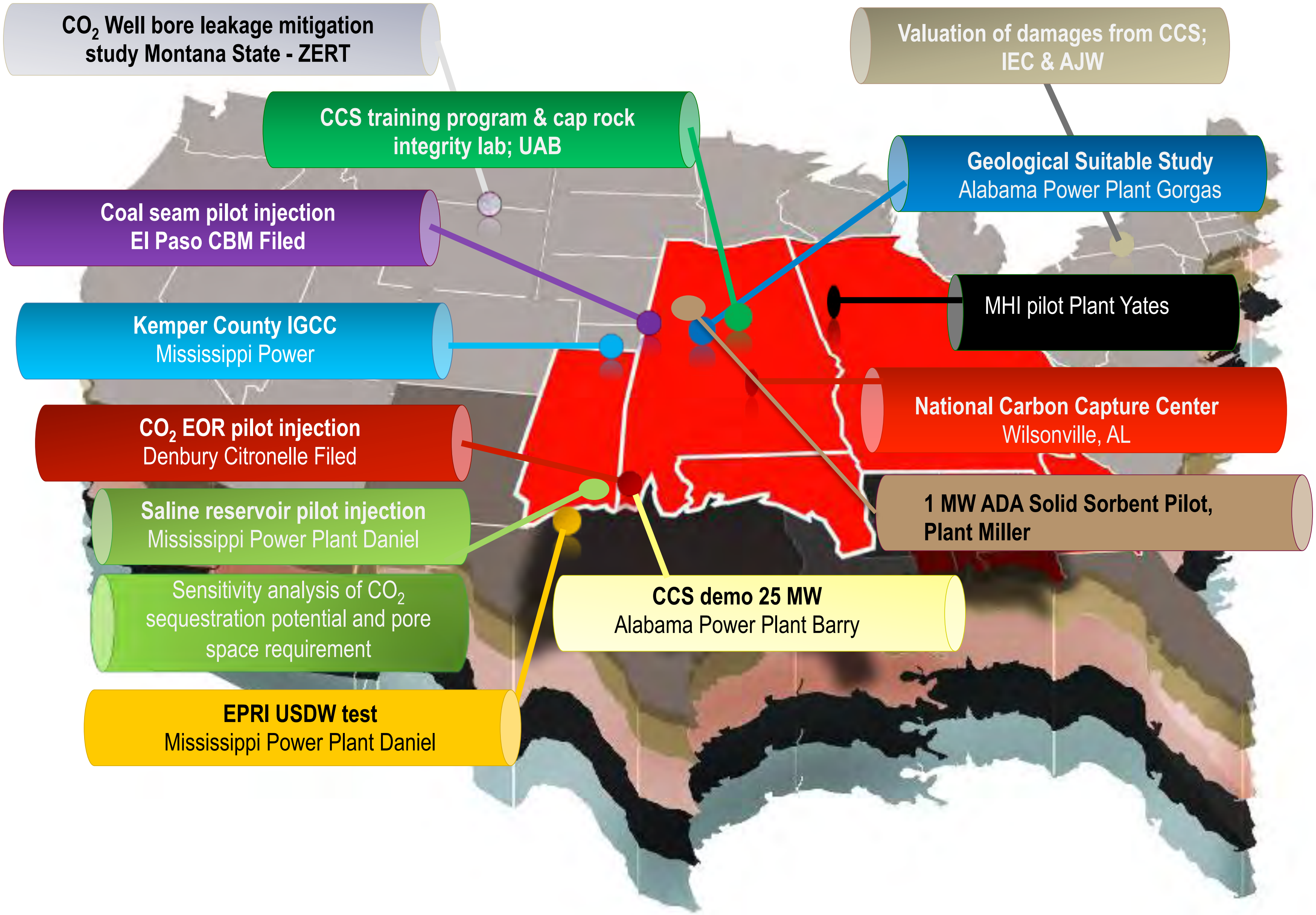
CO_2 Capture and Storage Technology

Capture	• Pure CO_2 captured from plant flue gas
Compression	• Compressed to ~100-150 atm (~1500-2250 psi)
Pipeline Transport	• Transported to injection site via underground pipeline
Underground Injection	• Injected into deep geologic formations and sequestered for thousands of years

Carbon Capture Process

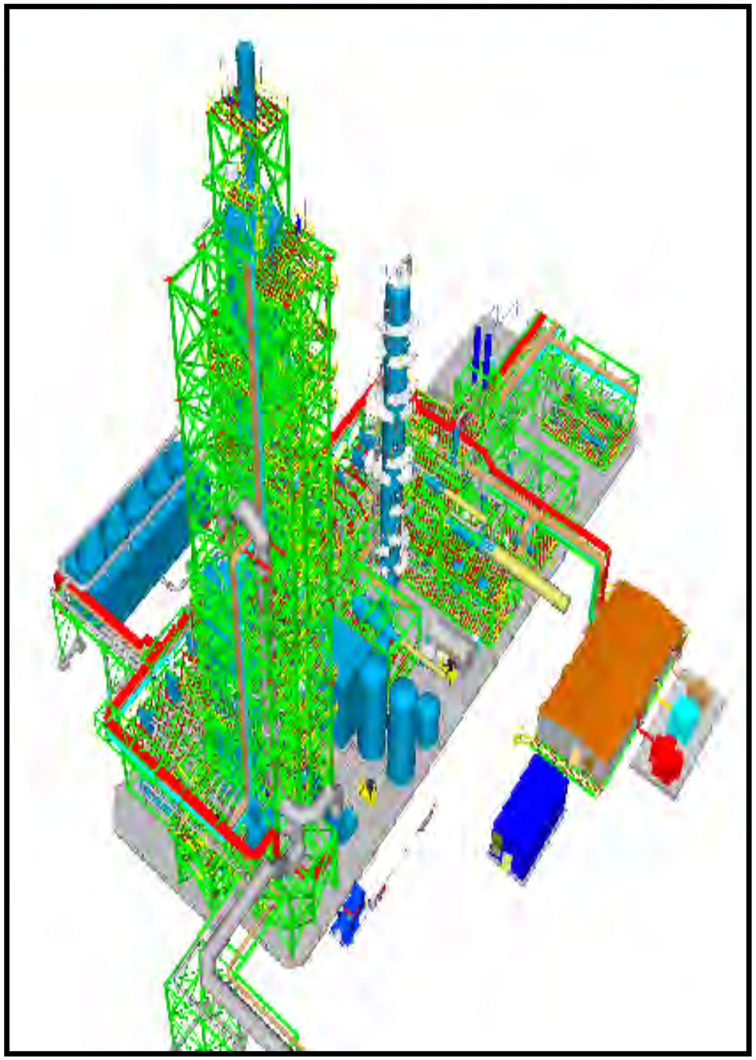


Southern Company CCS Research



25 MW Integrated CCS Demo – APC Plant Barry

- CO_2 Capture and Compression
  - SCS/MHI collaboration with partners
  - KM-CDR capture technology (500 TPD)
- Transportation and Sequestration
  - DOE SECARB Phase III “Anthropogenic Test”
  - 150k tpy for up to 4 years into saline geology
  - ~15 mile CO_2 pipeline to Citronelle Field
- Objectives/Goals
  - Advance saline sequestration technology through large field test
  - Characterize operations to support full scale deployment
  - Continue outreach and education to insure seamless deployment



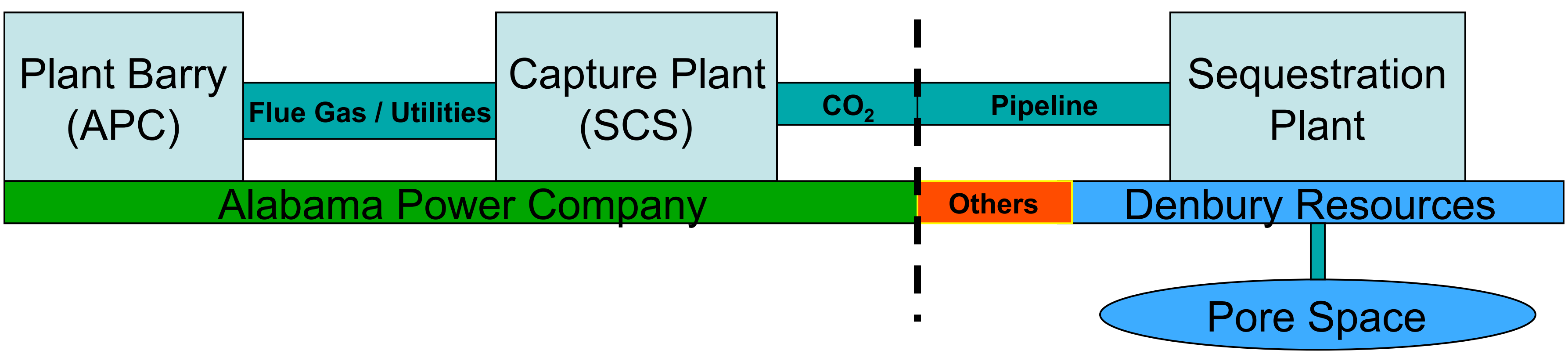
CCS Demo: Project Structure

Capture Project

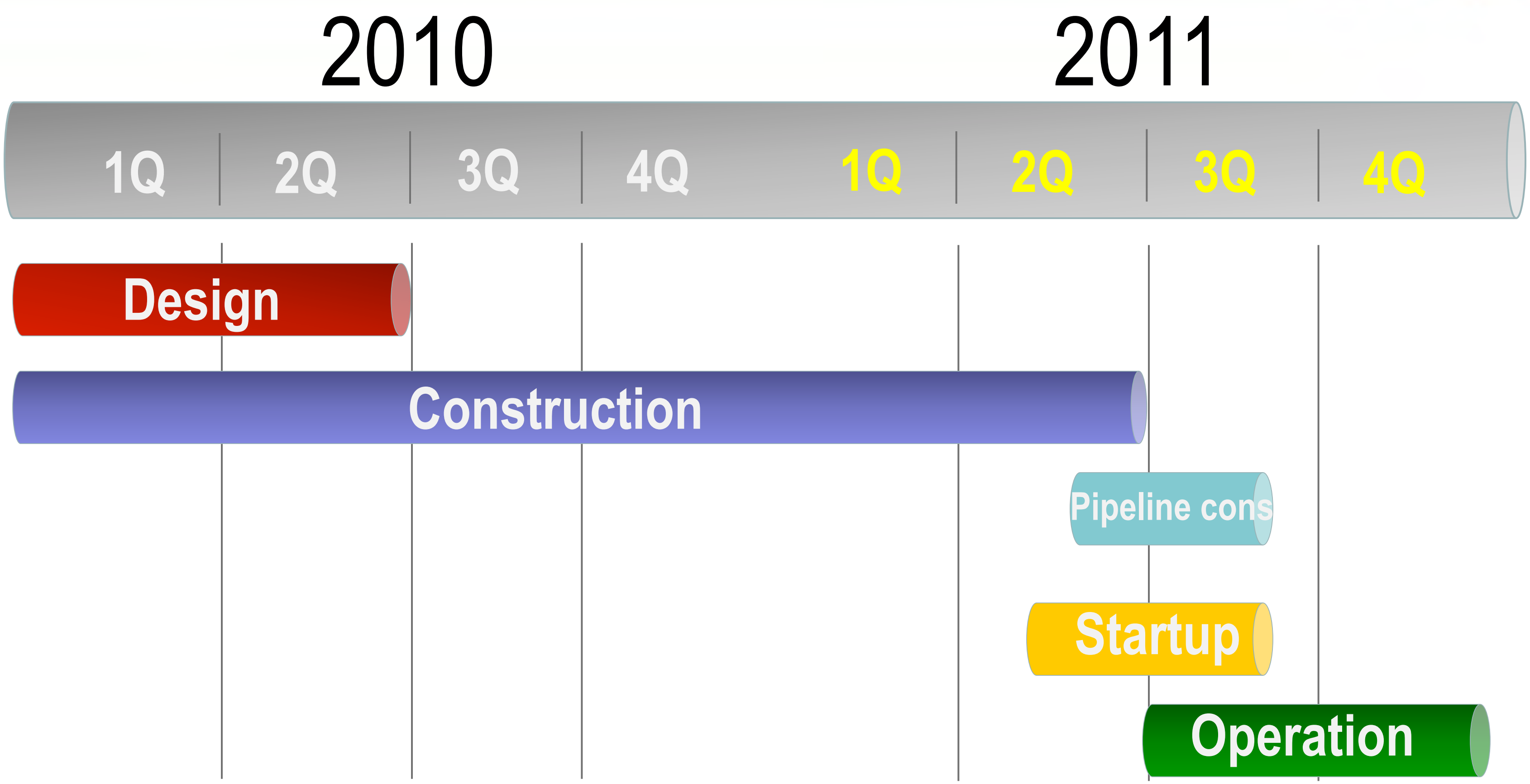
- SO collaborating with MHI
- Location: APC's Plant Barry
- Execution and contracting: SO

Sequestration Project

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



25 MW CCS Demo: Execution



Foundation-Startup : < ½ est time

$35 million construction execution: staff <10

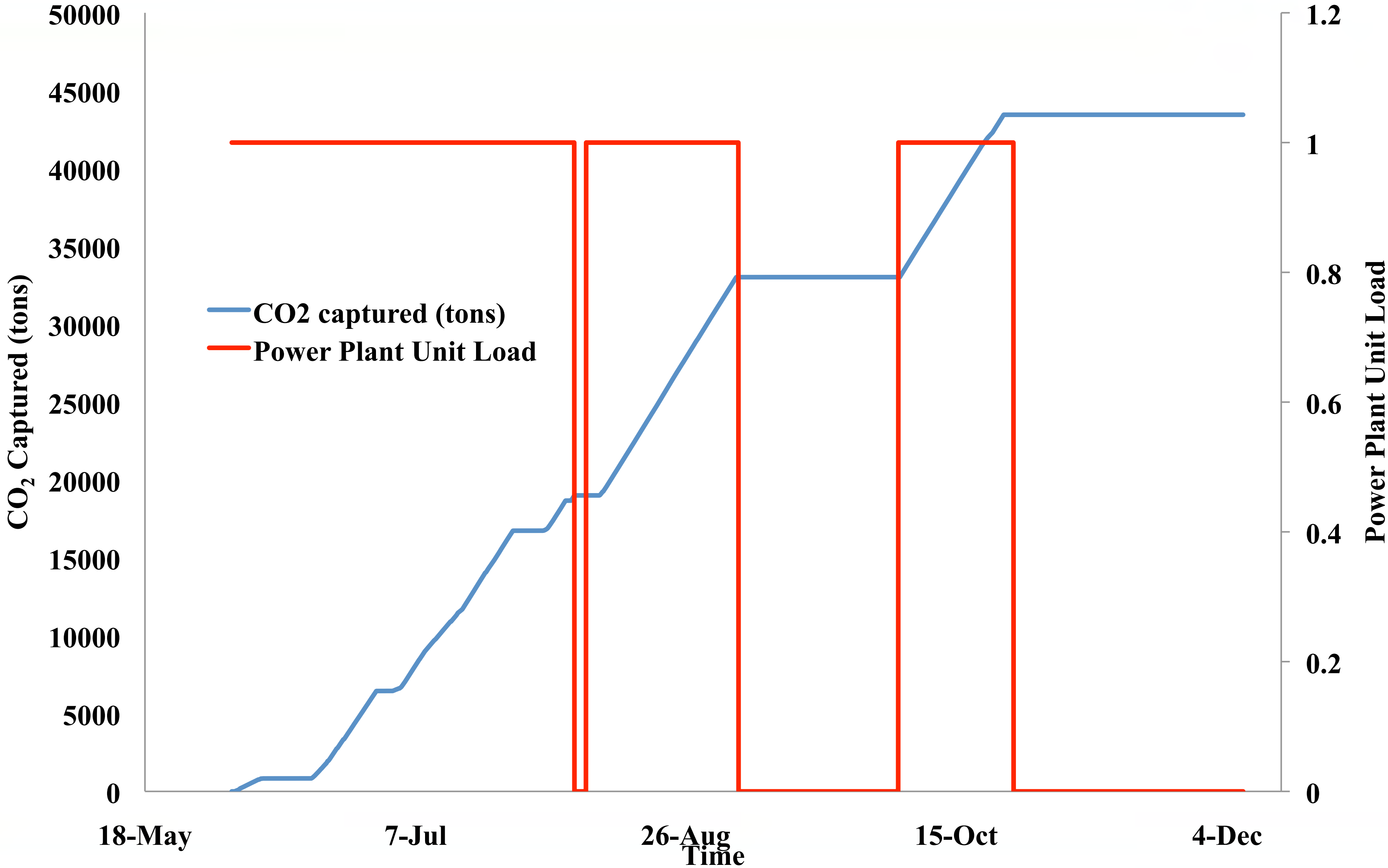
Man hours: 303,283

Safety: 1 recordable

2011 Update - Plant Barry

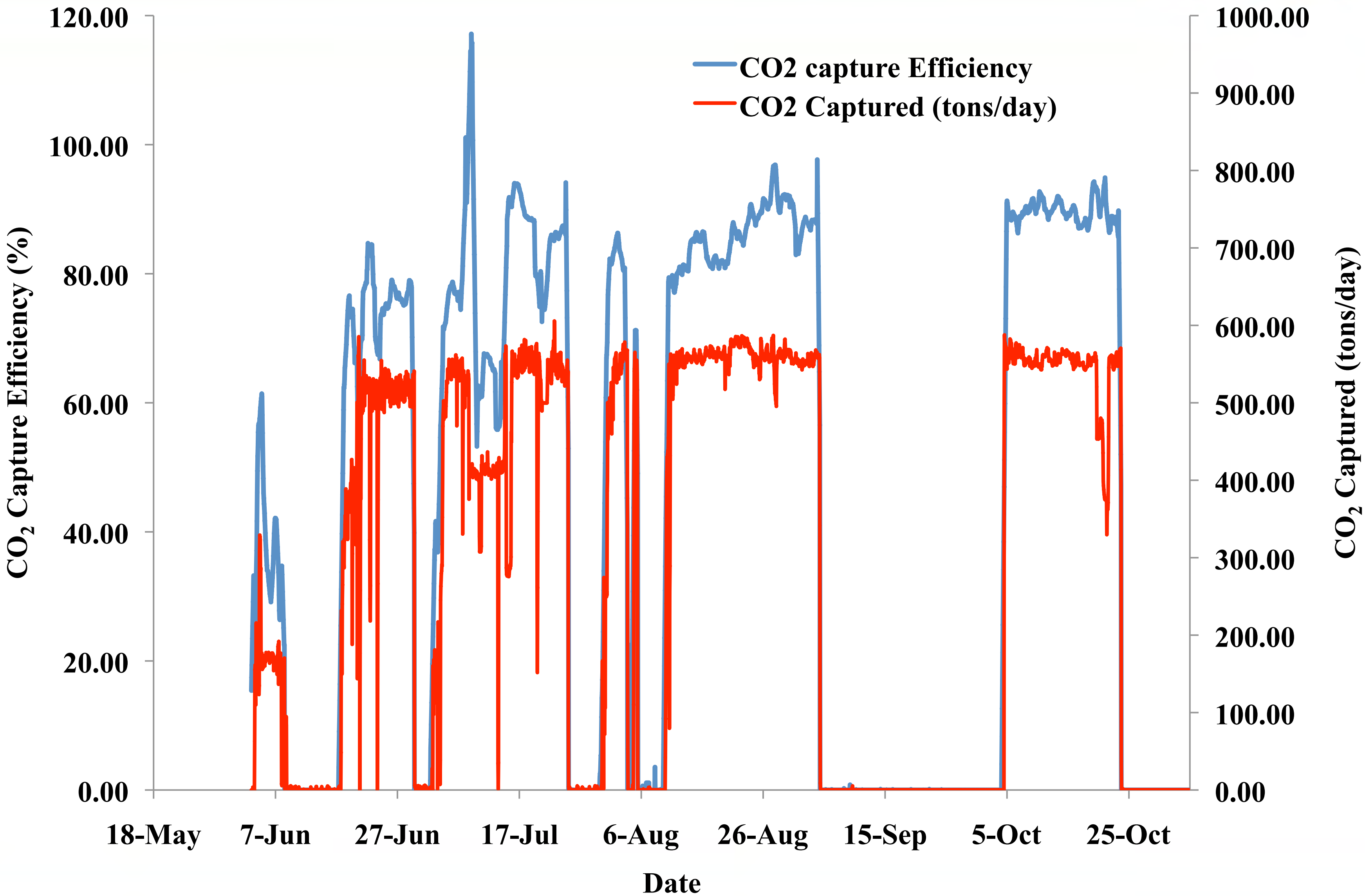
- Started up on June 2nd 2011
  - Steam Optimization and Parametric Testing
  - Compressor commissioning
- Unit 5 on reserve shutdown has been an issue
  - Capacity Factor ~ 38%
- Illinois basin coal test burn on unit 5 at Barry (October 7-October 22)
- 42,730 tons of CO_2 captured thru October 21
- World's largest start to finish CCS project on coal fired power plant

Results



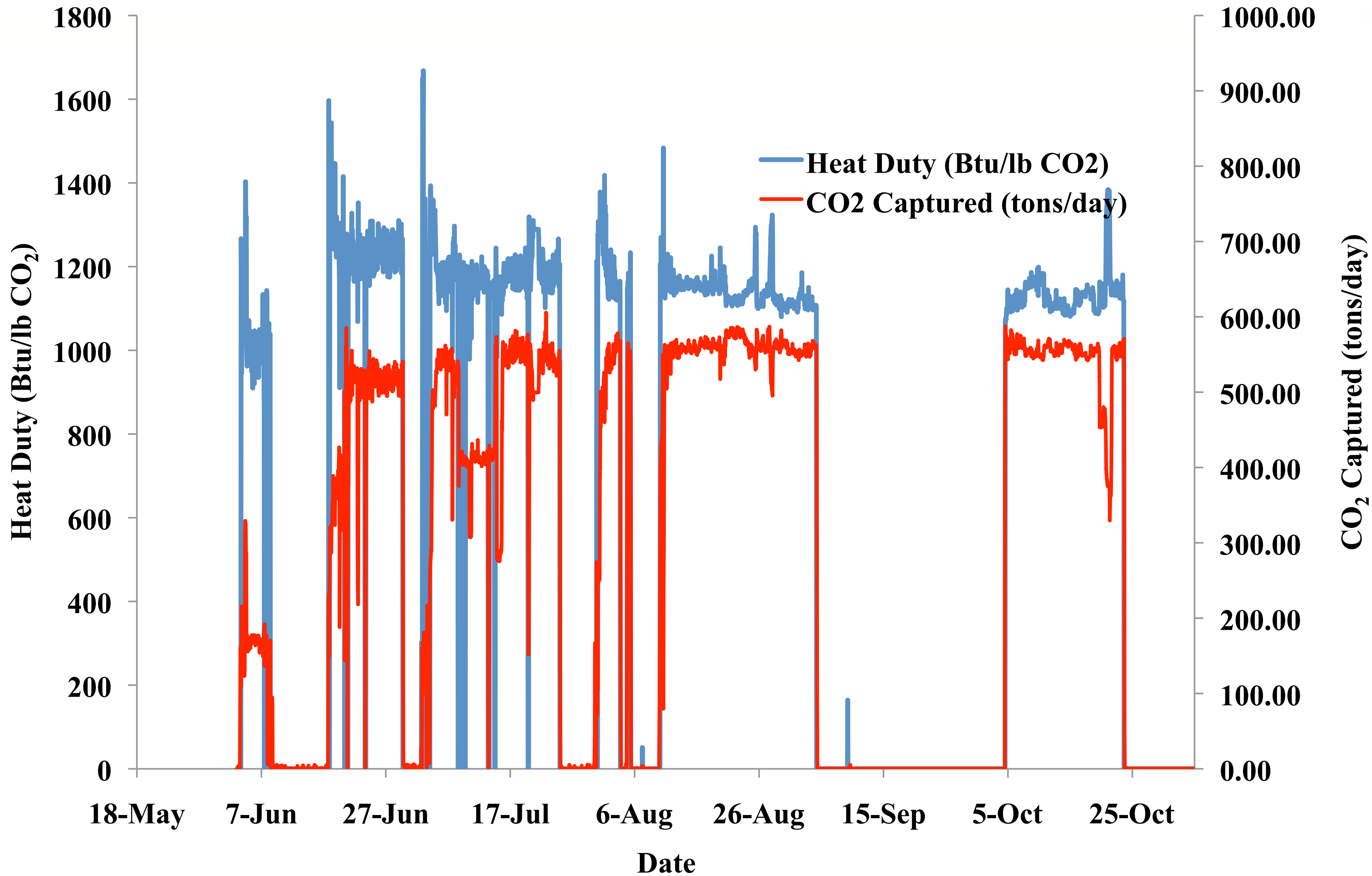
CO2 captured (tons)
Power Plant Unit Load
CO_2 Captured (tons)
Power Plant Unit Load
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
1.2
1
0.8
0.6
0.4
0.2
0
18-May
7-Jul
26-Aug
15-Oct
4-Dec
Time

Results



CO2 capture Efficiency
CO2 Captured (tons/day)
120.00
100.00
80.00
60.00
40.00
20.00
0.00
1000.00
900.00
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
CO$_2$ Capture Efficiency (%)
CO$_2$ Captured (tons/day)
18-May
7-Jun
27-Jun
17-Jul
6-Aug
26-Aug
15-Sep
5-Oct
25-Oct
Date

Results



Heat Duty (Btu/lb CO2)
CO2 Captured (tons/day)
1800
1600
1400
1200
1000
800
600
400
200
0
1000.00
900.00
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
Heat Duty (Btu/lb CO_2)
CO_2 Captured (tons/day)
18-May
7-Jun
27-Jun
17-Jul
6-Aug
26-Aug
15-Sep
5-Oct
25-Oct
Date

2012 Outlook

- Barry unit 5 (host unit) capacity factor increased to approximately 65%
- Pipeline in service April-May 2012
- Goals
  - 100 K tons CO_2 down the pipeline
  - Heat rate improvements
  - Robustness of plant with high impurities
  - Minimize amine emissions and KS-1 make-up requirement
- Test plans
  - Emissions testing
  - CO_2 compressor performance
  - Long-term parametric testing
  - Dynamic operation (load following testing)
  - Long term operability and reliability

Questions?

Denbury

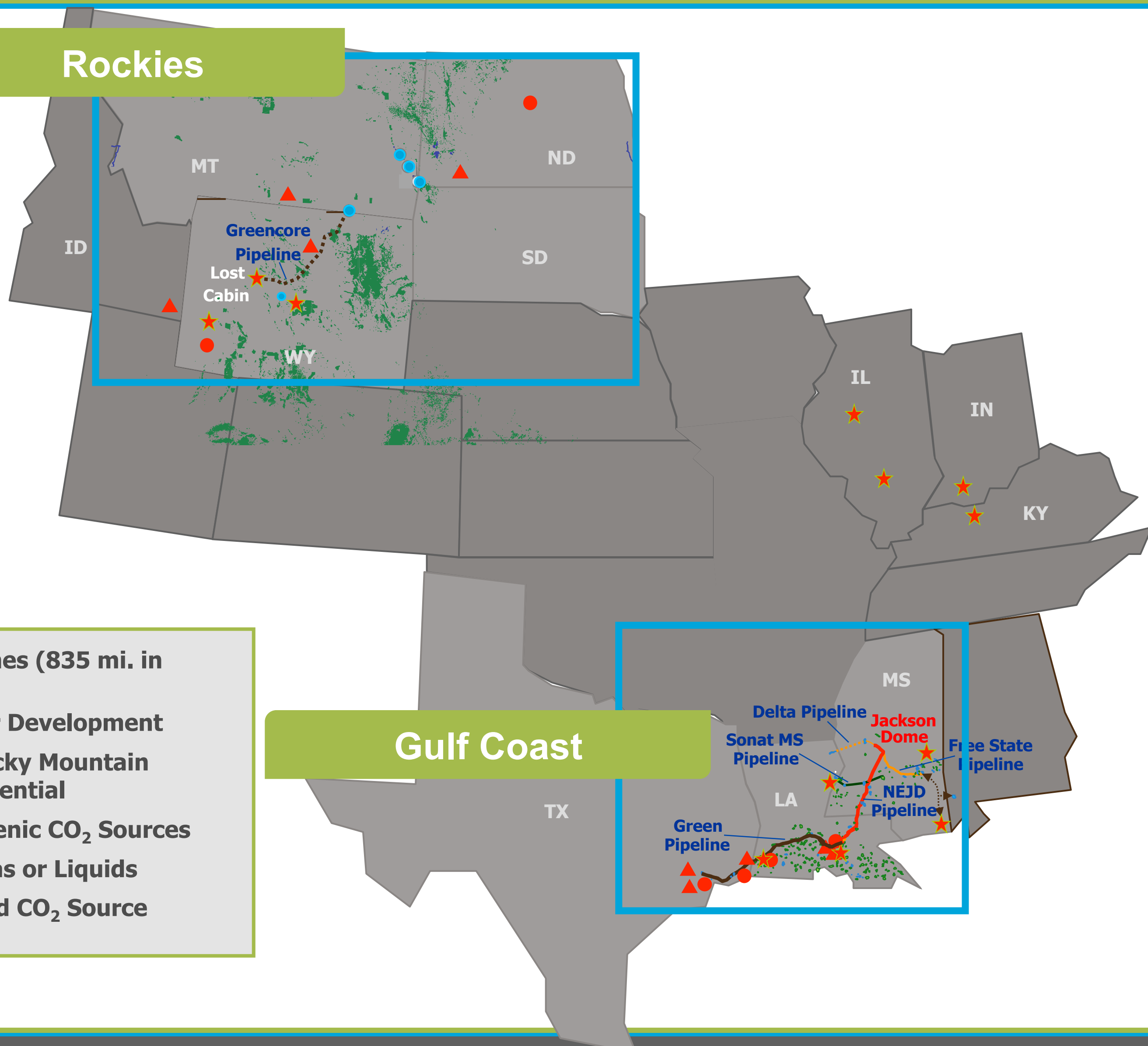
SECARB – Plant Barry to Citronelle 4" CO_2 Pipeline

Thursday, March 8, 2012

Speaker: Christina Harvick

CO_2 Pipeline Project Manager

Denbury CO_2 Pipeline Network



- Existing CO_2 Pipelines (835 mi. in operation)
- CO_2 Pipelines Under Development
- Denbury owned Rocky Mountain Fields With EOR Potential
- Existing Anthropogenic CO_2 Sources
- Proposed Coal to Gas or Liquids
- Existing or Proposed CO_2 Source

CO_2 Pipeline Right-of-Way

- Approx. 12 mi (19 km) to the SE operations unit in Citronelle Oil Field
- Right-of-Way
  - 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 commerical timber land
  - 3 mi (5 km) of emergent, shrub and forested wetlands
  - Endangered Gopher Tortoise habitat
    - 110 burrows in or adjacent to construction area

CO_2 Pipeline and Measurement Design

- Applicable regulatory standard: US Depart of Transportation, 49 CFR Part 195 —Transportation of Hazardous Liquids by Pipeline
- Welding - API 1104 & B31.3 (plant section)
- 4-inch (10 cm) pipe diameter
- X42/52 carbon steel pipe
- MOP – 2,220 psig (flange limitation)
- Normal operating pressure: 1,500 psig (10.3 MPa) maximum
- Buried average of 5 ft (1.5 m) with surface re-vegetation and erosion control

Handling pipe for horizontal directional drill

CO_2 Pipeline Design and Construction

- Directional drilled 18 sections of the pipeline under roads, utilities, railroad tracks, tortoise colonies, and wetlands.
- Trenched remaining sections
- Corrosion protection
  - Fusion Bond Epoxy coated pipe
  - "Jeep" pipe for coating damage; manually coat joint welds and scratches
  - Impressed current cathodic protection
  - AC mitigation for overhead powerlines using copper wire
  - ACVG survey after construction to check again for coating damage
  - Caliper tool run to check for dents caused by rock or equipment

Workers dressing welded pipe joints

CO_2 Pipeline and Measurement Design

- Denbury pipeline purity requirement is:
  - > 97% dry CO_2 at 115ºF (46ºC)
  - < 0.5% inerts (incl. N_2 & argon)
  - < 30 lb water per 1MMSCF
  - < 20 ppm H_2S
- Impurities affect and sometimes amplify pipe fracture toughness requirements
  - Hydrogen & N2 problematic
- Toughness requirements for this project met by standard X42 pipe. Other projects require added wall thickness, modified pipe chemistry and/or crack arrestor installation.

Custody meter station and building

CO_2 Pipeline and Measurement Design

- CO2 measured with senior orifice meter and gas chromatograph
- Custody measurement meets AGA Report #3, Parts 1 & 2
- Accuracy and mechanical issues with turbine, Coriolis, & ultrasonic meters
  - Turbine – CO_2 is dry – damages moving parts. CO_2 viscocity range can be problematic
  - Coriolis – Accuracy not as good as orifice
  - Ultrasonic – CO_2 absorbs and distorts signal
- Communication using SCADA and satellite.
- Check meter installed for pipeline leak detection and verification of injected volumes

Check meter station and building at Denbury Citronelle Field

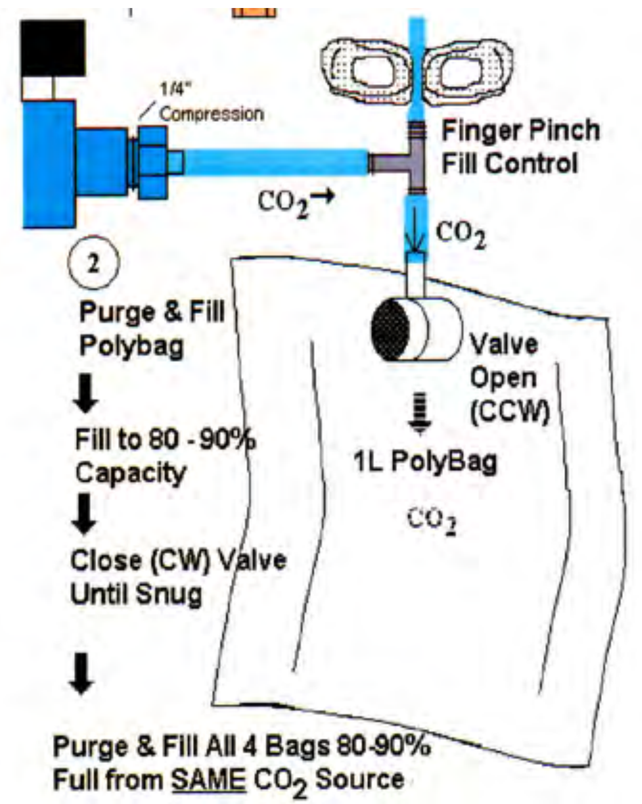
CO_2 Pipeline and Measurement Design

- CO2 Specific Design Requirements
  - Valve seals – Accepted: Nylon, peroxide cured Buna N (HBNR-90/95), ethylene propylene rubber (EPDM)
  - Valve packing – Teflon
  - Low temperature materials for valves used for blowdown service only.
  - Mainline valve station similar to natural gas with blowdowns for maintenance.

Mainline valve station & CP test station

CO_2 Pipeline and Measurement Commissioning

- Pipeline and meter stations left with 50 psig of nitrogen to inhibit moisture and corrosion until commissioning.
- Low pressure CO_2 used to sweep and vent nitrogen.
- Pressure increased to full operating pressure.
- Samples obtained for CO_2 stream analysis.
- System will be blocked in awaiting notice to begin injection activities.
- Analyzers at custody and check meter stations take ~ 1 day to stabilize.
- Samples will be taken periodicly for permits and GHG reporting.



Questions??

Thank you!

Geologic Characterization and Baseline Injection Modeling

David Riestenberg,
Advanced Resources International

7th Annual SECARB Stakeholders' Briefing
The Battle House Renaissance Hotel
Mobile, Alabama
March 7-8th 2012

NETL SOUTHERN COMPANY Energy to Serve Your World SSEB EPRI ELECTRIC POWER RESEARCH INSTITUTE SECARB Southeast Regional Carbon Sequestration Partnership Advanced Resources International, Inc.

Acknowledgement

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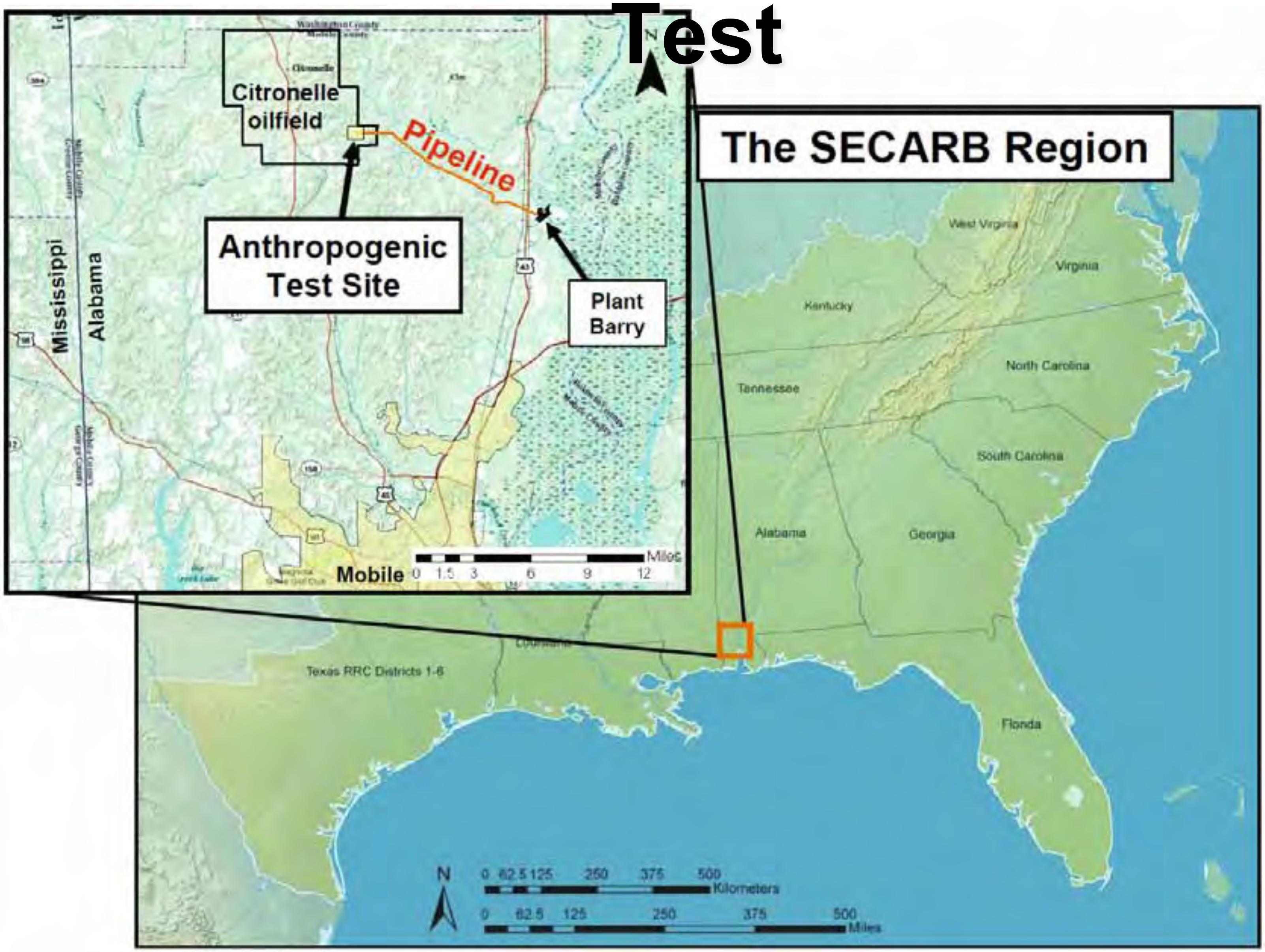
SECARB's Phase III Anthropogenic Test

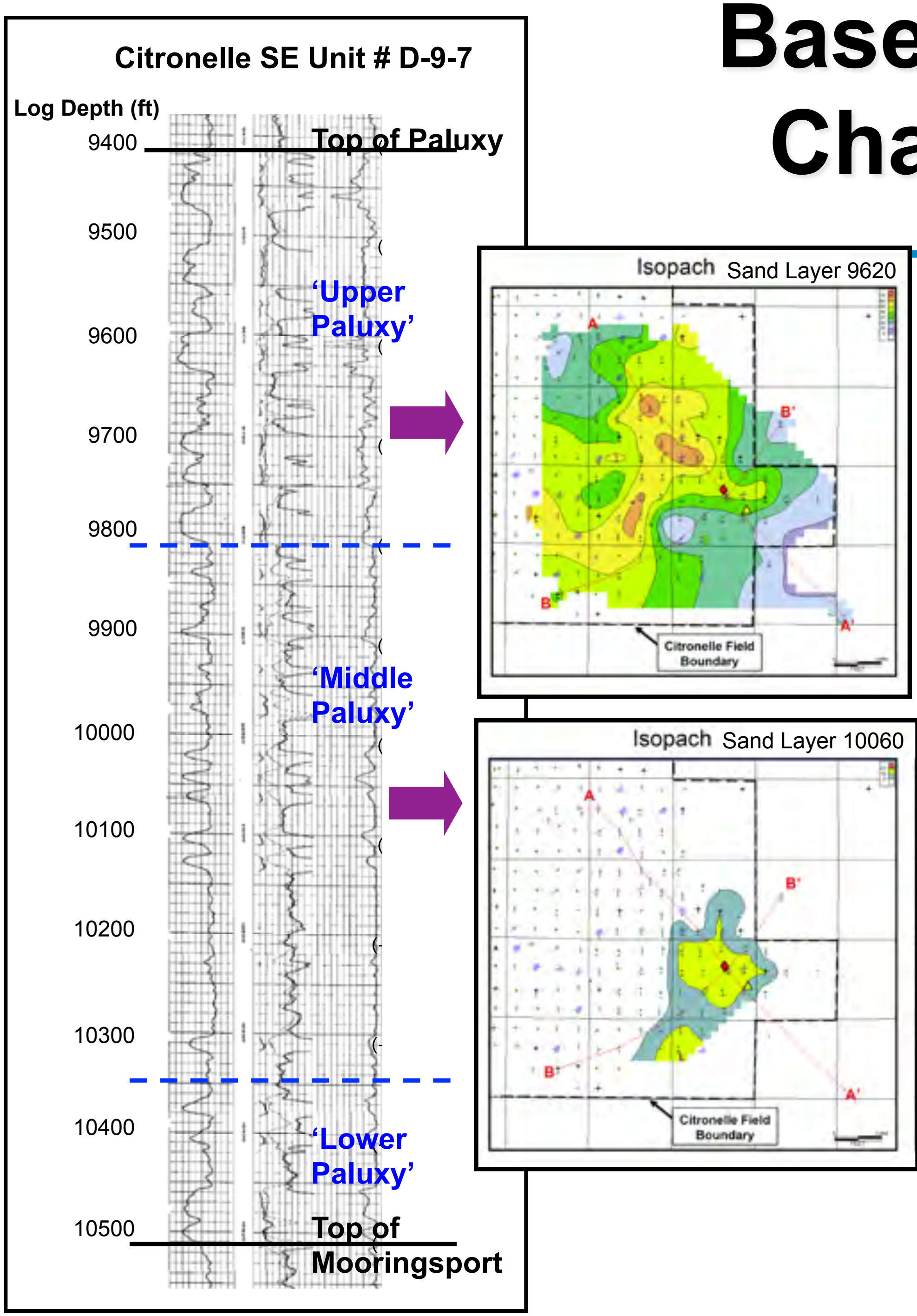


Storage Site Characterization

System	Series	Stratigraphic Unit	Major Sub Units	Potential Reservoirs and Confining Zones
Tertiary	Plio-Pleistocene		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 / 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'	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

- Proven four-way closure at Citronelle Dome.
- Injection site located within Citronelle oilfield where existing well logs are available
- Deep injection interval (Paluxy Fm at 9,400 feet)
- 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.

Baseline Reservoir Characterization



- Analysis of over 80 existing oilfield well logs for Paluxy porosity, thickness and depositional style.
- Regional core data and oilfield reports
- Sand mapping to determine "open" or "closed" sand units.
- Paluxy porosity ~19% and perm ~100 millidarcies

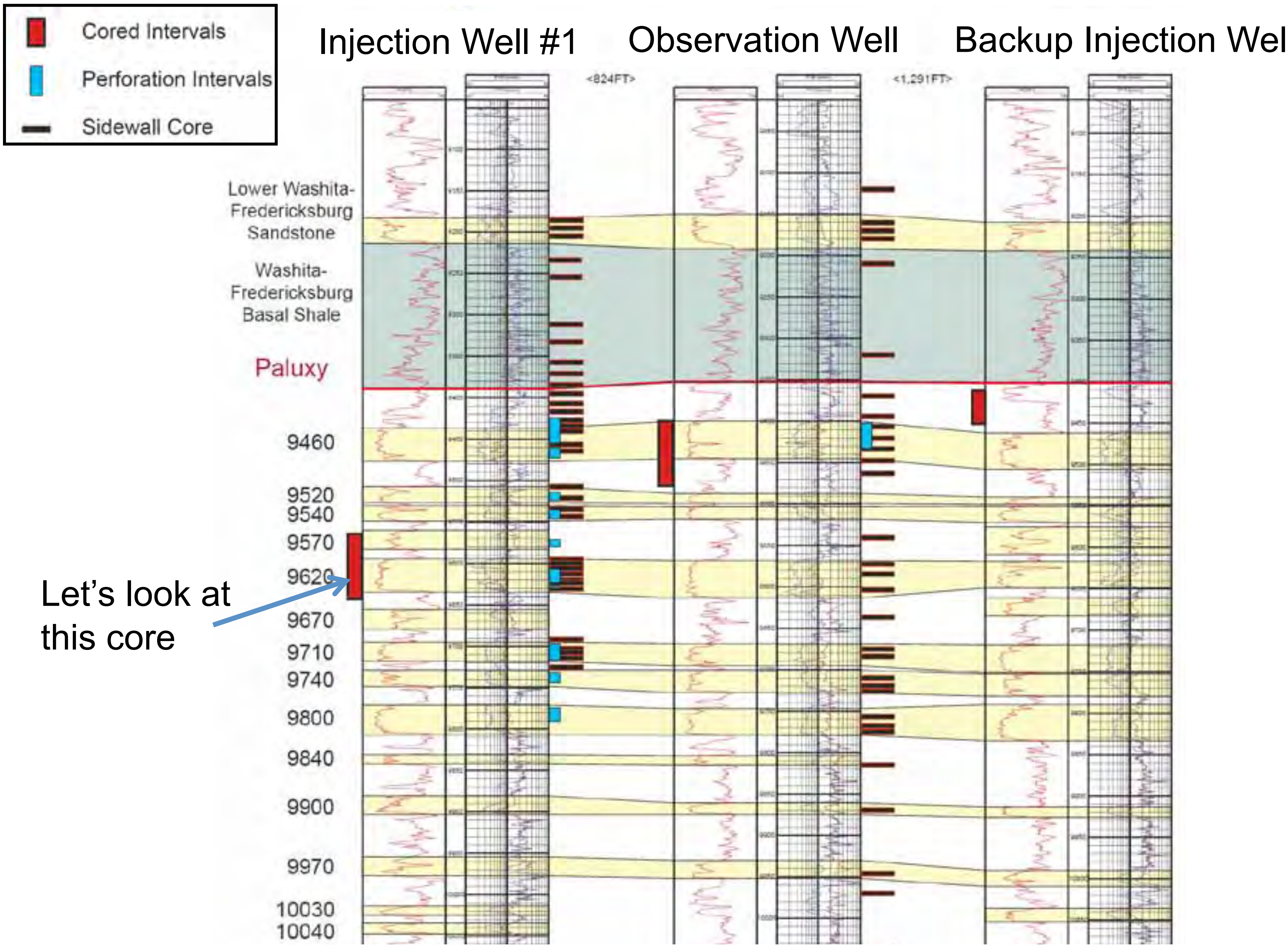
New Geological Data

We collected new geologic data on the Paluxy reservoir and confining unit with the drilling of the project's three new wells:

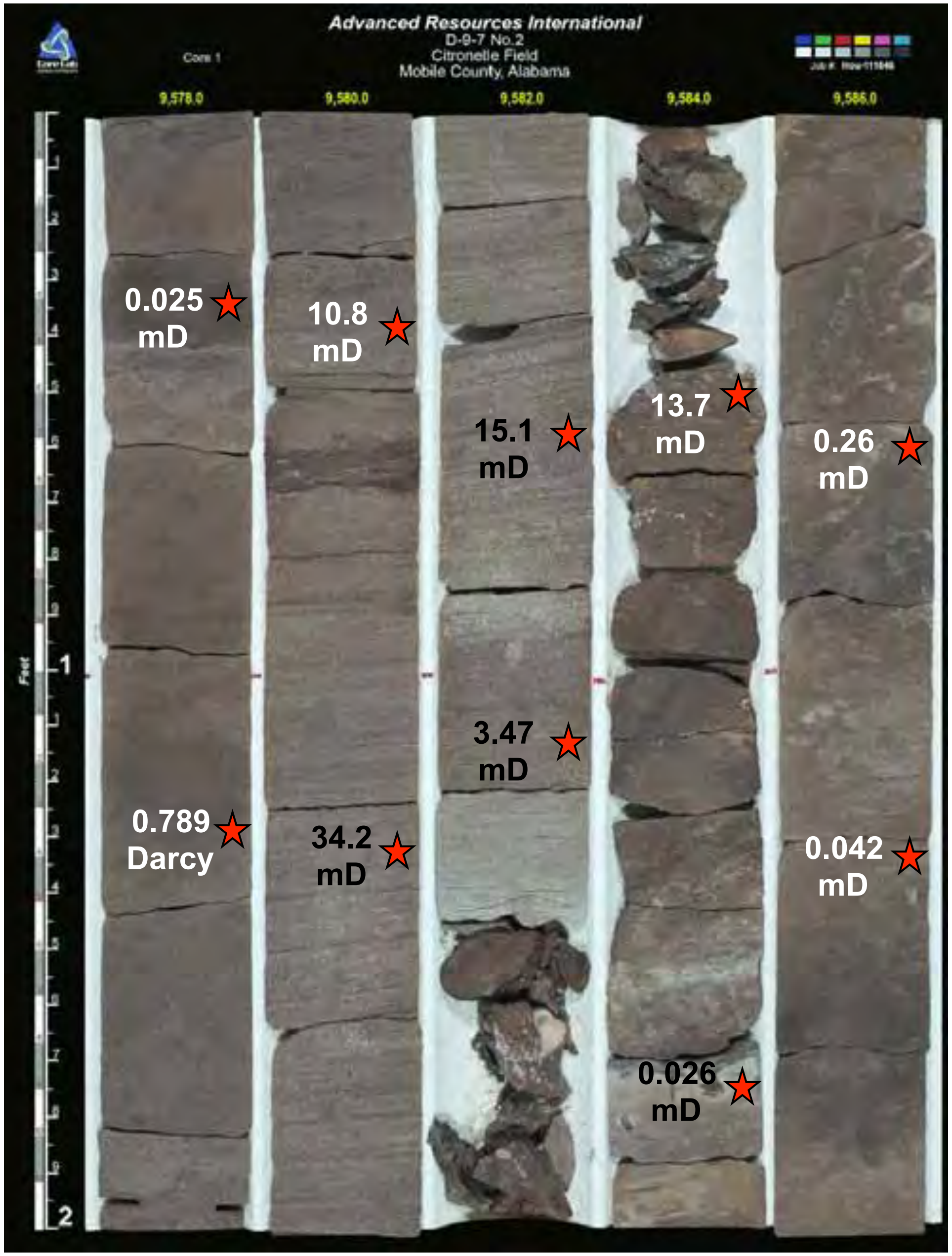
- Characterization Well (D-9-8#2) – 98 feet of whole core (two intervals) plus 45 sidewall cores.
- Injection Well #1 (D-9-7#2) – 68 feet of whole core plus 32 sidewall cores
- Injection Well #2 (D-9-9#2) – 44 feet of whole core
- Full set of open hole logs on all three wells
  - Spontaneous potential, gamma, array resistivity, photoelectric, sonic and neutron and density porosity
  - Magnetic resonance imaging (permeability)
  - Spectral gamma ray, mineralogical evaluation
  - Waveform sonic

Baseline vertical seismic profiles and crosswell seismic collected in Feb 2012

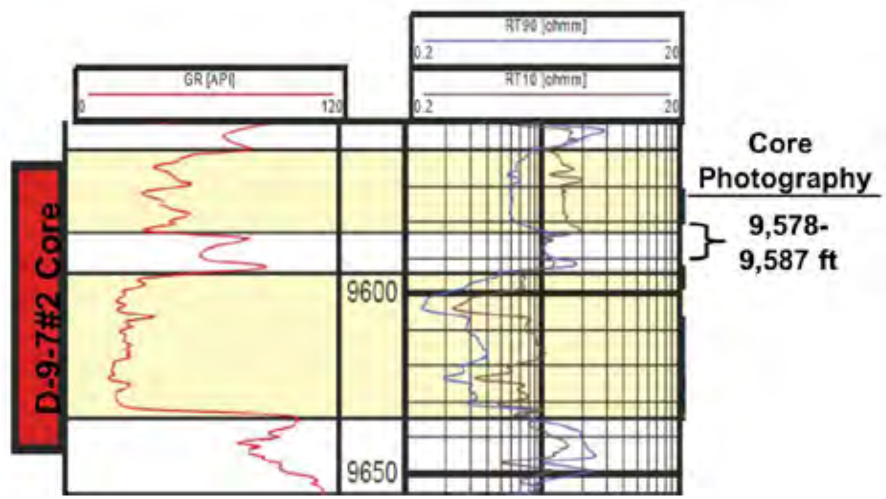
Whole and Sidewall Core Data



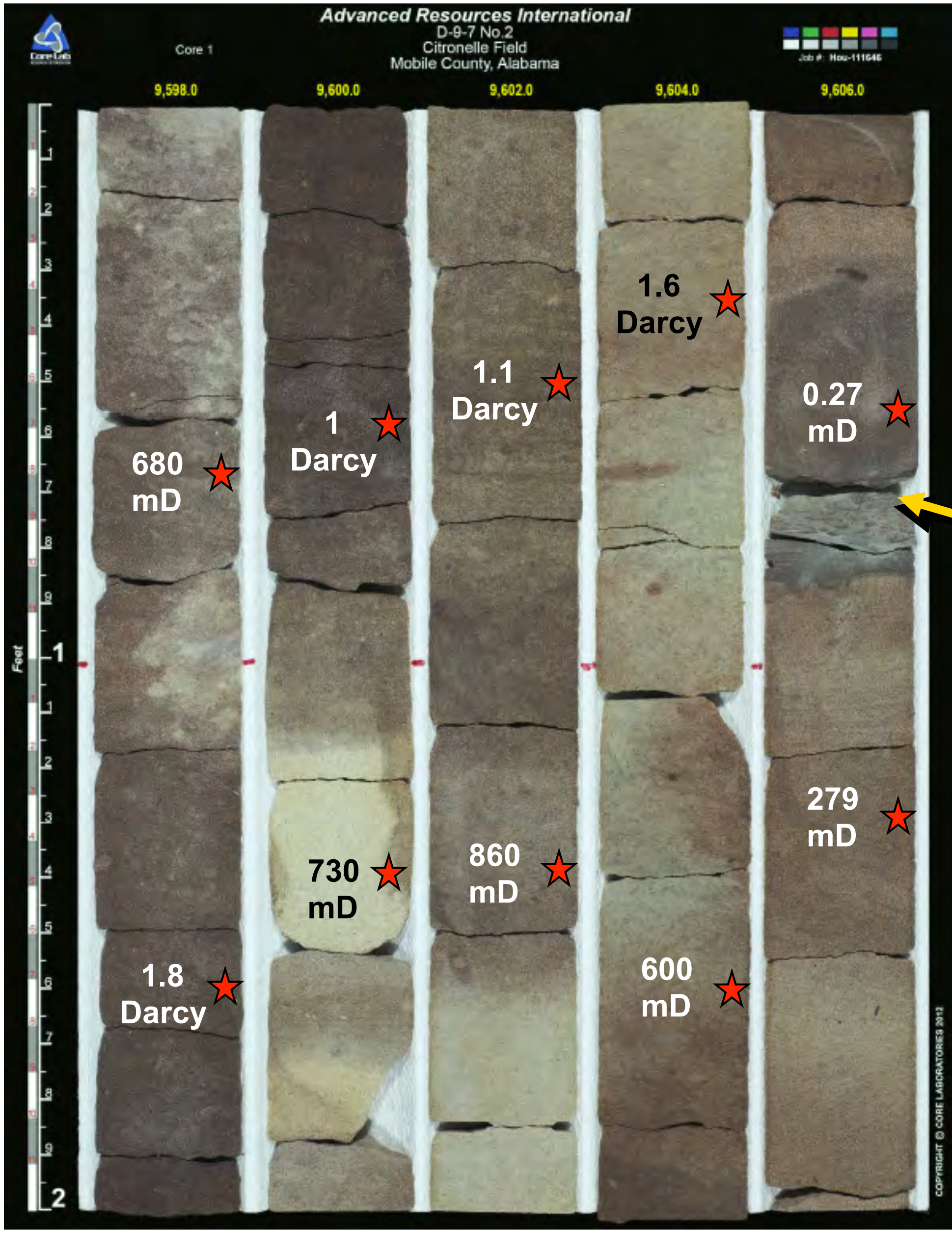
Paluxy Siltstone/Shale Core Example



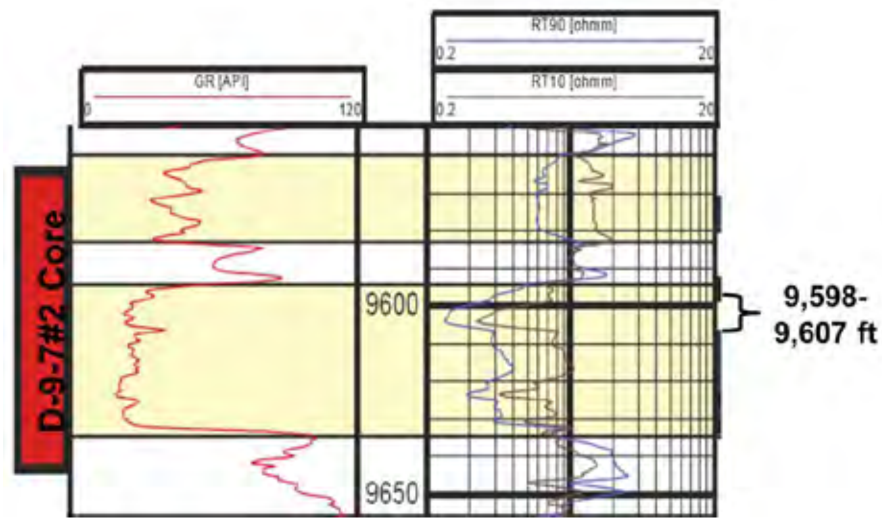
- Bioturbated silty sandstone
- Laminated siltstone
- Shale zones
- Indications of a low energy environment
- Siltstone/shale units within the Paluxy will likely act to isolate the sands



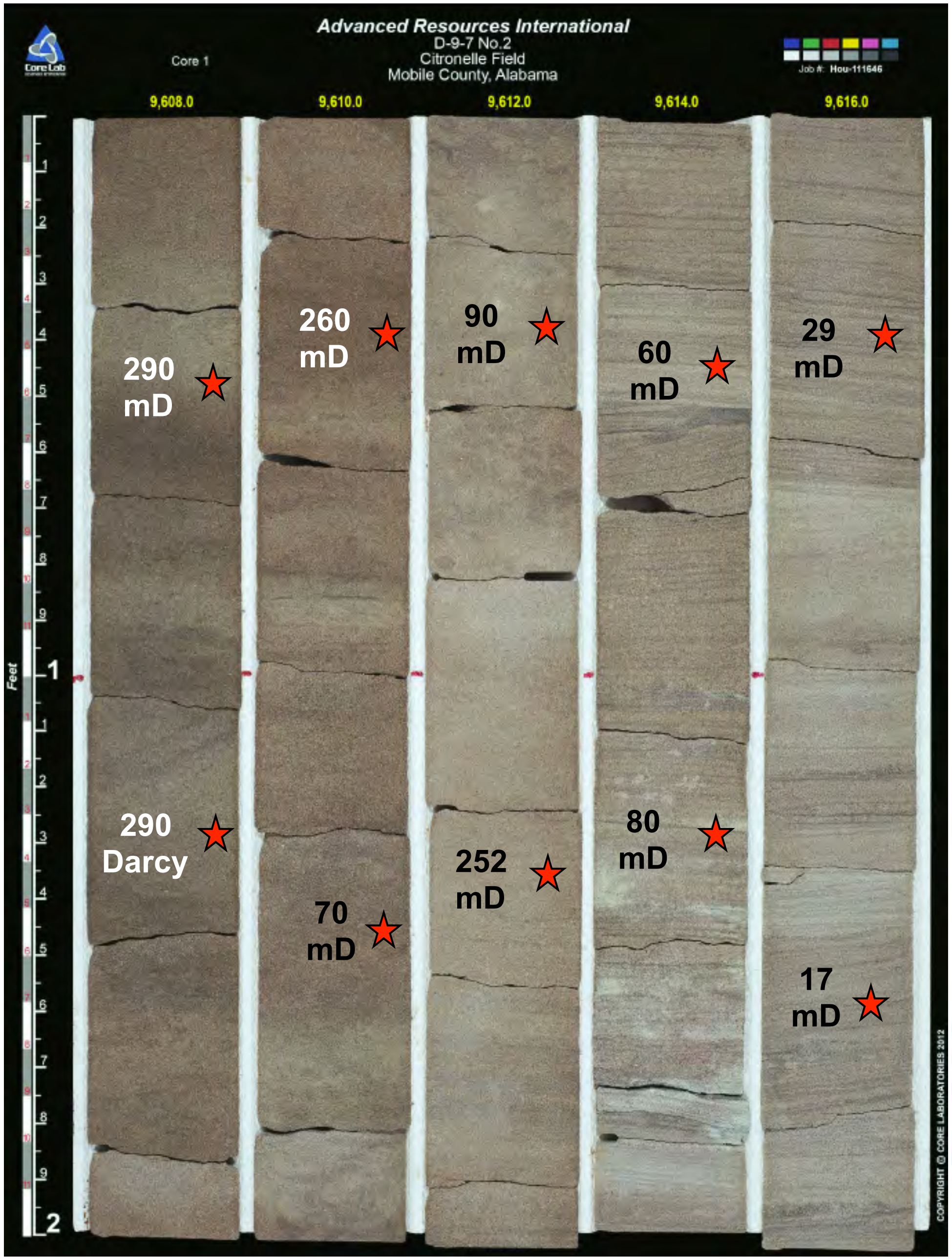
Paluxy Sandstone Core Example



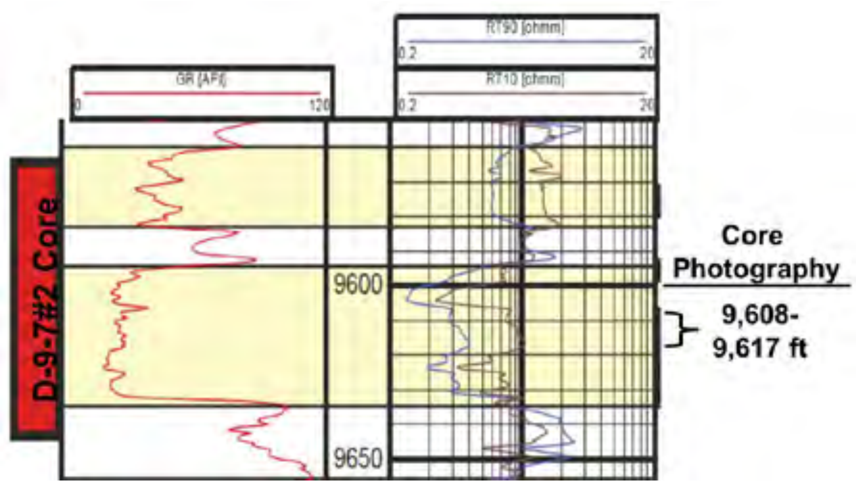
- Red in color with some surfaces that are a light brown
- Overall coarse grain size indicates a high energy environment
- We interpret these as fluvial channel sands
- Shaley siltstone with green micaceous interlayers (base of a channel)



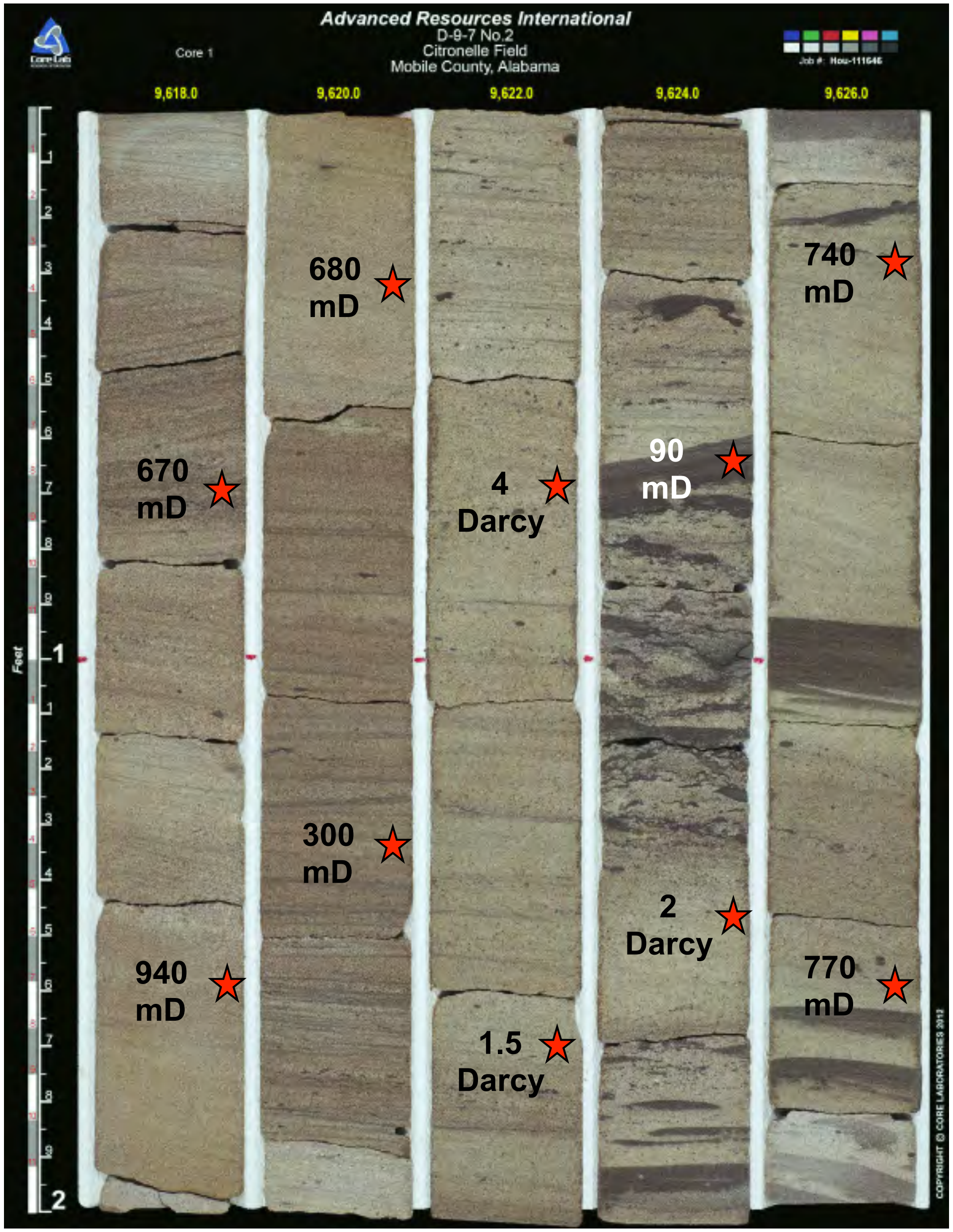
Paluxy Sandstone Core Example



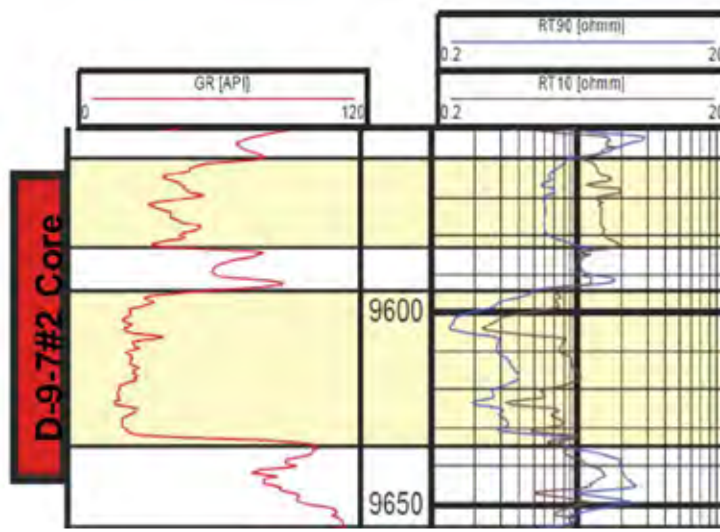
- Light red to tan in color
- Moderately sorted and rounded to sub-angular grains
- Parallel and sub-parallel laminations
- Zones of moderate bioturbation



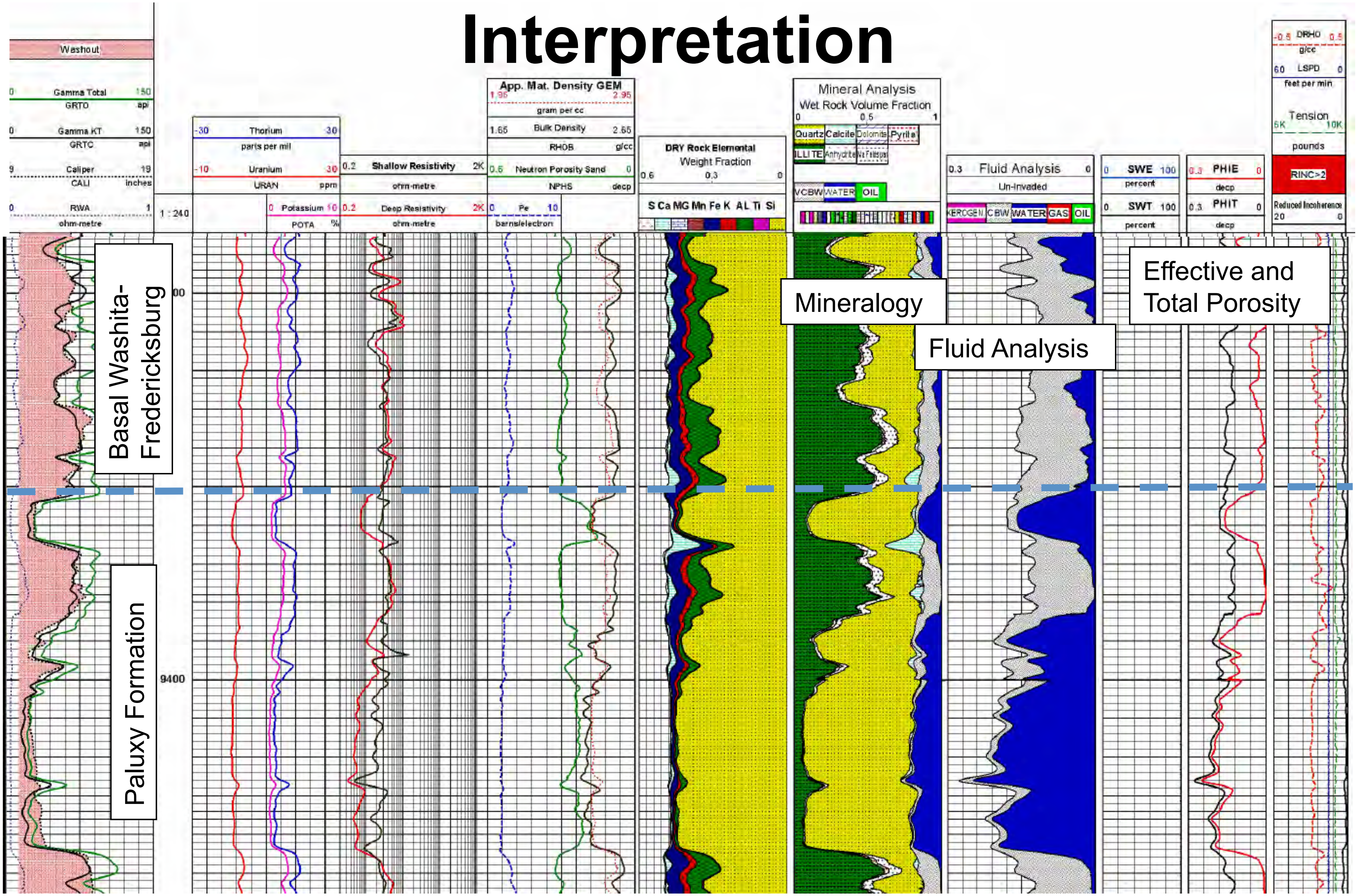
Paluxy Sandstone Core Example



- Zones of sub-parallel laminations
- Cross beds
- Zones of moderate bioturbation
- Clay rip up clasts are present
- Permeability is vertically heterogeneous

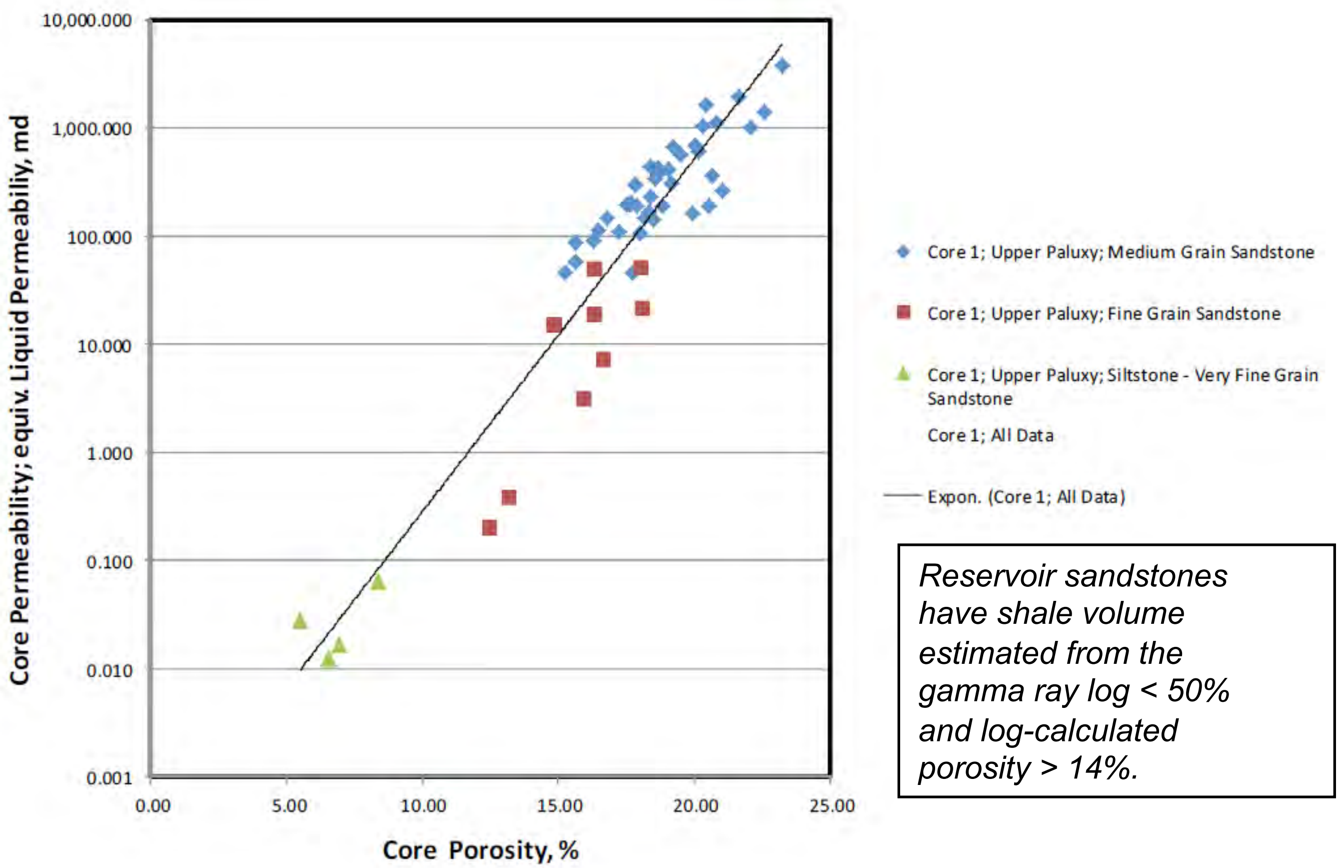


Mineralogical and Petrophysical Log Interpretation



Upper Paluxy Sandstone Characteristics

- Thick, channel sandstones of the upper Paluxy Formation appear to be the excellent target reservoirs for CO_2 injection.
- Sandstone porosities range from 14 to 23%, porosities range from <10 millidarcies to 4 Darcys
- Lower Paluxy Sandstones are less porous and permeable overall due finer grain size and higher shale content.
- Permeability is strongly associated with grain size.



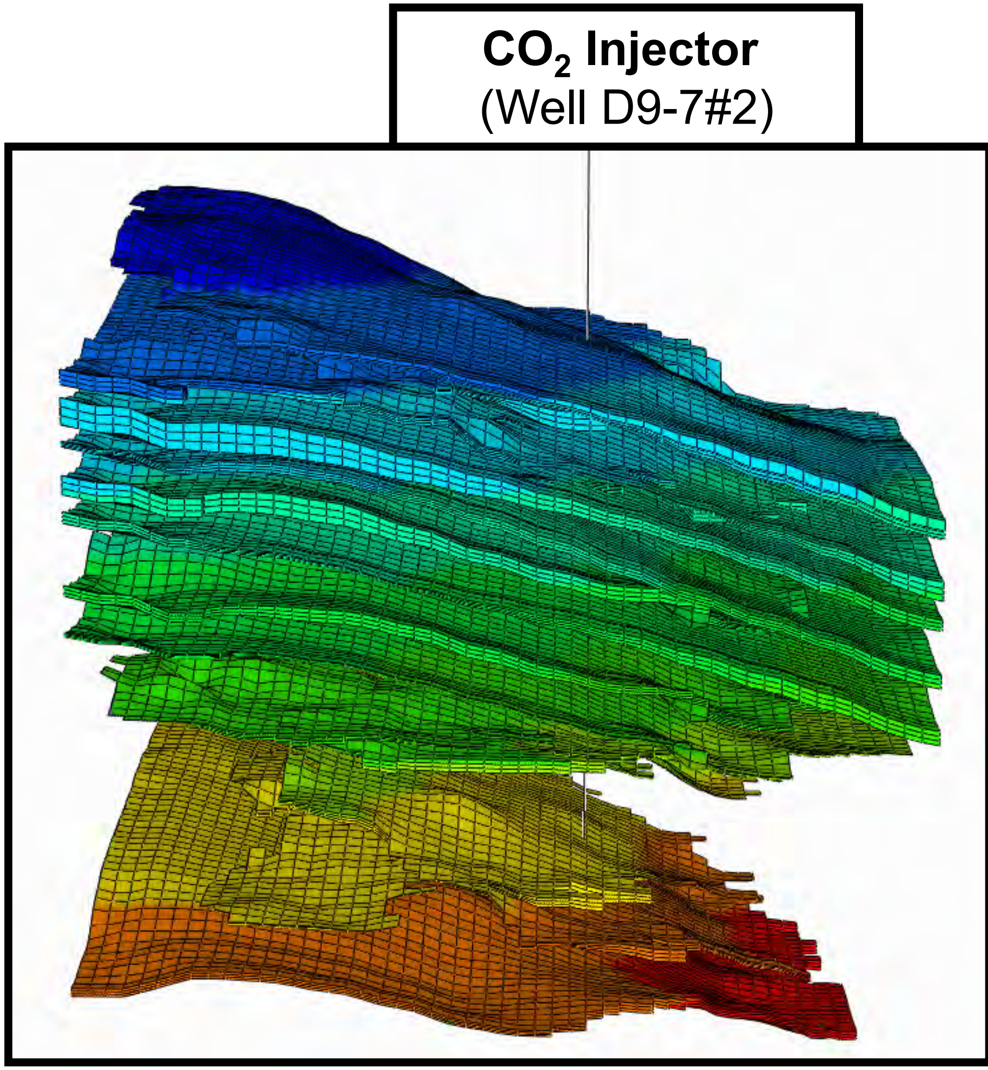
Reservoir sandstones have shale volume estimated from the gamma ray log < 50% and log-calculated porosity > 14%.

Paluxy Reservoir Characteristics

Injection Well (D-9-7#2)

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**

Baseline Reservoir Simulation

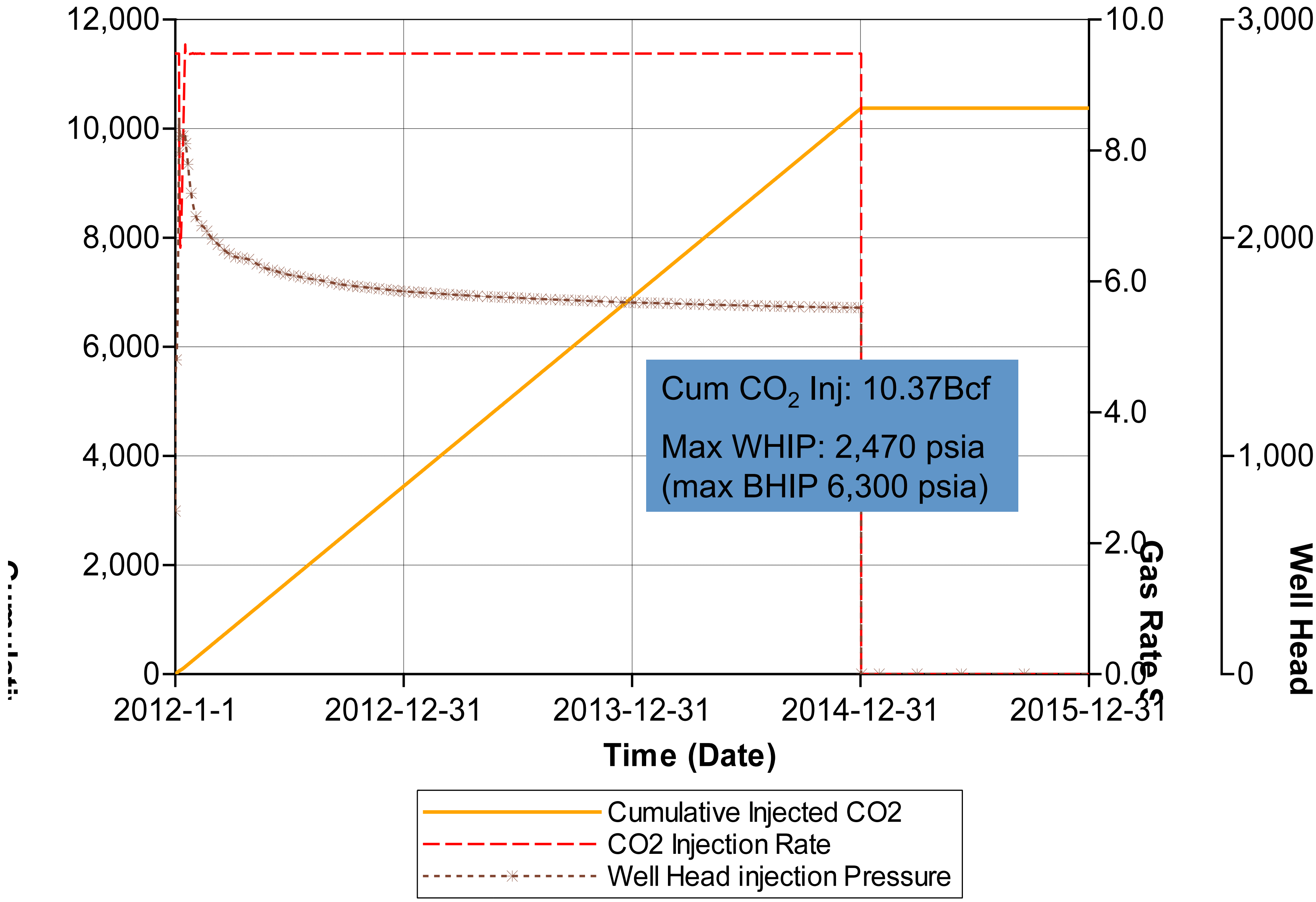


Building the Geologic Model

Based on detailed characterization of the Paluxy sand/shale interval, we selected 10 of the sand units for CO_2 injection:

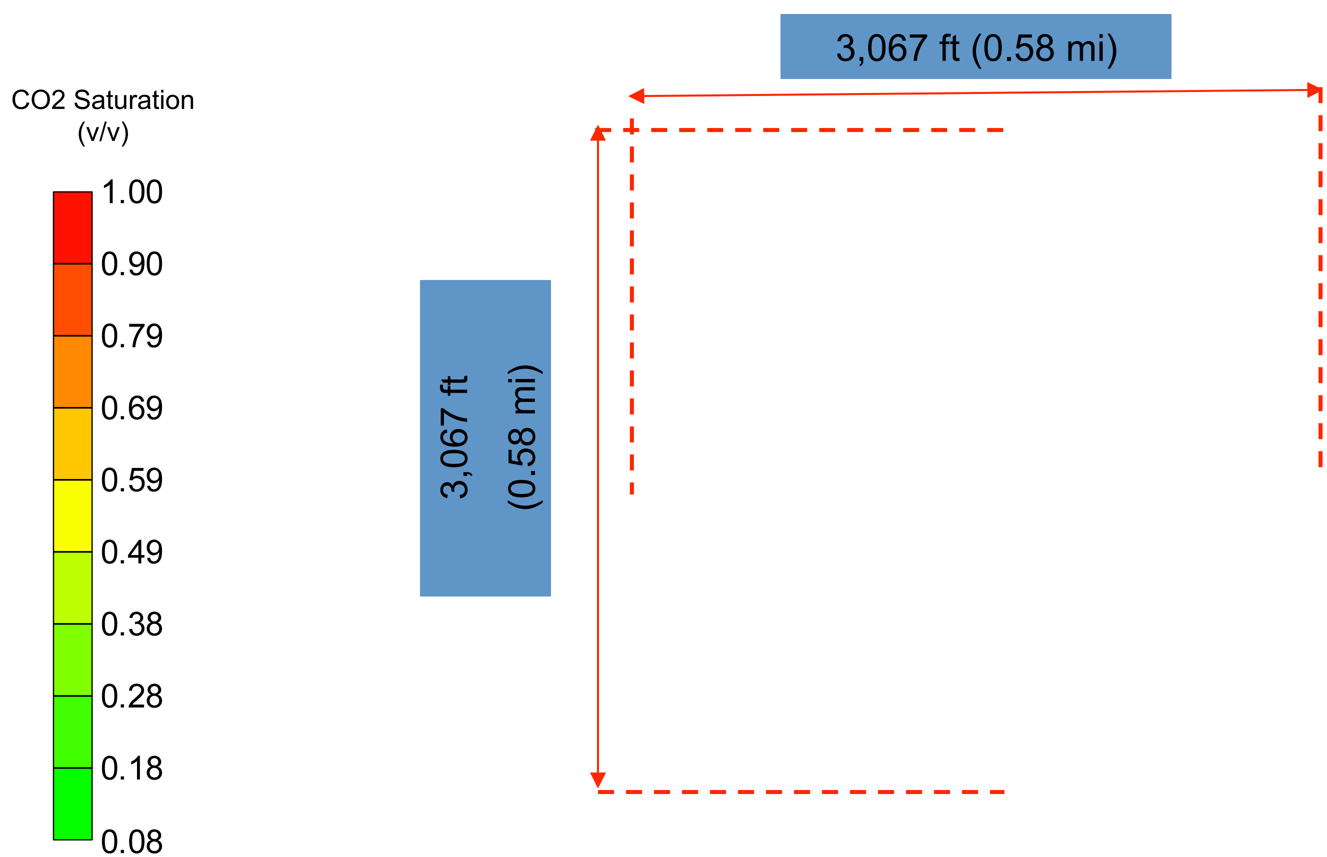
- 170 net feet of “clean” sand
- Average porosity of 18%
- Average permeability of 200md
- Normal pressure and temperature gradients
- 3 years of continuous injection at max. injection BHP of 0.6psia/ft and max. rate of 500 metric t/d (**547,500 tonnes total**)

Injection Rate and Volume



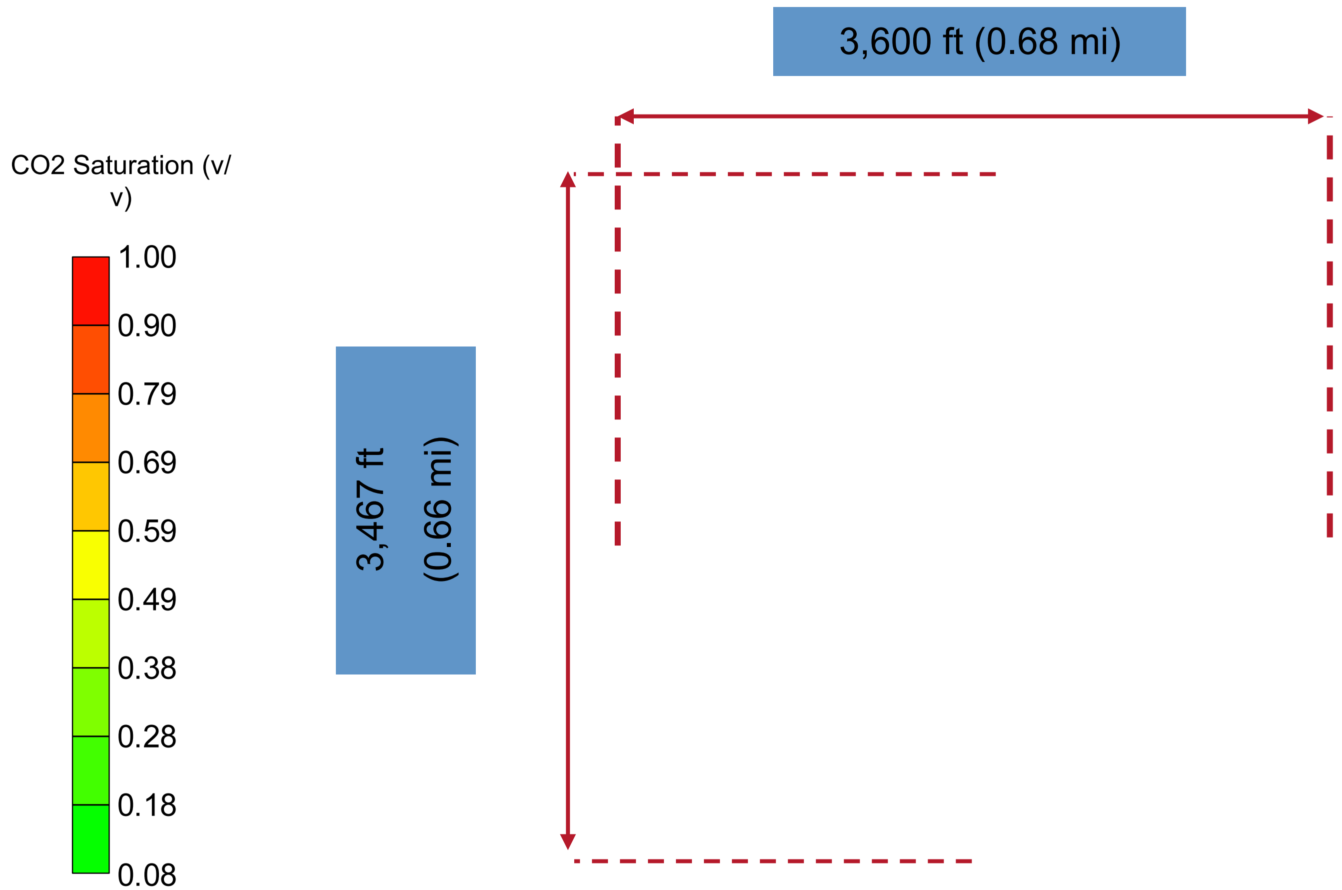
Maximum Plume Extent
End of Injection

Area = 0.26mi² (170 acres)



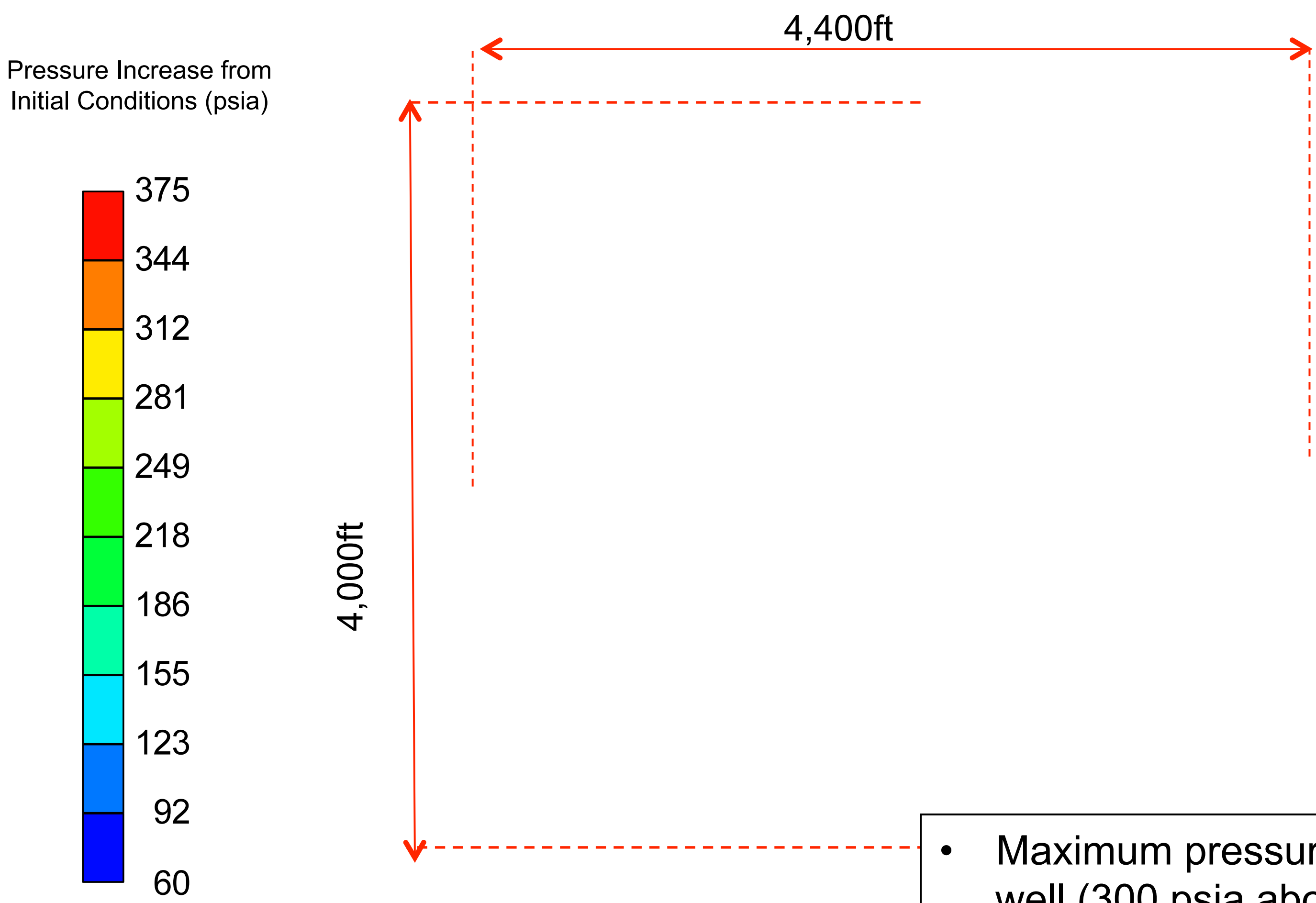
Maximum Plume Extent – 10yrs After End of Injection

Area = 0.35mi^2 (225 acres)



Pressure Field
End of Injection

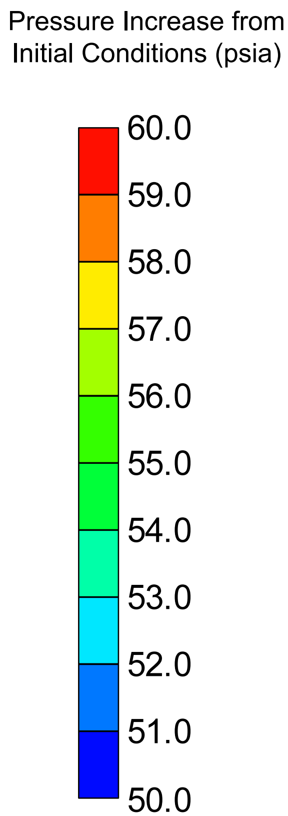
Area of >60 psia increase is 0.50mi^2 (317 acres)

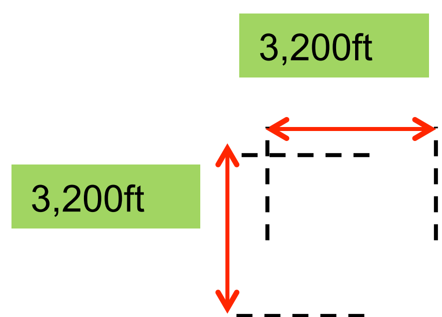


- Maximum pressure is at injection well (300 psia above native)

Pressure Field
1 year after End of Injection

Area greater than 50 psia of 0.29mi^2 (184 acres)

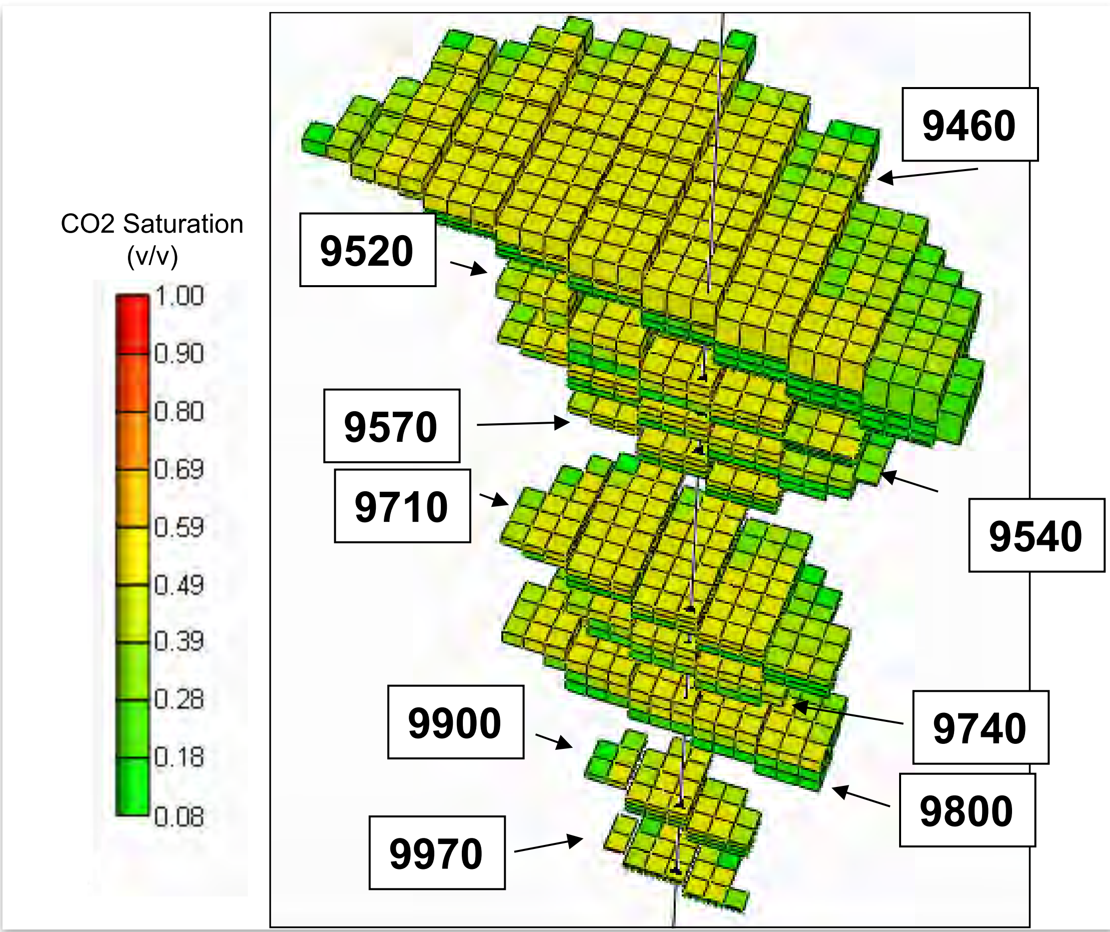




- Maximum pressure is at injection well (60 psia above native)
- 1.3% elevated over native pressure

Baseline Reservoir Simulation Summary

CO_2 Plume Extent
10 yrs after End of Injection



- The Paluxy formation is capable of accepting the proposed CO_2 injection volume
- Most of the CO_2 enters the upper Paluxy sands due to higher permeability and injection gradient
- Plume area in sand 9460 is 225 acres ten years after injection operations have ceased
- Due to high permeability the pressure field diminishes rapidly
- Next steps are to discretize sand units and incorporate early injection data

End



Permitting and Injection Status

George J. Koperna, Jr.,

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SECARB 7th Annual Stakeholders' Briefing
March 7th – 8th, 2012

NETL SOUTHERN COMPANY Energy to Serve Your World SSEB EPRI ELECTRIC POWER RESEARCH INSTITUTE SECARB Southeast Regional Carbon Sequestration Partnership Advanced Resources International, Inc.

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.

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Presentation Outline

- Anthropogenic Test Introduction
- Permitting and Injection
    1. Permitting
    2. Monitoring
    3. Well Completion
    4. Injection Equipment
    5. Schedule

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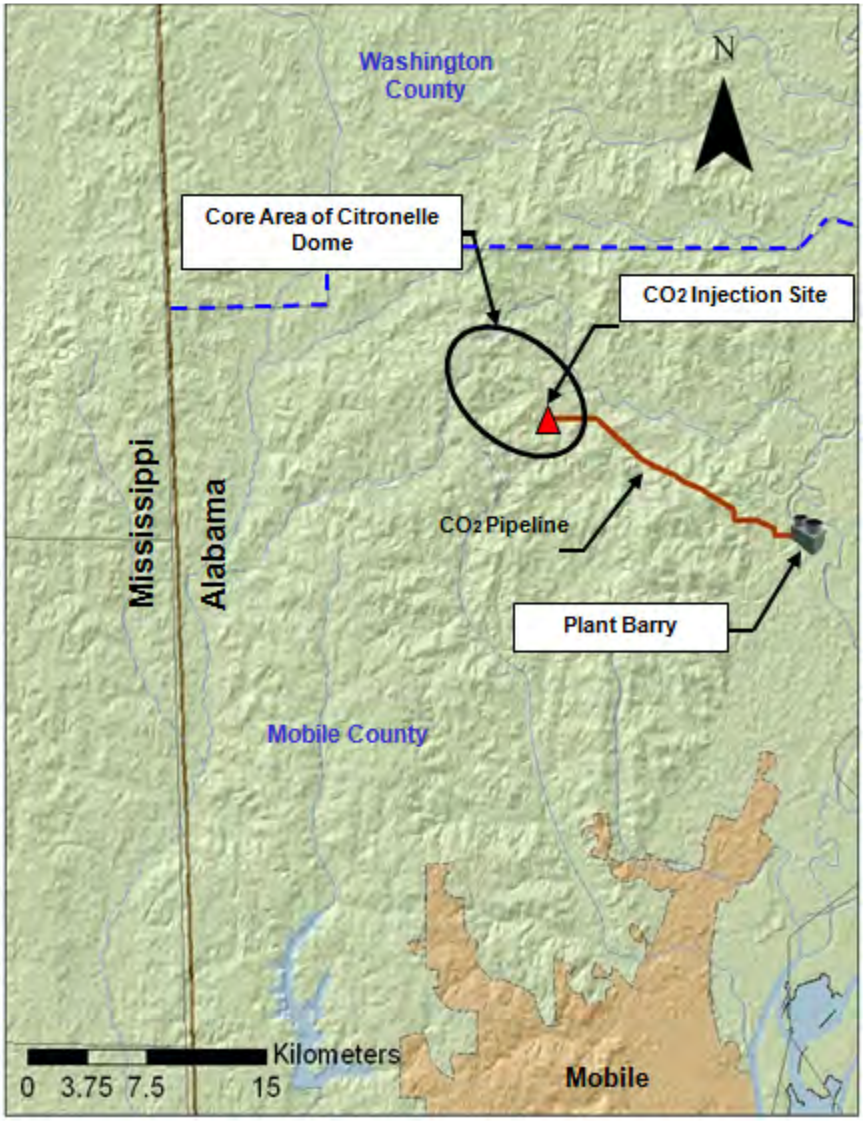
SECARB's Phase III Anthropogenic Test



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 confirmed geology.

Injection wells were drilled in 4Q 2011.

100 to 300 thousand metric tons of CO_2 will be injected into a saline formation over 2 to 3 years beginning in 1Q 2012.

3 years of post-injection monitoring.

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Anthropogenic Test Goals and Objectives

1. Support a fully integrated, commercial prototype CCS project (capture, transport and storage)
2. Test CO_2 flow, trapping and storage mechanisms of a regionally extensive Gulf Coast saline formation.
3. Test the adaptation of commercially available oil field tools and techniques for monitoring CO_2 storage
4. Document the permitting and risk management processes for all aspects of a CCS project
5. Understand the coordination required to successfully integrate all components of a CCS project
6. Opportunistically test developmental monitoring protocols, as appropriate.

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1. Permitting

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Permitting

- **Army Corps of Engineers permit – Wetlands Impacts**
  - Covers wetland impacts due to pipeline and injection site construction
  - Pipeline crosses 15 acres of wetlands
  - Horizontal drilling under wetlands is preferred over "open-cutting" and mitigation
  - Wetland impacts during well pad construction operations (fill) mitigated after well drilling completed

- **U.S. Fish and Wildlife permit – Threatened and Endangered Species**
  - Potential impacts to threatened species (gopher tortoises)
  - Over 30 gopher tortoise burrows encountered long pipeline easement
  - Directional drilling under tortoise burrows/colonies temporary relocation

Gopher tortoise: Photo courtesy of Southern Company

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Permitting

- **SHPO (State Cultural/Archaeological Assets)**
- **ADEM Underground Injection Control (UIC) Permit – Protect Underground Sources of Drinking Water (USDWs)**
  - A Class V Experimental Well permit was sought for the following reasons
    - Short duration of injection (3 years)
    - Modest volumes of CO_2 (less than 2% of Plant Barry's annual CO_2 output)
    - Characterization and modeling of "stacked" CO_2 storage
    - CO_2 Injection Under "Real World" Conditions
    - Demonstration of experimental monitoring tools and methods

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Permitting

After comments by EPA, most Class VI (CO_2 sequestration well) standards were applied

- Injection Area of Review (AOR) determined by annual modeling
- Periodic AOR updates based on monitoring and modeling results
- Extensive deep, shallow and surface CO_2 monitoring
- Monthly reporting of injection pressures, annular pressures and injection stream composition
- Injection stream monitoring
- Periodically updated Corrective Action Plan
- Site closure based on USDW non-endangerment demonstration (5-yr renewal)
- Pressurized annulus throughout injection (+/- 200 psig)
- Emergency and remedial response plan
- Post-injection site care plan

Class V Experimental injection permit was awarded in November 2011, eleven months after initial draft application

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Permission to Inject (D-9-7 #2)

1. Well Drilling and Completion Narrative
   - Detailed Drilling Narrative
   - As-built Diagrams
   - Mechanical Integrity Testing

2. Whole Core and Sidewall Core Analysis/Results
   - Percussion Sidewall Core Results
   - Geologic Interpretation
   - Advanced Core Tests
   - Core Results Conclusion

3. Open Hole Log Results
   - D-9-7 #2 (Injection Well #1) Open Hole Log Field Acquisition
   - Mud Log Interpretation
   - Quad Combo Open Hole Log Interpretation
   - Reservoir Quality
   - Supplemental Well Logs

4. Confining Zone
   - Lithology, Thickness and Fracture Pressure
   - Confining Zone Lithology and Thickness
   - Confining Zone Fracture Pressure

5. Cased-Hole Log Results

6. CO_2 Stream Analysis

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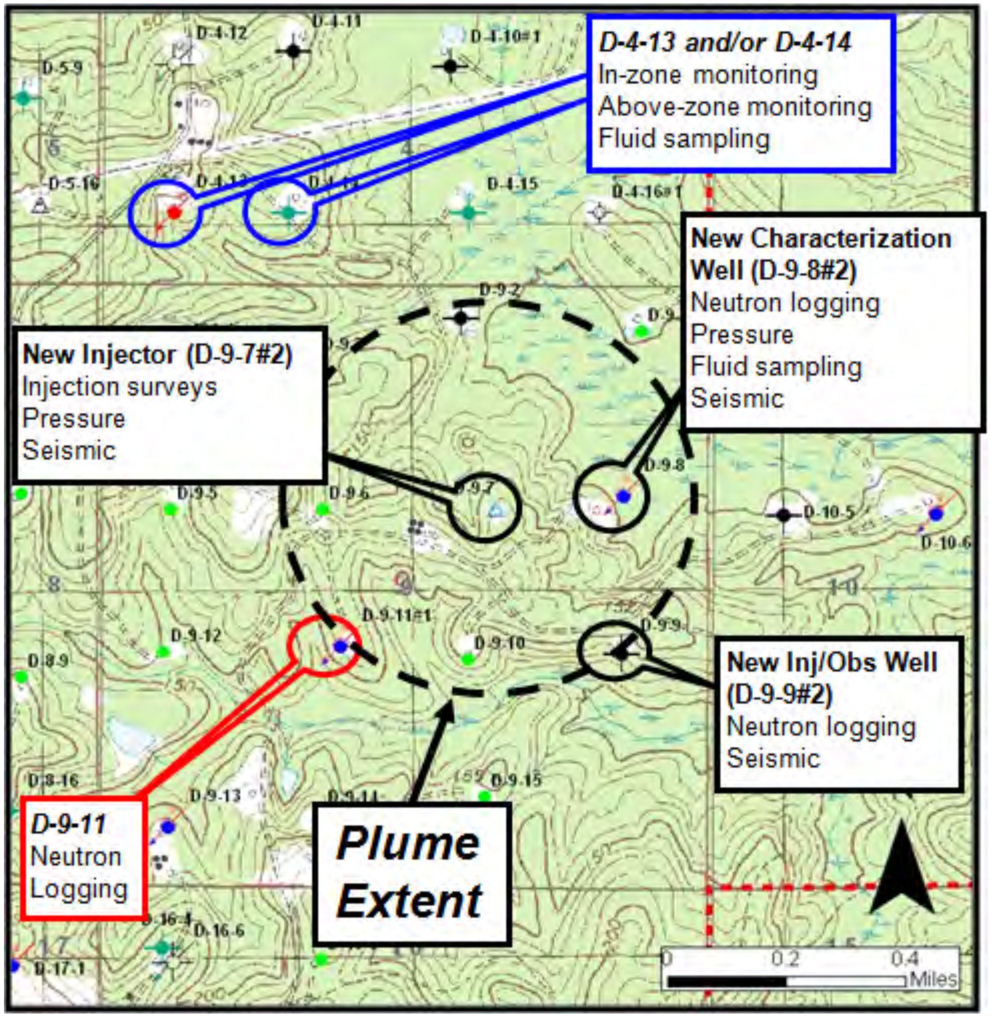
2. Monitoring

CO_2 Monitoring, Verification and Accounting

CO_2 Injection and Storage Site



CO_2 Monitoring Design

The anthropogenic test will use five deep wells to track the CO_2 plume plus three shallow water monitoring wells:

- Near-surface and 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

Monitoring plan utilizes proven CO_2 monitoring methods within and beyond the estimated plume area.

Results will be used to periodically update the reservoir model.

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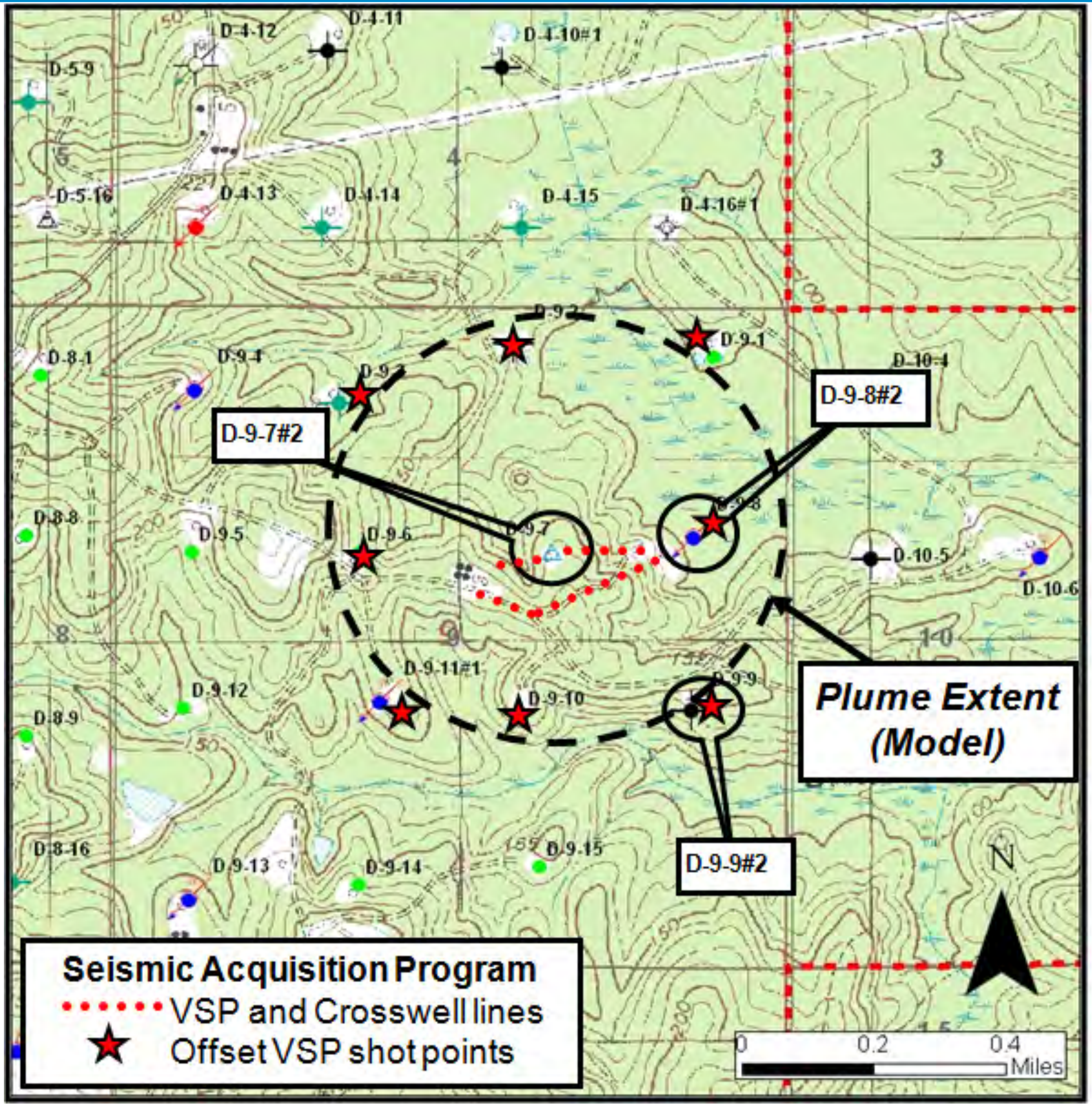
Crosswell Seismic and Vertical Seismic Profile



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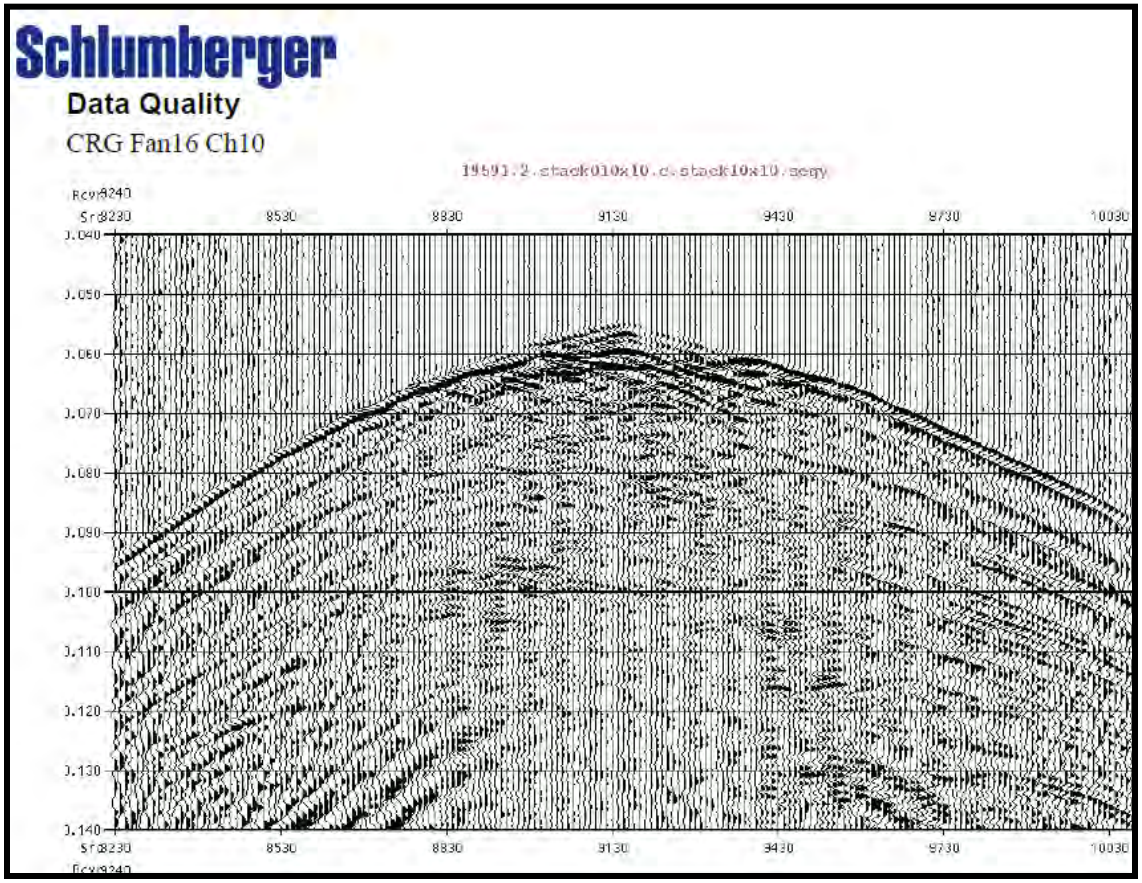
Baseline Crosswell Seismic Imaging for Citronelle



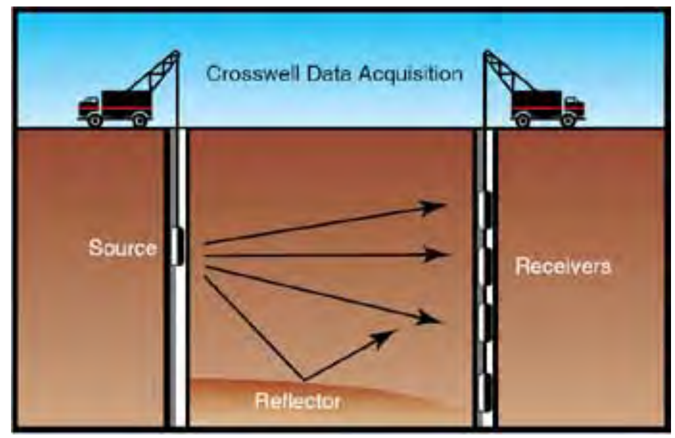


Image Source: AAPG Explorer, Jan 1997

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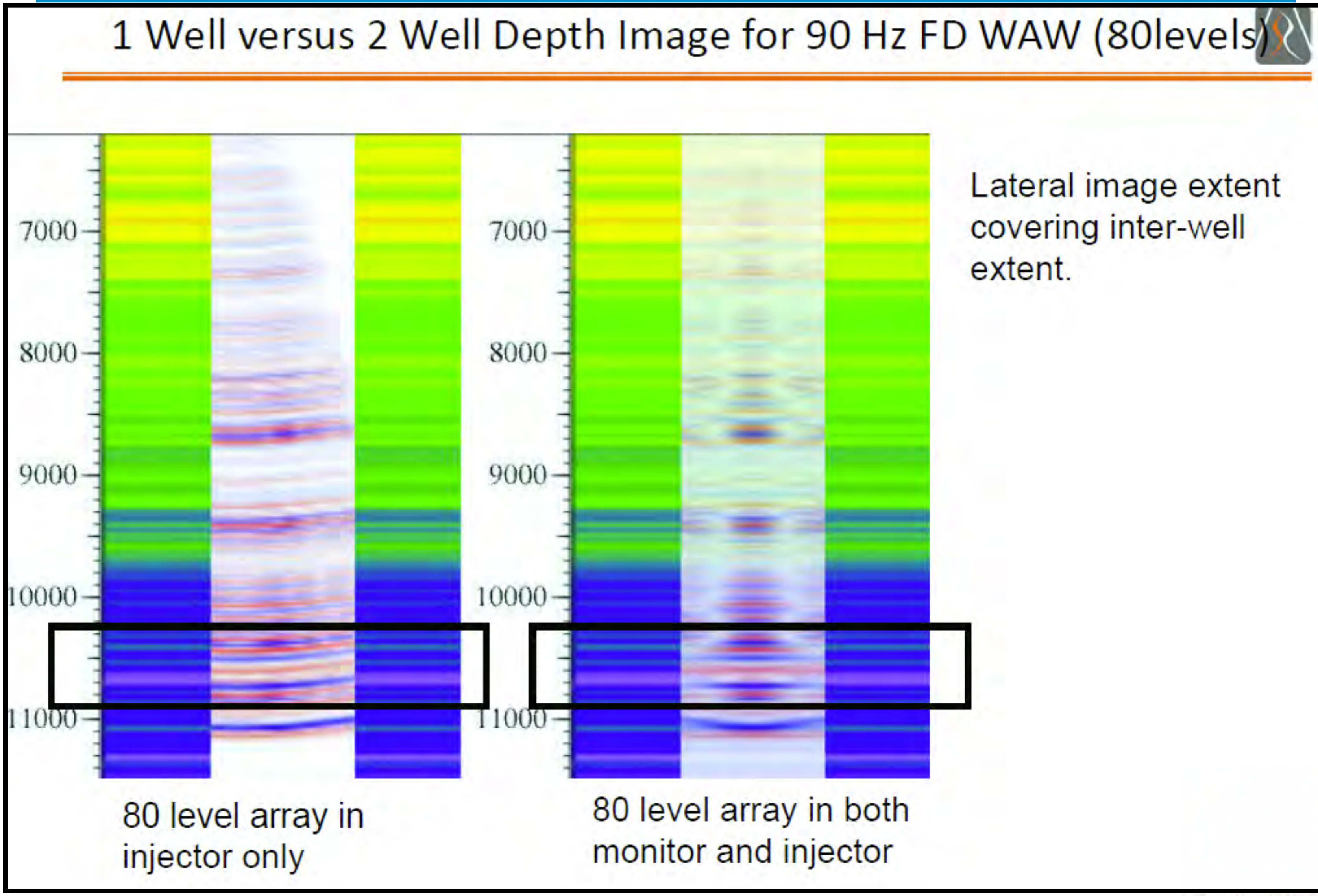
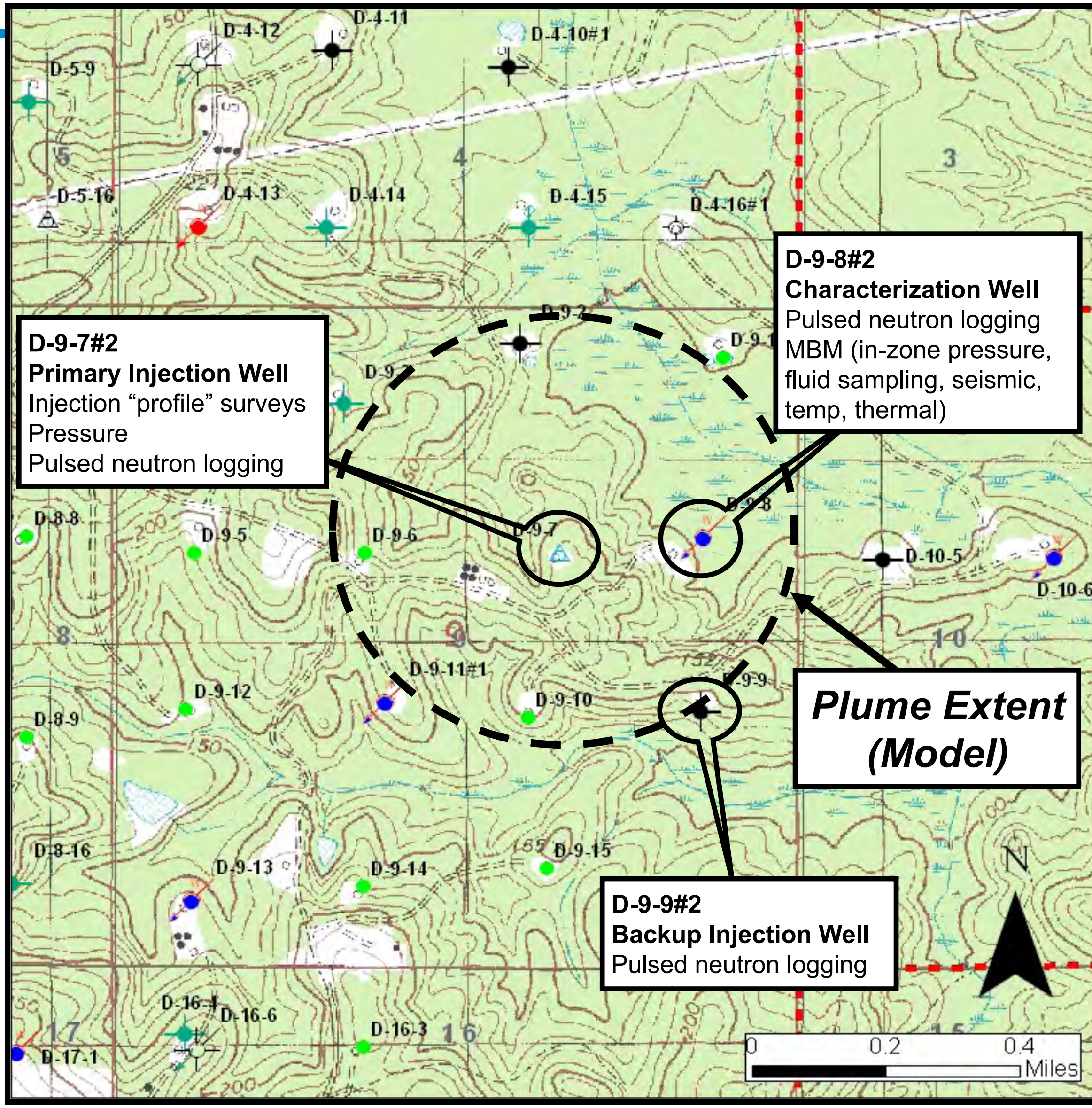
VSP Image



Lateral image extent covering inter-well extent.

Other Deep MVA Activities



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CO_2 Storage Research

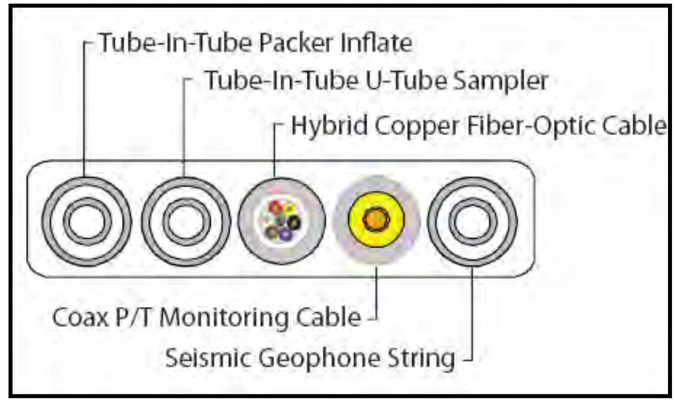
- **We have been opportunistic about adding "experimental" aspects to the test.**

- **Modular Borehole Monitoring (Carbon Capture Project) -** Sensor platform for acquiring multiple measurements using one deployment completion

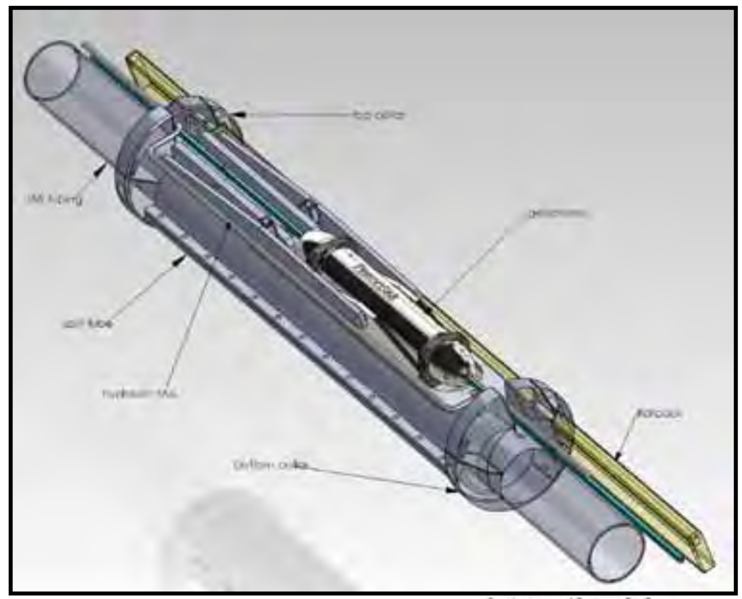
- **Comparison of Groundwater Sampling Methodologies -** Deploy different methods (e.g., u-tube, gas-lift, pumping and wireline sampling) to evaluate impact on groundwater quality results

- **Reservoir Dynamics and Formation Saturation** - in-zone tracer tests and fluid sampling to assess changes in inter-well formation saturation, sweep efficiency changes in the geochemistry of formation fluids

MBM Flat Pack



MBM Geophone Clamp



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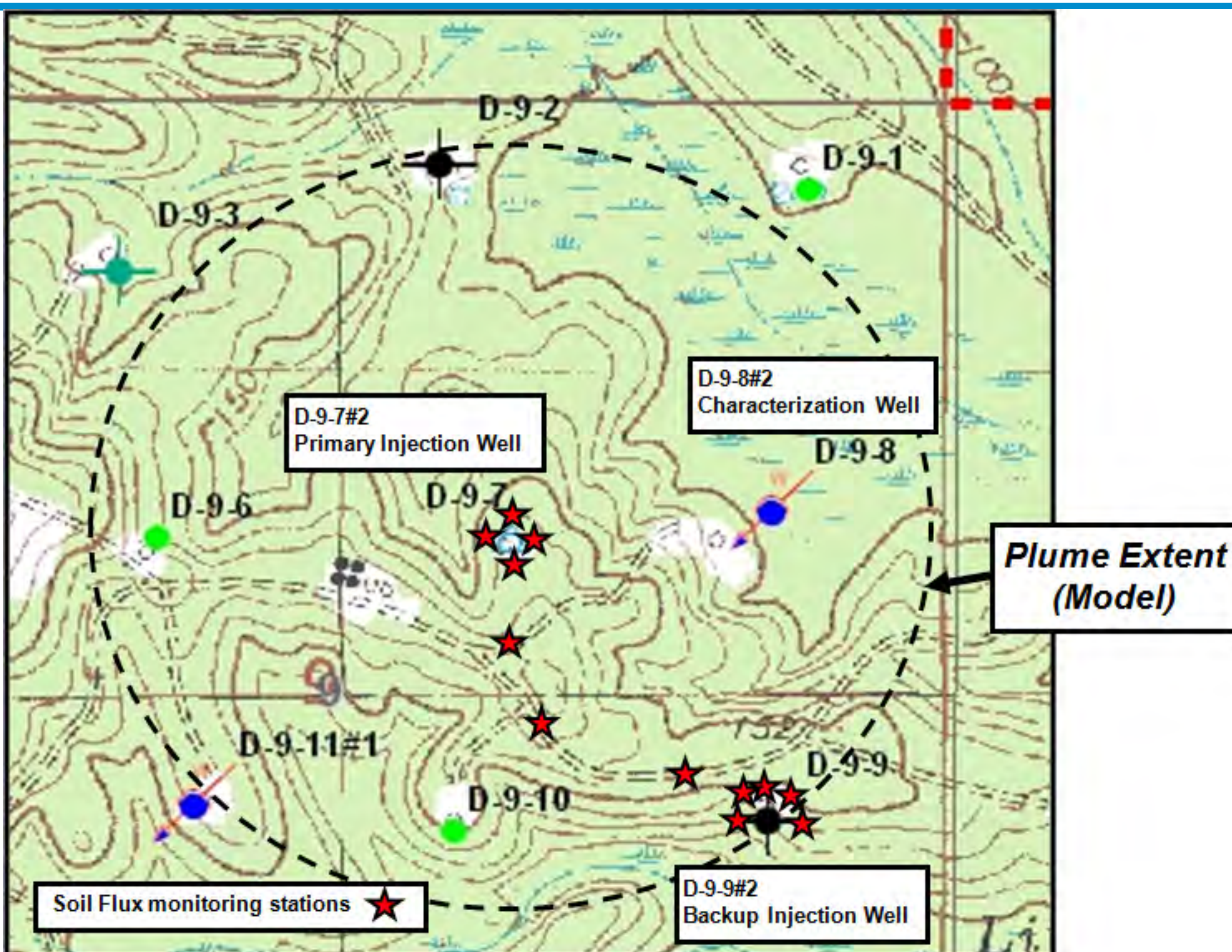
MVA Plan Soil Flux



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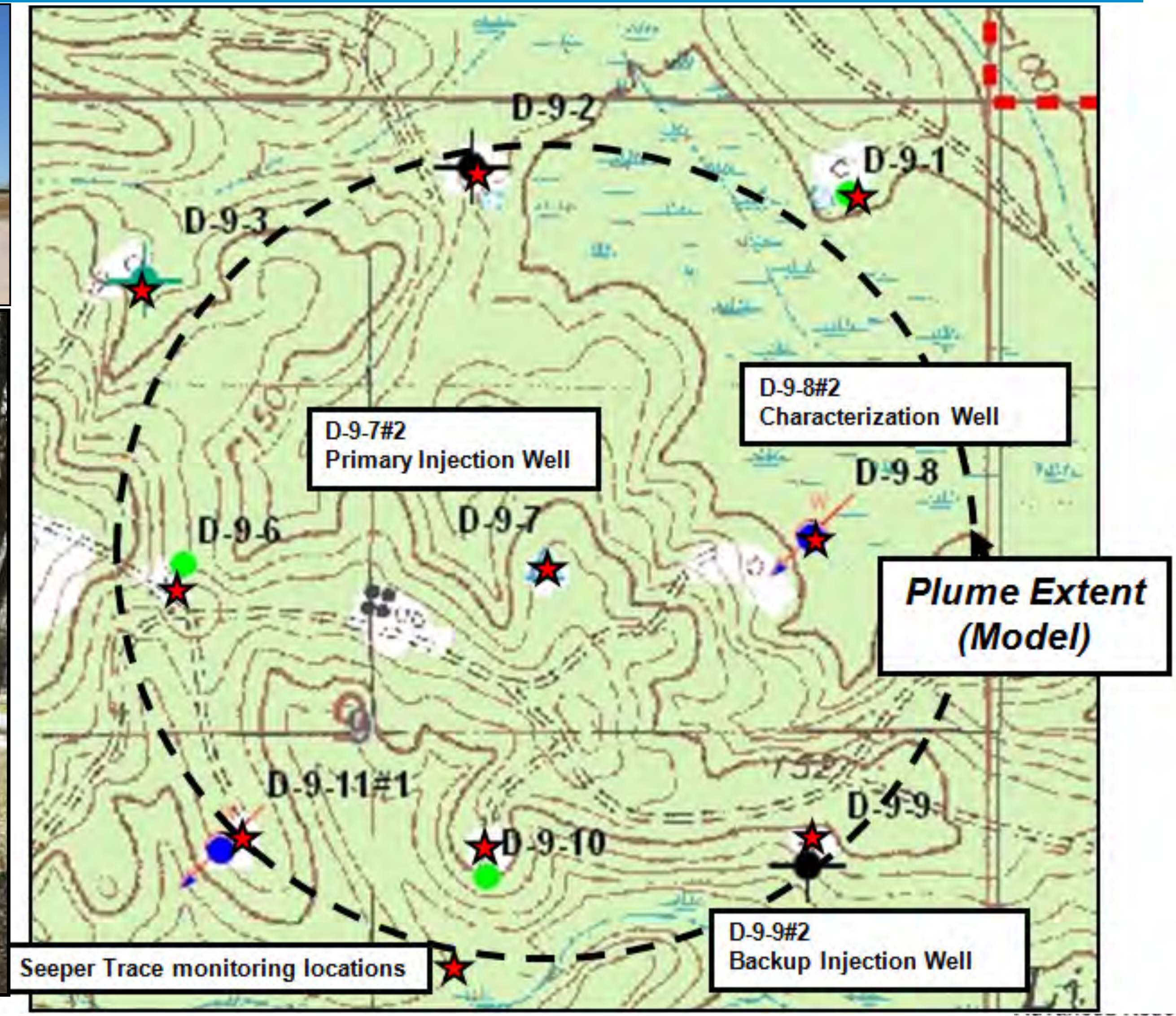
MVA Plan Seeper Trace



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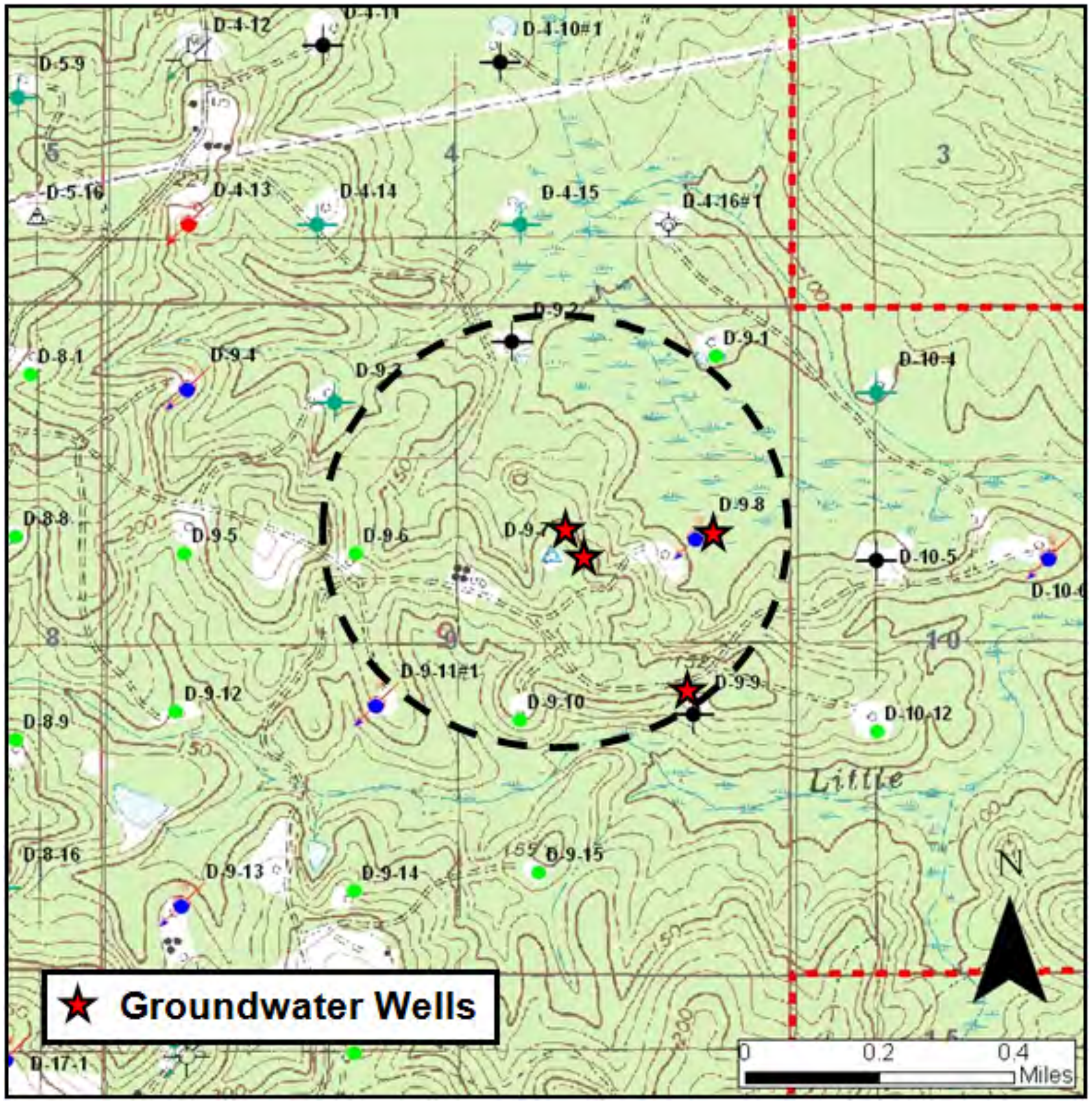
Groundwater Wells



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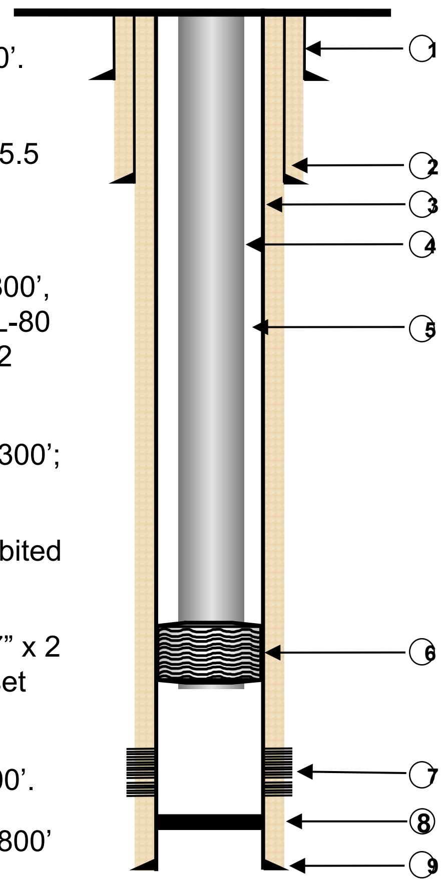
Monitoring Frequency

Measurement Technique	*Level*	*Measurement Parameters*	*Application*	*Frequency*
Reservoir and above-zone pressure	Subsurface	Pressure transducers on wireline with real-time readout	Key measurement for assessing the reservoir's pressure field and for regulatory compliance. Above-zone monitoring to detect leakage through the confining unit	Constant during injection operations, annually post-injection
Cased-hole pulsed neutron logging	Subsurface	Neutron capture as a function of CO_2 saturation buildup	CO_2 saturation buildup near new and existing wellbores. Demonstrates CO2 plume migration and monitor for above-zone leakage	One baseline deployment, annually during injection, bi-annually post-injection
Time-lapse seismic (crosswell and/or vertical seismic profiling)	Subsurface	CO_2 incuded change from baseline sonic velocity and amplitude	Distribution of CO_2 plume vertically and horizontally	One baseline deployment, once post-injection
Reservoir fluid sampling	Subsurface	Pressurized fluid samples taken from the injection zone. Analyze for pH, and selected cations and anions	Geochemical changes to injection zone that occur as a result of CO2 injection	Semi-annually during injection phase, annually post-injection
Injection well annular and tubing pressure	Subsurface and wellbore	Pressure gauges located on the wellhead to monitor casing annular and tubing pressure	Annular pressure is an indication of wellbore integrity. Tubing pressure assures regulatory compliance with maximum injection pressure	Constant during injection operations and post-injection
Drinking water aquifer (USDW) monitoring	Shallow	Alkalinity, DIC, DOC, selected cations and anions.	Monitoring of area freshwater aquifers for geochemical changes related to shallow CO_2 leakage.	Quarterly during and post-injection
Soil CO2 Flux	Surface	Mass of CO2 emitted from the soil per unit time and area	Monitor for anomalous increases in the amount of CO2 that is emitted from the soil surface as an indication of CO2 leakage	Quarterly during and post-injection
Perfluorocarbon tracers (PFT's) introduced in the CO_2 stream	Surface	Measure tracer levels around existing injection and oilfield wells	Monitor for the presence of tracer buildup near new and existing wellbores which would suggest leakage of CO_2 along the well	Single baseline, annually during and post-injection

3. Well Completion

Well Completion

1. 16” Conductor Pipe set at 60’.
2. 10-3/4” Surface Casing @ 2,500’, set in 13 1/2” hole; 45.5 lb/ft J-55 STC; Cemented to surface.
3. 7” Protection Casing @ 11,800’, set in 9-7/8” hole; 26.0 lb/ft L-80 LTC; Cemented to surface (2 stage).
4. 2-7/8” Injection Tubing @ 9,300’; 6.5 lb/ft L-80 EUE 8rd.
5. Annular Fluid: 8.4 lb/gal inhibited fresh water.
6. Injection Packer @ 9,300’; 7” x 2 7/8” Ni-plated full-bore lockset packer.
7. Perforations: 9,400’ to 10,000’.
8. Cast Iron Bridge Plug at 10,800’ capped with cement.
9. Total Depth @ 11,800’.



Note: The Injection Well #2 design is the same without tubing (4) and packer (6)

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Completion Program

- CO_2-resistant cements were pumped into the production casing and placed across the injection horizon.
- DV tool set at 6,000 feet will allow cement to be carried into the surface casing string (two-stage cement job).
- Additional completion equipment run with the casing included centralizers (to center the casing in the hole) and cement baskets (cement weight mitigation tool).
- Formation access will be via standard perforating charges. sized at approximately > 0.4 inches and the shot density should be at least 2 shots per foot (spf) and phased (oriented) at 90° to adequately access the reservoir.

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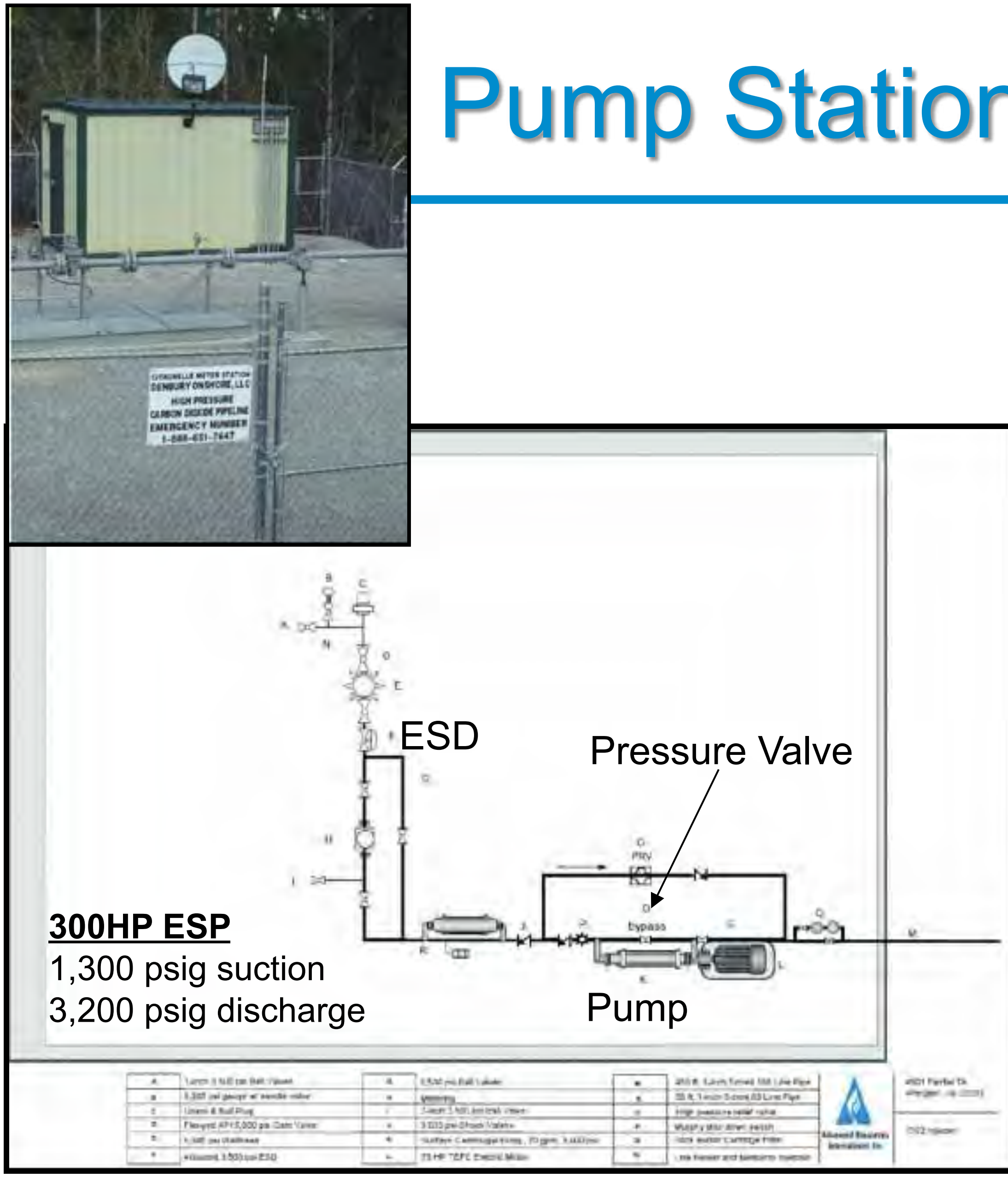
4. Injection Equipment

Pump Station



1. The CO_2 will be pumped downhole, using a horizontal electric submersible pump to increase the pressure from the delivery pressure (1,500 psig) up to the injection pressure (maximum injection pressure (3,300 psig).

2. The CO_2 will then flow through a series of check valves: pressure, rate, temperature metering equipment, and an emergency shutdown valve (ESD).

3. Before entering the wellhead automated data recorders will be deployed to continually monitor both the annular pressure and the tubing injection pressures to ensure compliance with ADEM requirements.

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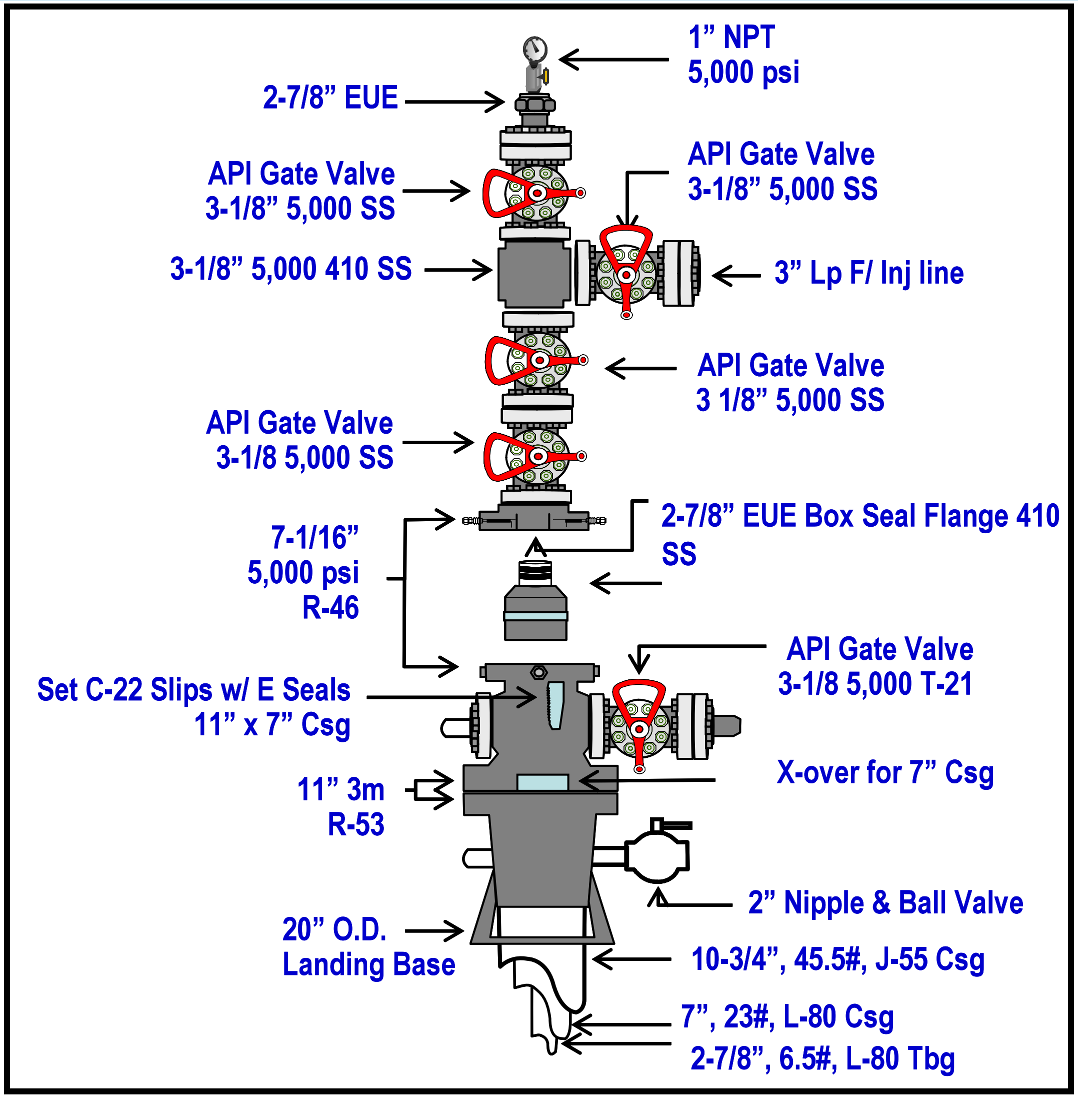
Injection Wellhead Schematic



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5. Schedule

Schedule

- Work at the up-dip monitoring wells, D-4-13 and D-4-14, is completed (still awaiting pressure monitoring gauge deployment).

- This week, the rig will move to the D-9-7#2 (injector) for completion work. A full **mechanical integrity test** will be run on the well. This may be occurring during the SECARB Stakeholders Briefing field trip on the 8th.

- A second rig is being used to complete the D-9-8#2 well (observation well). The **deep groundwater sampling methodology comparisons** are ongoing. The **Modular Borehole Monitoring System (MBM)** will then be run in the D-9-8#2 well, beginning March 19th.

- The project team continues to measure baseline **soil flux samples** and are developing the three **USDW monitoring wells** for geochemical sampling.

- The CO_2 capture unit at Plant Barry has begun operations. Around March 13th a **sample of the injection stream** will be analyzed. Shortly after the results of this analysis are finalized, Denbury will submit the **permission to inject request** for the D-9-7#2 well.

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Next Steps

- Permission to inject anticipated in April 2012
- CO_2 injection operations begin in April 2012, continue for 1 to 2 years
- 3+ years of post-injection monitoring, then close site

	Fiscal Year									
Anthropogenic Test	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**
Public Outreach & Education										
Site Permitting										
Site Characterization and Modeling										
Well Drilling and Completion										
Transportation and Injection Operations										
Operational Monitoring and Modeling										
Site Closure										
Post Injection Monitoring and Modeling										
Project Assessment										

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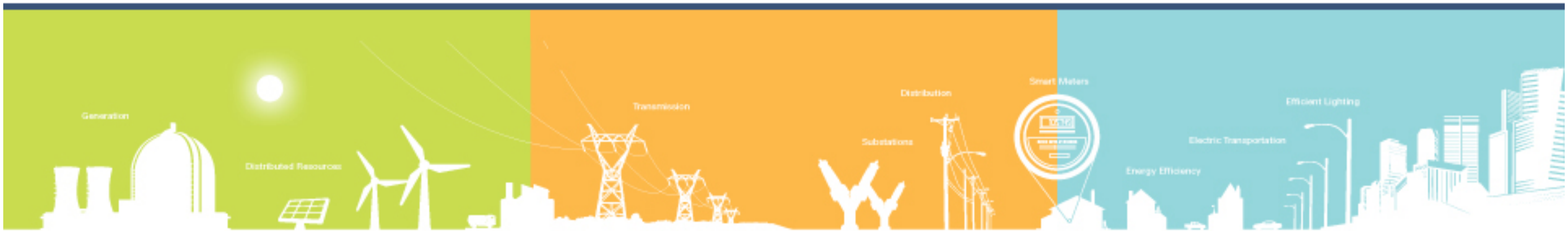
Advanced Resources International, Inc.

Southern Company/MHI Ltd.
500 TPD CCS Demonstration

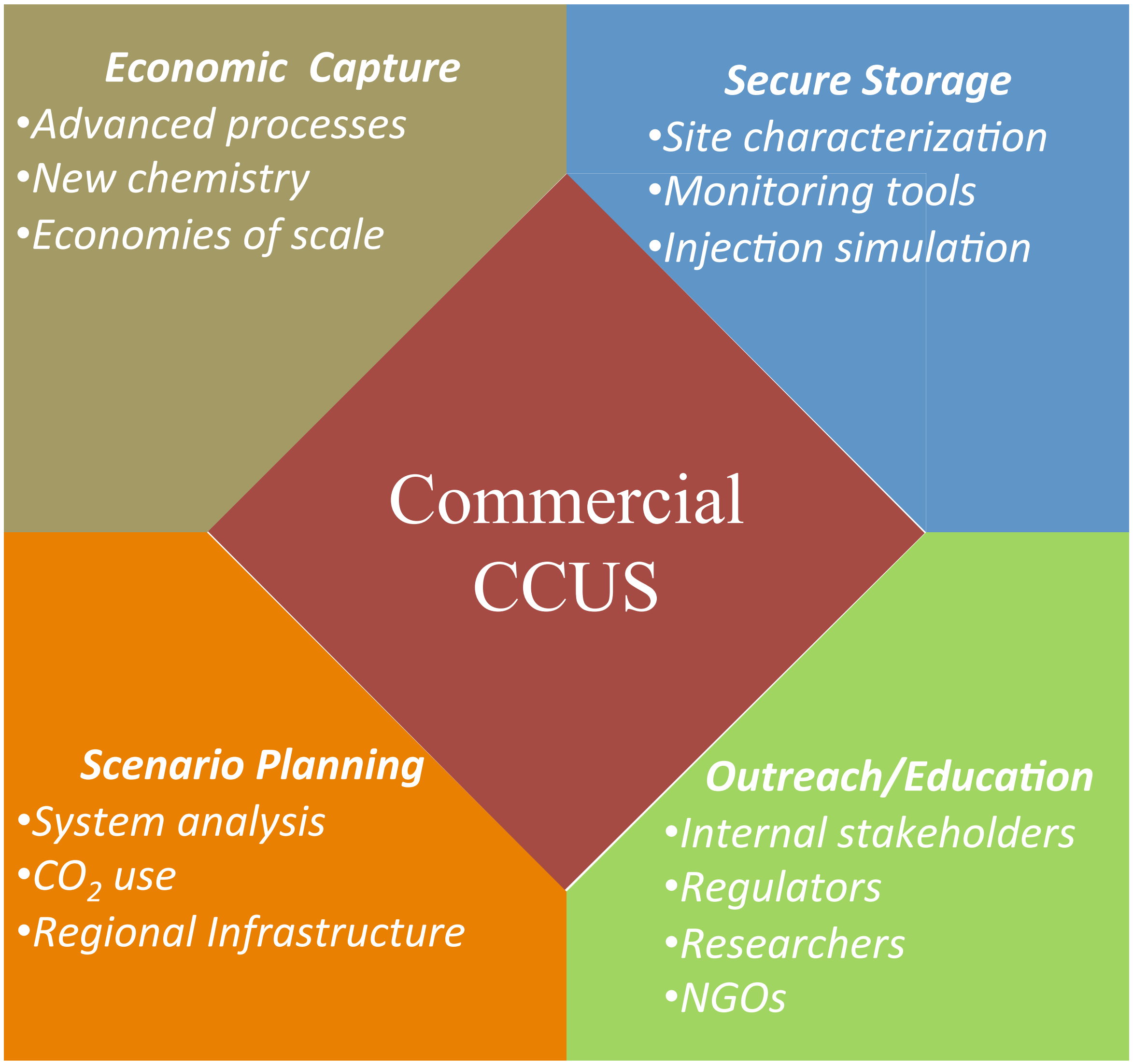
Nick Irvin, P.E.

Program Manager, AES and CCUS



SOUTHERN COMPANY

The Commercialization Puzzle



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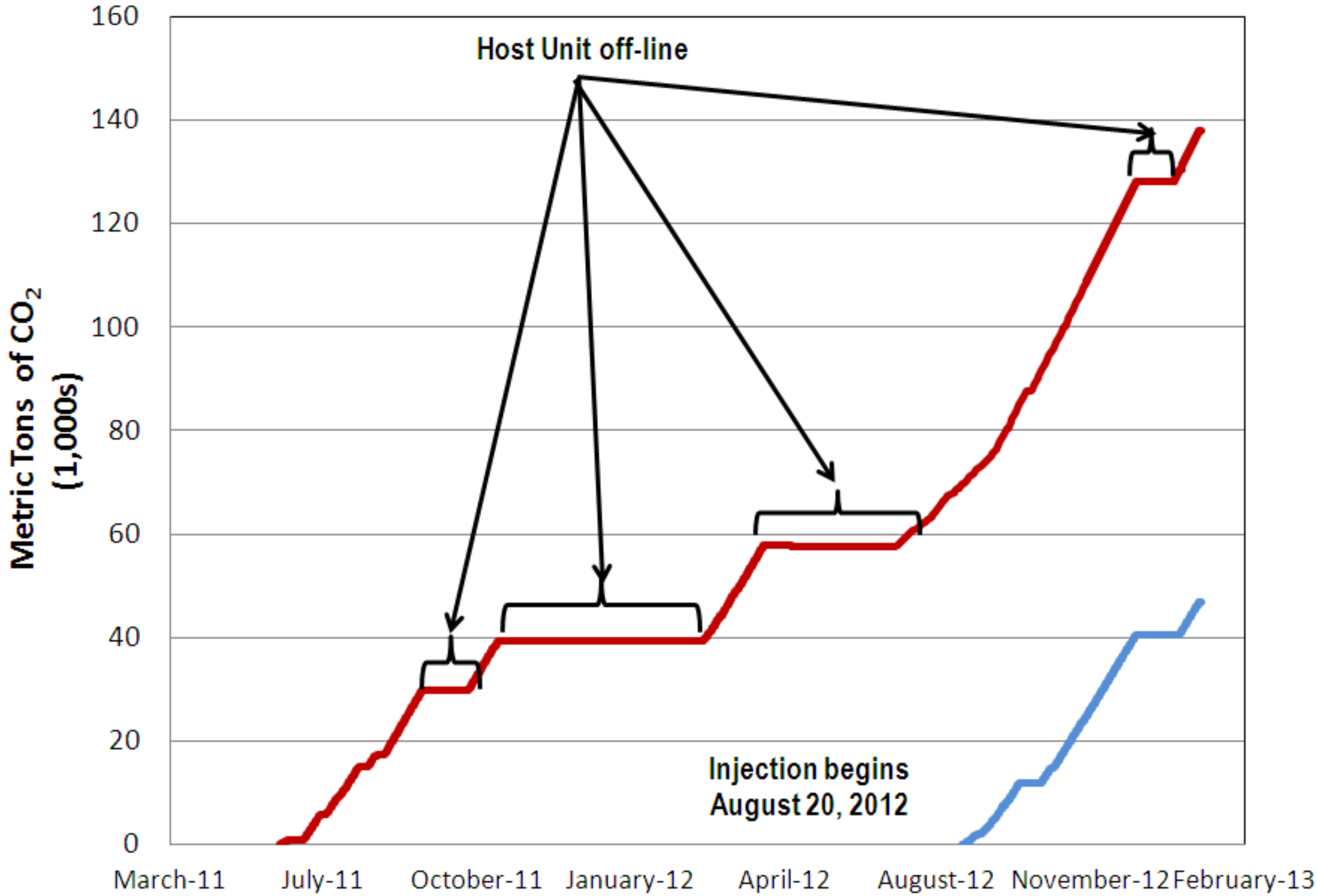
500-TPD Demonstration

CO_2 Captured and Injected



Online Amine Analyzer

- Proprietary on-line analyzer to monitor the process conditions and amine emissions
  - consists of an auto sampling unit and a high resolution analyzer with computational control unit
- Improvement of operability and controllability
  - provides the operational status to allow immediate response to optimize operational parameters

Fig. Online Amine Analyzer

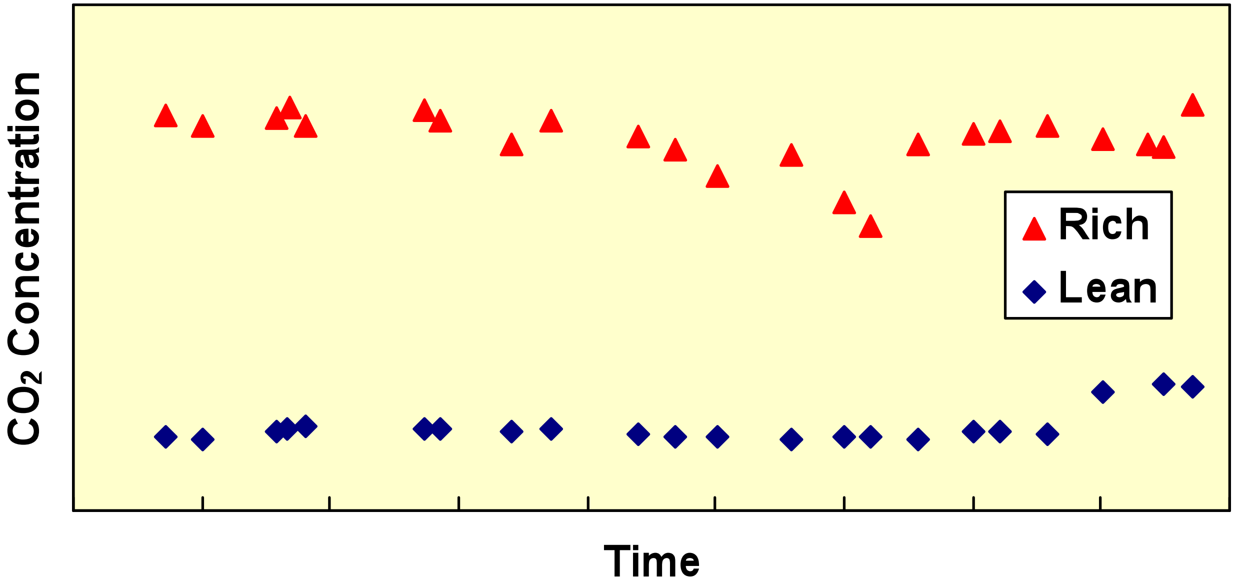
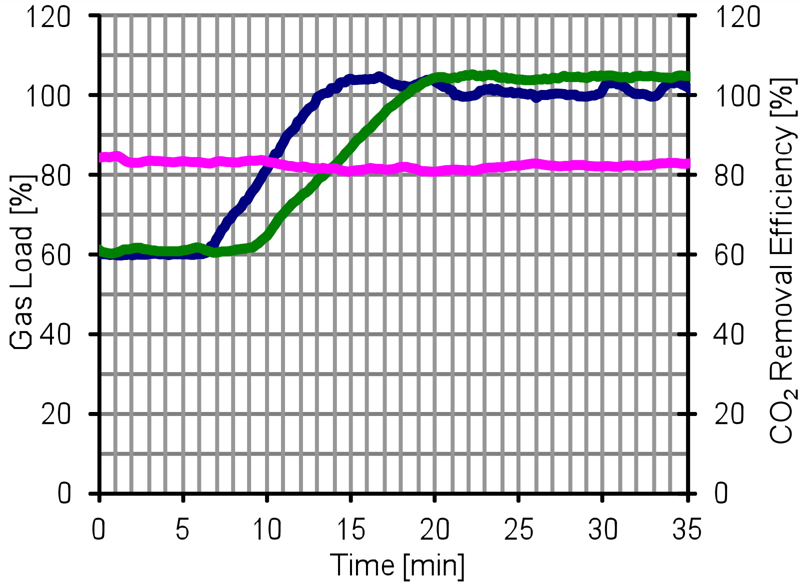


Fig. Periodic Results of CO_2 concentration trends in KS-1™ solvent

Actual load following data in 2 modes



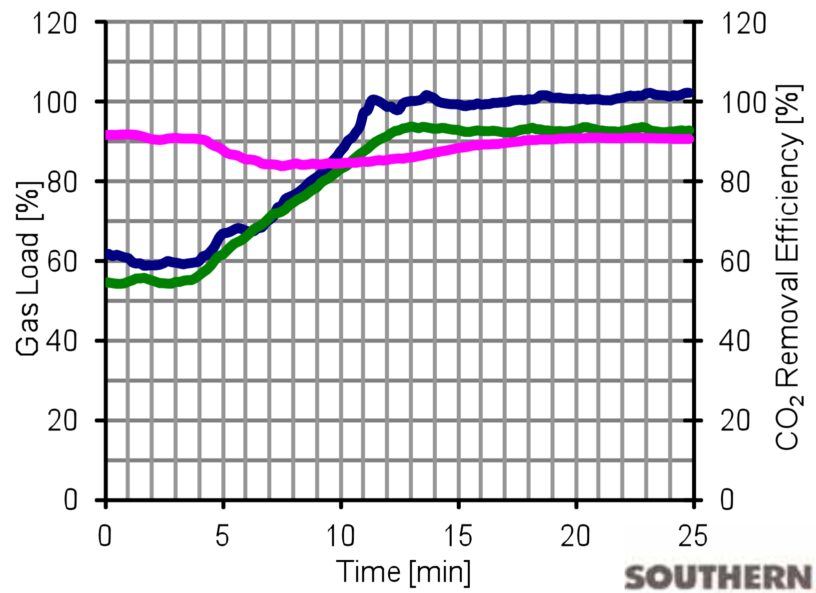
CO_2 compliance scheme

- Demand dictated by additional boiler load (leads to more flue gas flow)
- Ramp of ~5%/minute
- Small dip in removal (5%), but recovery to 90% within 10 minutes

CO_2 Production Scheme

- Demand dictated by additional CO_2 product requirement
- Ramp of ~5%/minute
- Very stable removal rate

- Capture Rate
- CO_2 Flow
- Flue Gas flow



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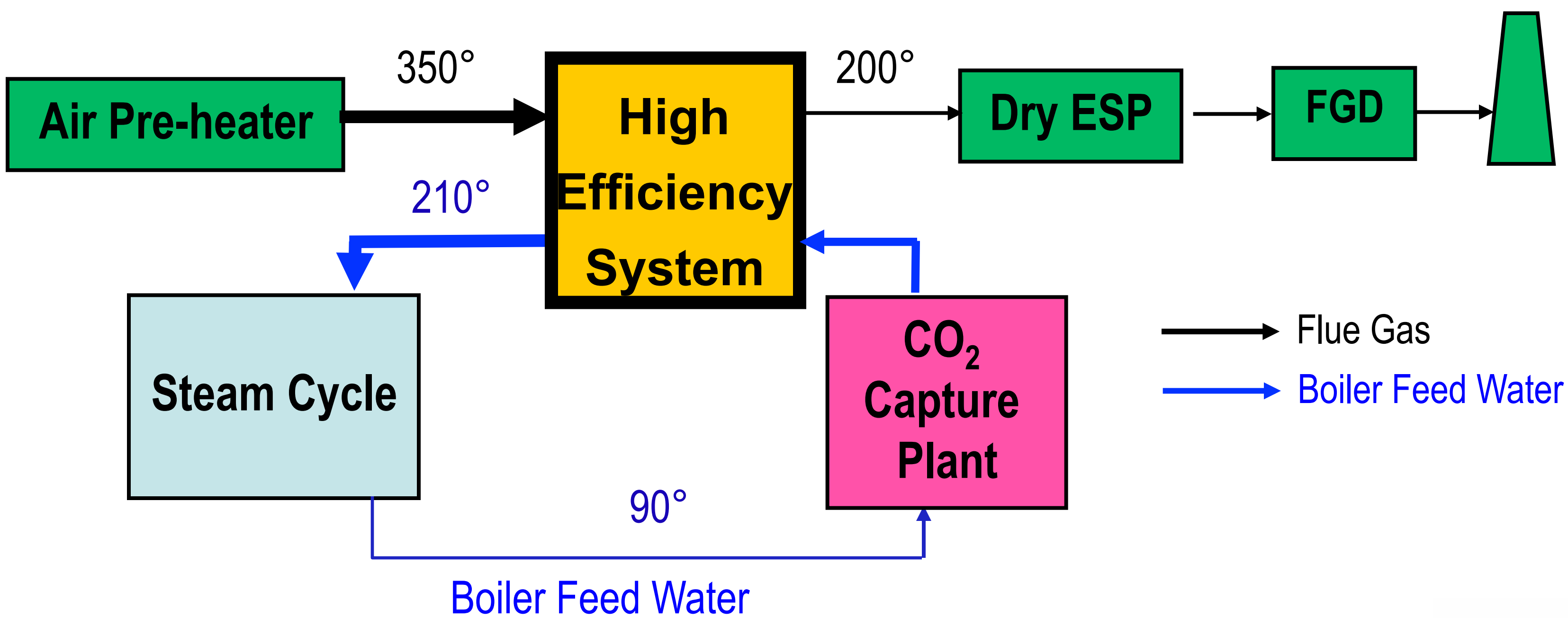
Process Flow & Technology Benefits

- **Improve efficiencies of host steam cycle and CO_2 recovery plant**
- Reduce water consumption in FGD by lowering flue gas inlet temperature
- Improve ESP performance
- Remove SO3 and heavy metals (mercury and selenium) in ESP



Summary

- The 500 tpd demonstration plant successfully started up and achieved full load in June 2011 with ~150k tonnes captured
- Plant performance is very stable at full load condition with CO_2 capture rate of 500 tpd at 90% CO_2 removal and lower steam consumption than the conventional process
- Operation by Southern Company staff has been very successful
- Collaboration between Southern Company and MHI has lead to significant process improvements and enhanced operability

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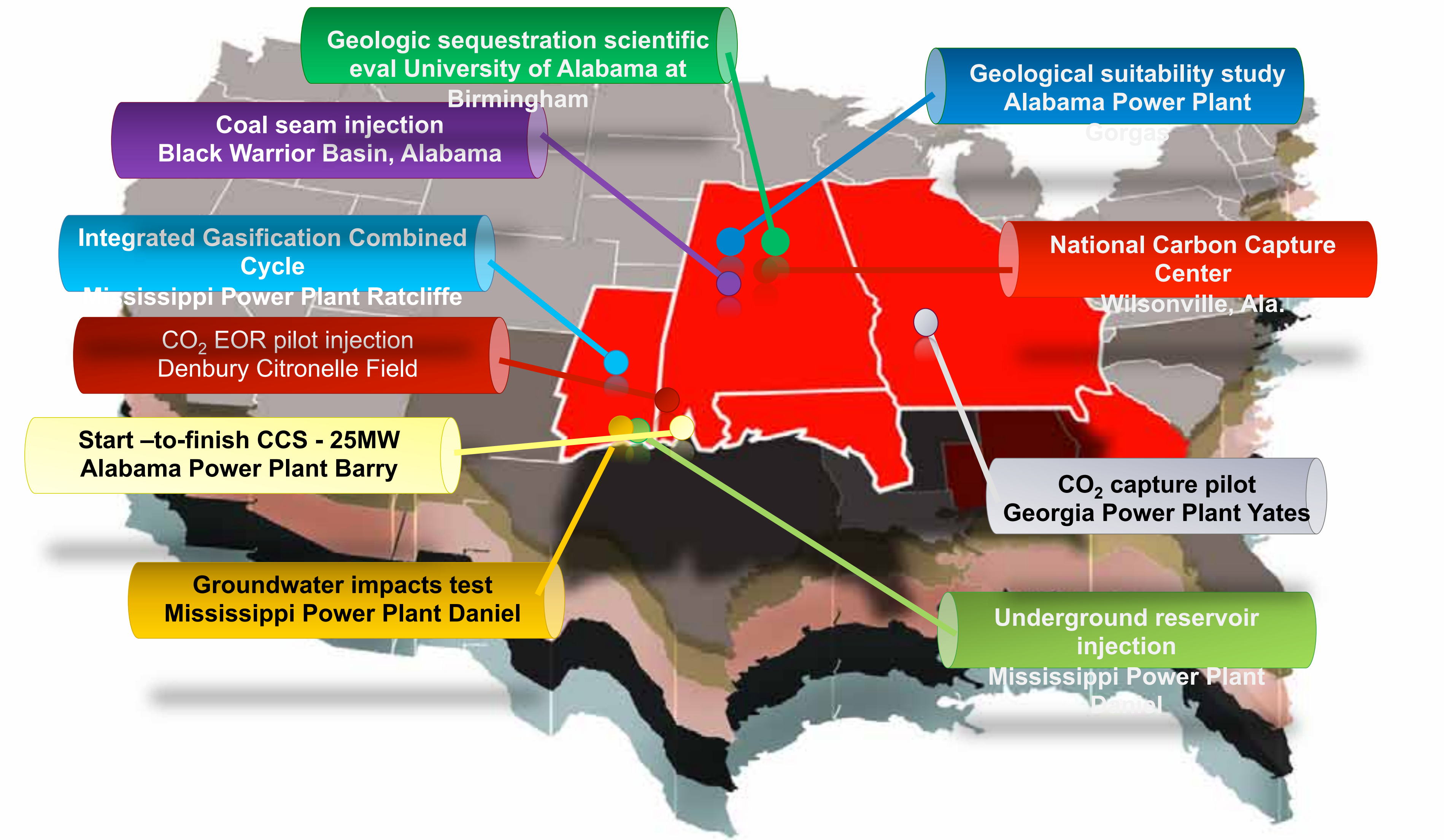
Southern Company

Leading the Industry in CCS



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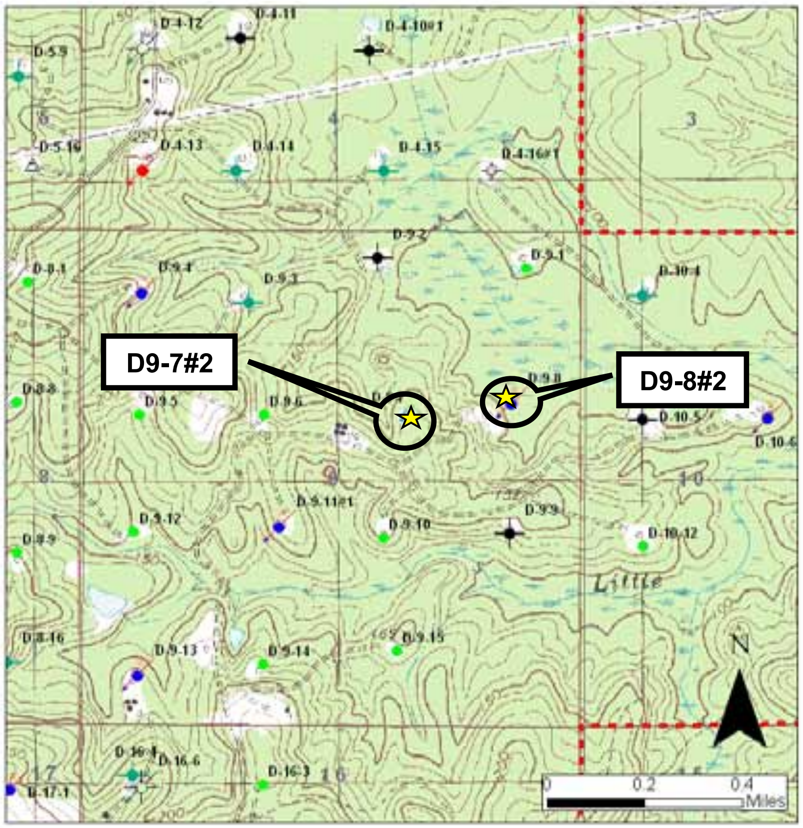
Advanced Monitoring Techniques

Robert C. Trautz
Sr. Project Manager

SECARB Annual Business Meeting
13-Mar-2013

R&D Effort is Focused on Studies Performed at the Characterization Well (D9-8#2)



CO_2 injection well D9-7#2 and observation well D9-8#2

- Characterization well (D9-8#2) is:
  - Approx. 850 ft east of the CO_2 injection well
  - Perforated at a depth of 9,394-9,424 ft (30 ft)
  - Completed in the upper-most sand in the Paluxy Formation
    - Ave. 21% porosity
    - Ave. 450 mD

Comparison of Groundwater Sampling Methodologies

In Collaboration with

USGS
science for a changing world

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

Industry needs best available practices for compliance

Groundwater Sampling Comparison

- Purpose:
  - Compare sampling methods to identify significant differences in groundwater quality results
- Scope: Collect and analyze groundwater samples using four artificial lift techniques

1. N_2 gas lift
2. Pumping
3. Kuster Sampler (wireline)
4. U-tube sampler

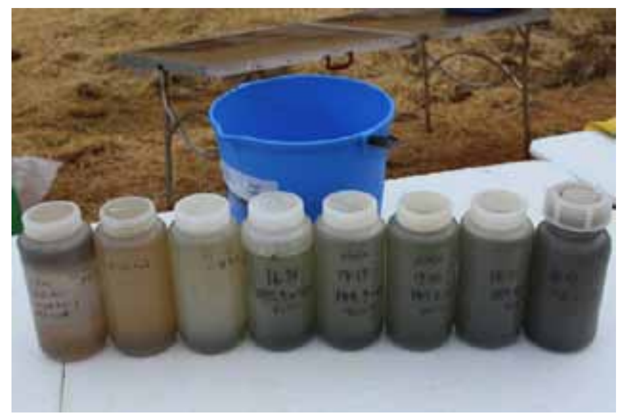
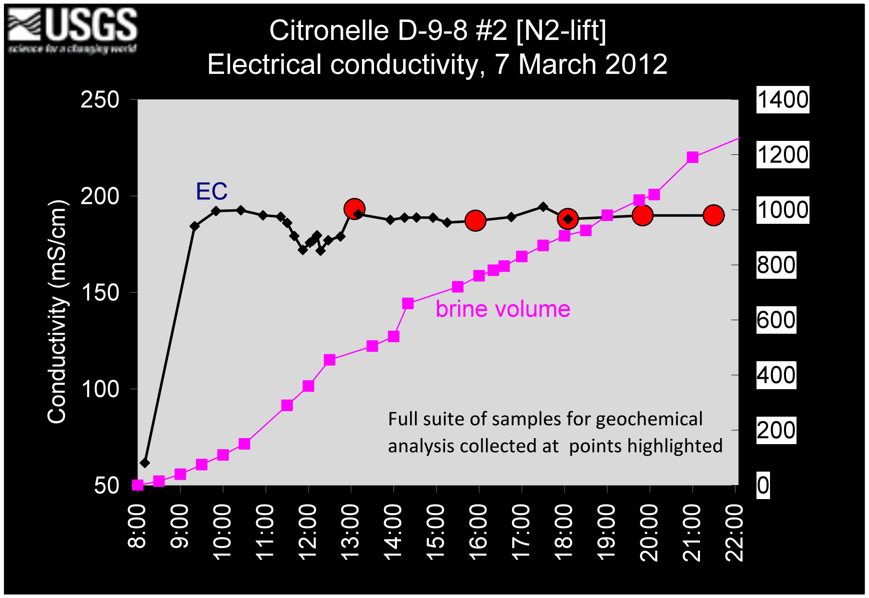
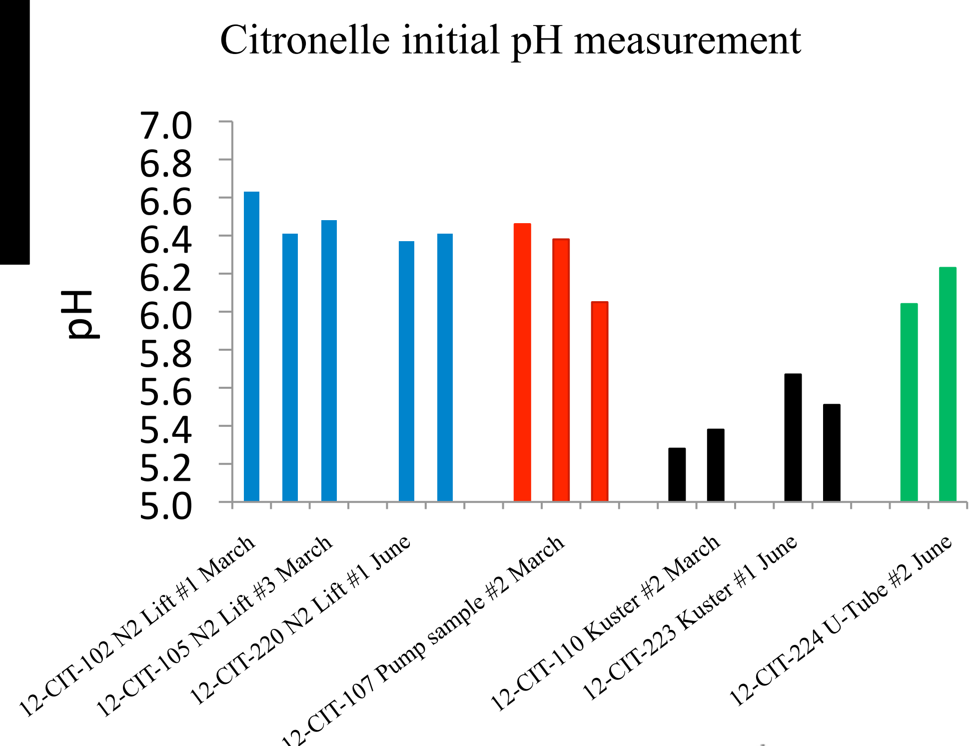


Photo Courtesy of the USGS photo: Fluid Samples from Gas Lift

USGS Field Sampling Campaign at Observation Well D-9-8#2 (March 2012)



Time series for electrical conductance



Images Provided by the USGS

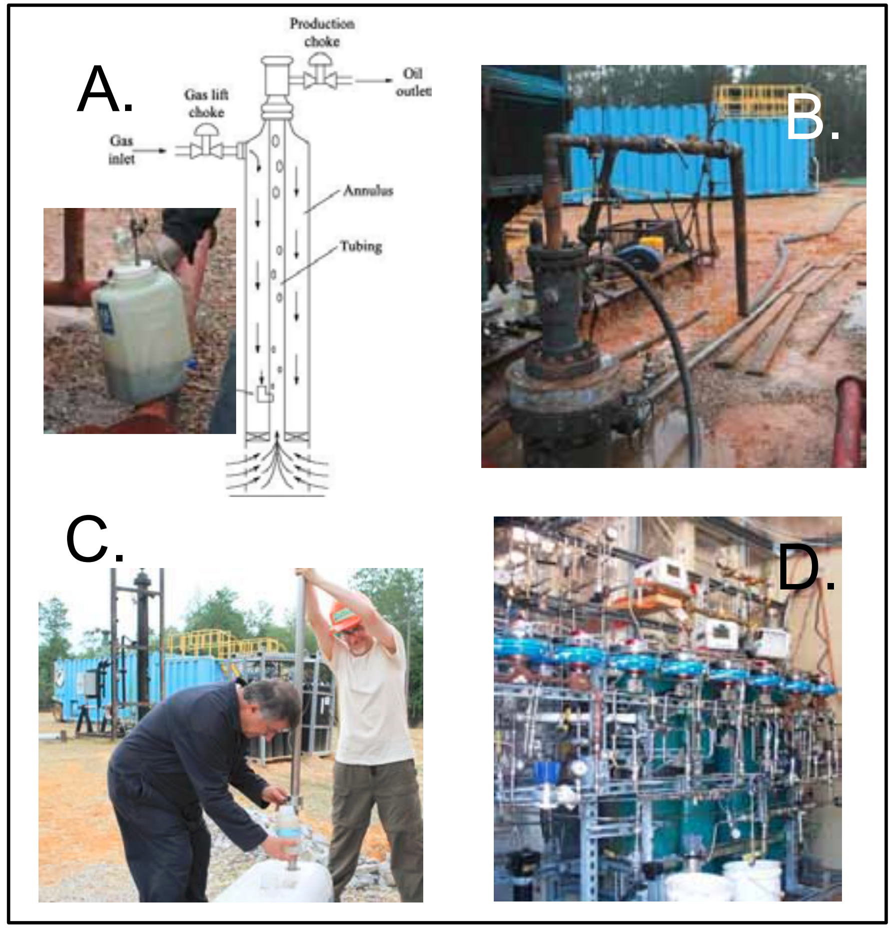
Testing & Monitoring: In-zone Comparison of Sampling Methodologies

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

Modular Borehole Monitoring (MBM) System

In collaboration with

Motive Behind MBM Development

Deep monitoring wells are expensive to drill and complete and have limited space available for instrumentation

- Goal: Develop a rugged, modular, multi-sensor monitoring platform designed for a single-well deployment
  - ✓ Monitor CO_2 plume location
  - ✓ Reservoir pressure and temperature
  - ✓ Fluid sampling
  - ✓ Leak detection
  - ✓ CO_2 saturation

Integrated Modular Borehole Monitoring (MBM) System

- Plume location using a semi-permanent geophone array (6,000-6,850 ft)
  - Three, xyz-comp. phones
  - 15, z-comp. phones
  - 50 ft spacing
  - Clamping assembly
- Two in-zone quartz pressure/temperature gauges for reservoir diagnostics
- U-tube for 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

Geophone pod and clamp assembly

Terminus of the fiber optic cable assembly

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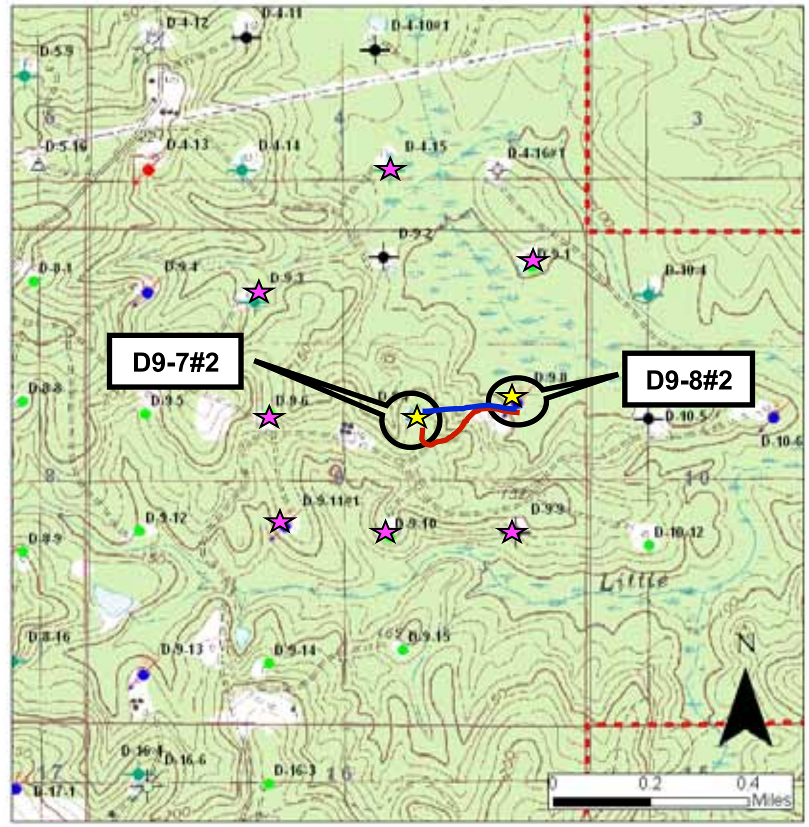
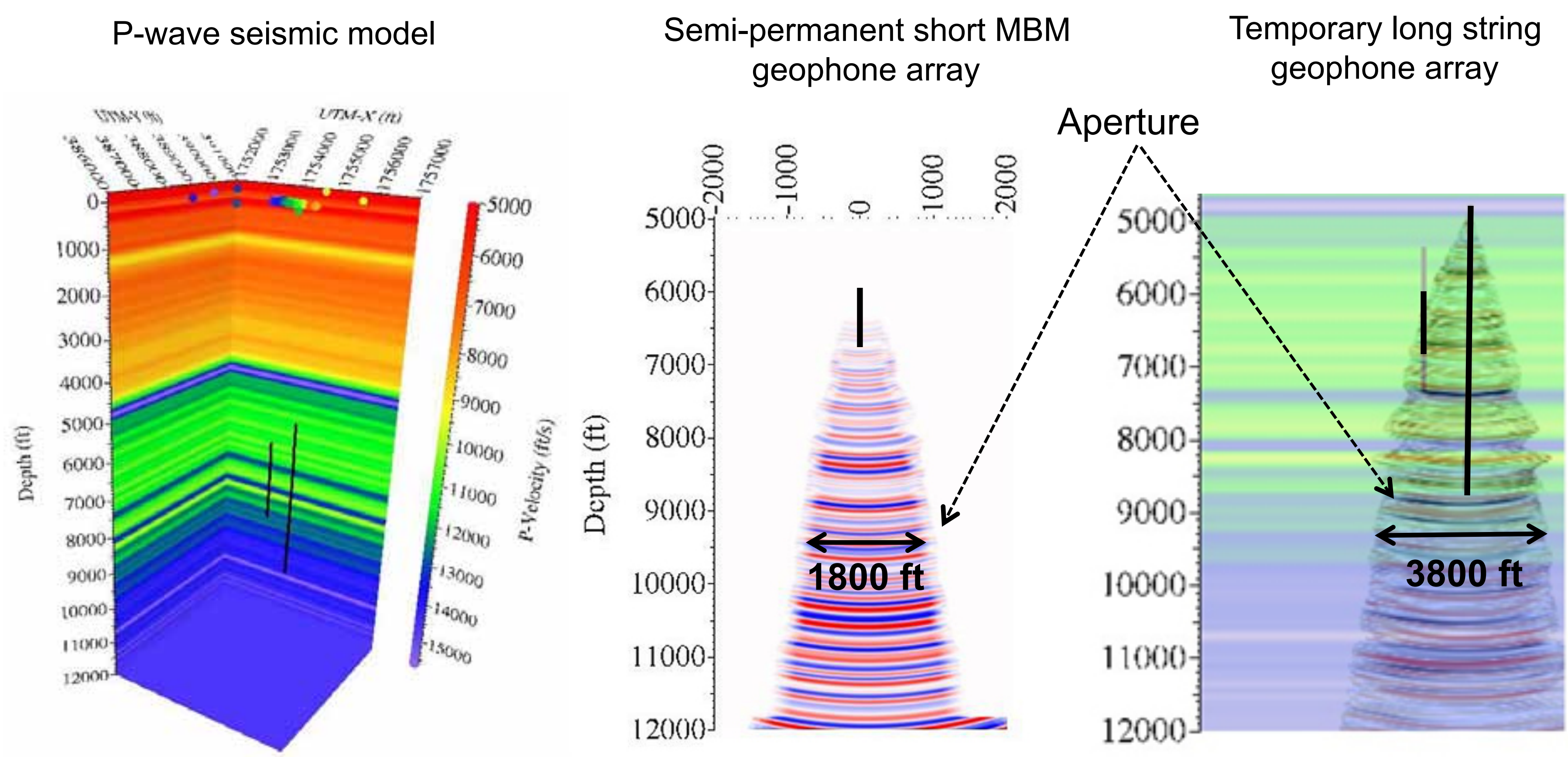
Citronelle Offers a Unique Opportunity to Compare Seismic Methods to Monitor CO_2 Plume Location

- Seismic methods deployed at Citronelle include:
  - Cross-well seismic surveys
  - Offset vertical seismic profile (VSP) surveys using long geophone arrays deployed in the injector and D9-8#2
  - Offset VSP using semi-permanent short geophone array deployed in D9-8#2
  - Walk away VSPs
  - Fiber-optic based acoustic sensor arrays



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

Comparison of Baseline VSP Surveys



Shorter MBM array has an lateral image area that is small and dominated by limited aperture migration artifacts, but it should be able to see changes in the gather response and images over time due to CO_2 injection

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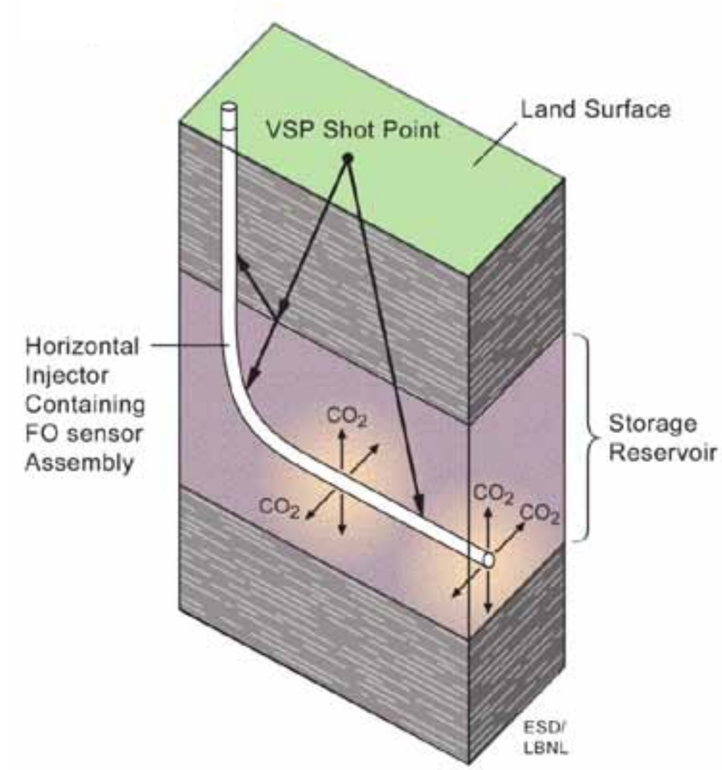
Fiber Optic Based, High Density Sensor Arrays

Benefits: Fiber optic cables can operate in harsh downhole environments, long life span (50 yrs), high data transfer rates, high spatial resolution, easily adaptive to changing technologies, and have many applications

Applications include:

- Distributed temperature sensing
- Strain measurements
- High density seismic arrays
  - Leak detection
  - Compliance monitoring
- Heat-pulse monitoring
  - Leak Detection
  - CO_2 distribution behind casing
  - Flow monitoring and allocation



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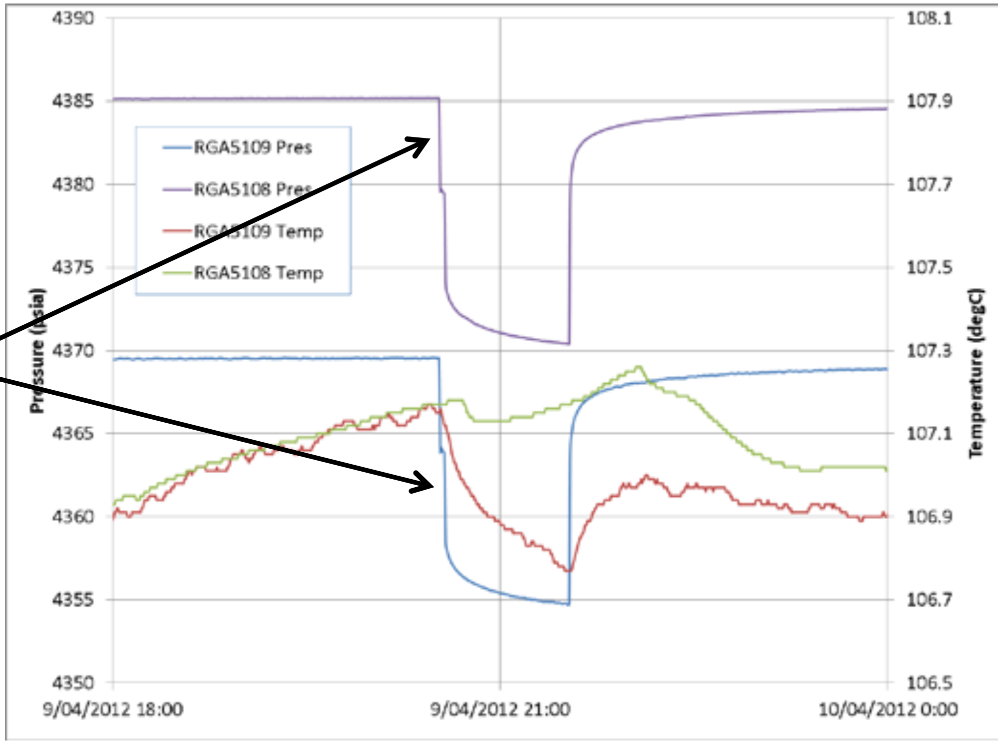
Pressure Communication Observed Across Packer

Hydroset II Packer

- Packer set at 9,384 ft
- Kill fluid was unloaded from the annulus but …
  - Flow continued
  - Annulus pressure climbed when shut in
- Pressure response was observed by both gauges below the packer
- Damaged Packer?



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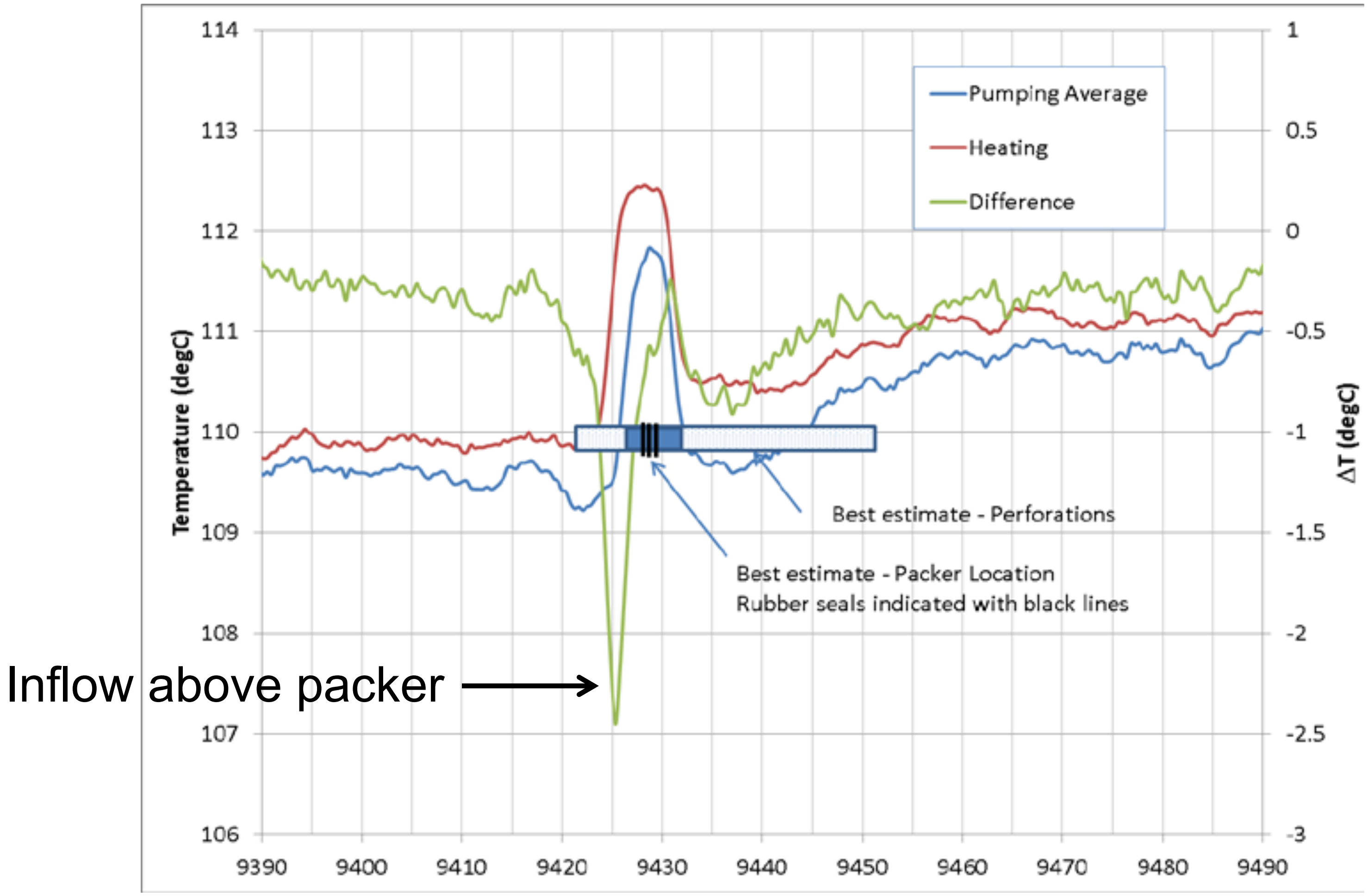
T Profiles During Heating – Comparison of No Flow to Flow (8.7 gpm) Conditions



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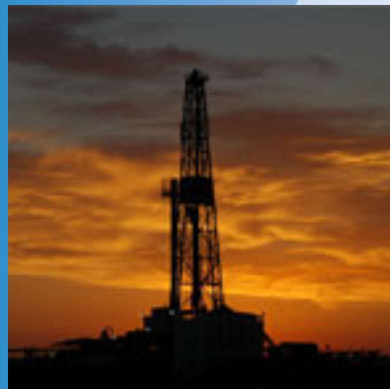
Summary

- Kuster and U-tube sampling methods provide the best water quality results
- Gas-lift and pumping may be used for non-reactive solutes
- The semi-permanent geophone array has a smaller aperture, but surveys can be performed more frequently at lower overall cost
- Heat-pulse monitoring was successfully used to pinpoint inflow above the packer
  – Discussed options with State Regulators including MBM removal
  – Successful diagnostics saved project $200,000 - $430,000 and prevent delays
- Fiber-optic based sensor arrays are innovative and robust

Together…Shaping the Future of Electricity



SECARB Citronelle CO_2 Storage & MVA Status

Steven M. Carpenter, George J. Koperna, Jr. , and Shawna Cyphers

Advanced Resources International, Inc.

SSEB 8th Annual Stakeholders Briefing

March 13, 2013

Southern States Energy Board
NETL
Southern Company — Energy to Serve Your World™
SECARB — Southeast Regional Carbon Sequestration Partnership
EPRI — Electric Power Research Institute
Denbury
Advanced Resources International, Inc.

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SECARB Southeast Regional Carbon Sequestration Partnership

SOUTHERN COMPANY Energy to Serve Your World

SOUTHERN STATES ENERGY BOARD

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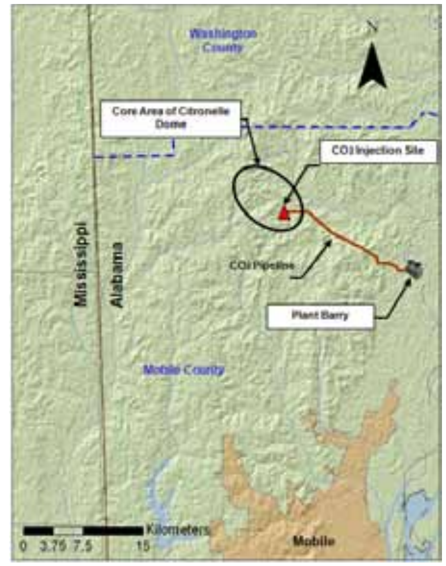
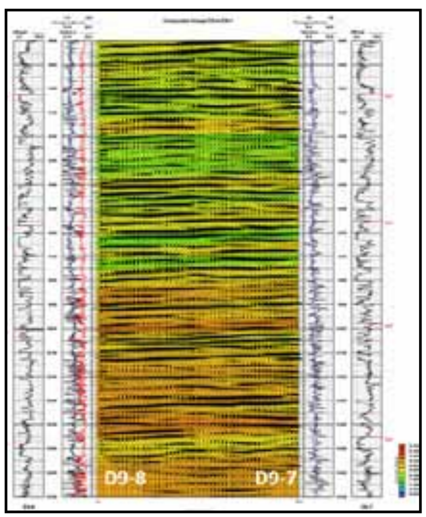
Denbury

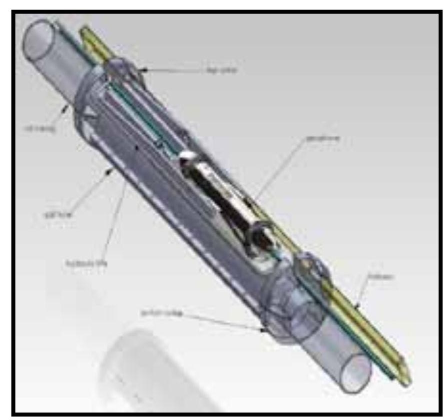
Advanced Resources International, Inc.

Presentation Outline

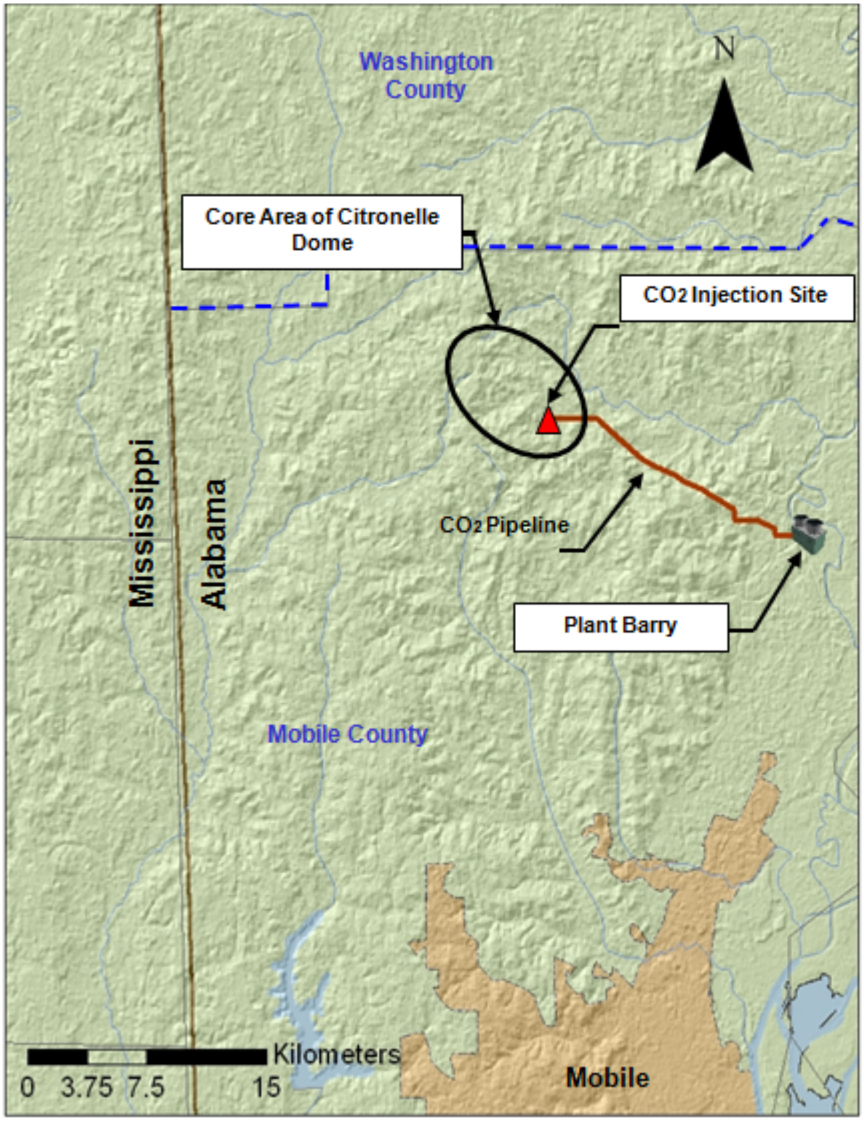
- **Storage Overview**
- **MVA Program**
- **Key Results**







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 confirmed geology.**

Injection wells were drilled in **3Q 2011**.

100k – 300k 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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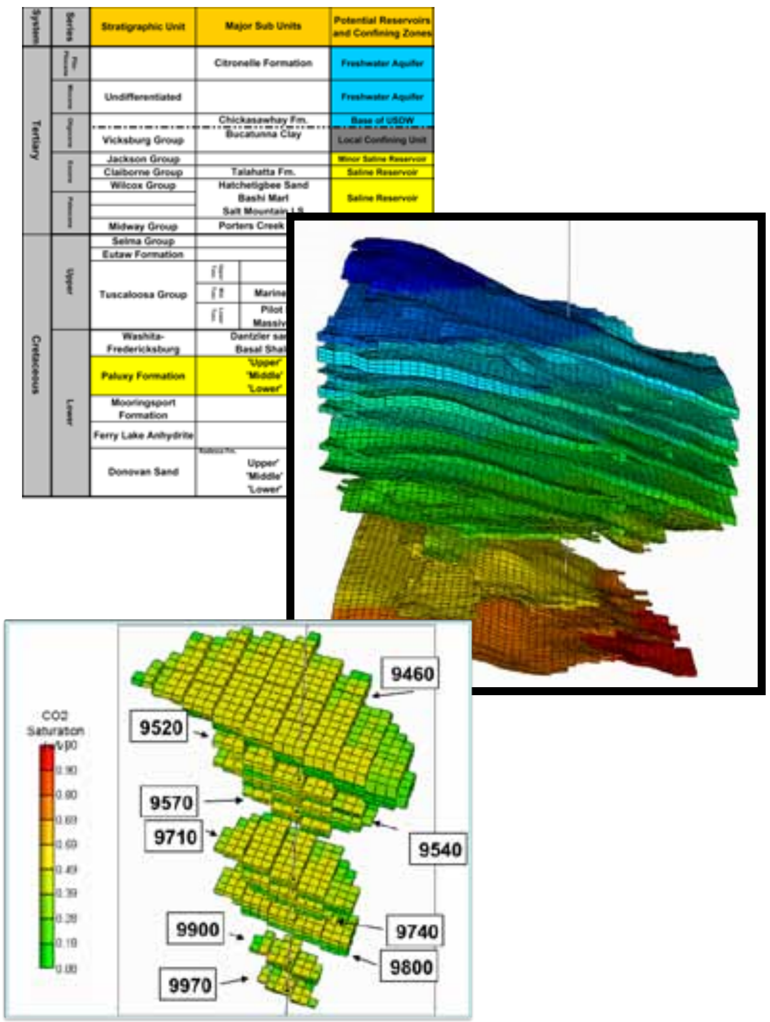
Good Geology, Model, & Design



- Proven four-way closure at Citronelle Dome with existing logs
- Injecting into Paluxy @ 9,400 feet
- >260 net feet of "clean" sand
- Average porosity of 18%
- Average permeability of 200 md
- No evidence of faulting/fracturing (2D)
- Max. injection rate 500 tonnes/day
- Plume area in topmost sand is 0.35 mi^2 (225 acres)
- Modeled for UIC AoR

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Injection (Storage) Totals

	UIC Permit Number ALS19949664						
	Denbury Onshore, LLC Well No. 1 (Citronelle D-9-7 #2)						
	Citronelle Oil Field, Mobile County, Alabama						
Month	Year	Total MCF	Total Tonnes	Cumulative MCF	Cumulative Tonnes	Downtime (Hours)	Comments
August	2012	44,001	2,256	44,001	2,256	40	Inj start date 8/20/12
September	2012	175,630	9,007	219,631	11,263	135	Plant Barry shut down Sep 27
October	2012	160,789	7,874	380,420	19,137	286	Plant Barry compressor
November	2012	265,723	12,647	646,143	31,785	13	Pump maintenance & inj survey
December	2012	99,292	4,726	745,435	36,511	476	Unit 5 down at Plant Barry
January	2013	119,220	5,535	864,655	42,045	432	Unit 5 & capture down at Plant Barry
February	2013	190,746	7,792	1,055,401	49,837	169	Capture Unit down at Plant Barry
March	2013	0	0	1,055,401	49,837	96	Unit 5 down at Plant Barry
conversion factor - MCF to Tonnes			24.48	Based on the following			
for Current Month					1450	psi	
					66	deg F	
				which yields:	53.96	lbm/ft3	

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Elements of the MVA Program

- **Shallow MVA**
  - Groundwater sampling (USDW Monitoring)
  - Soil Flux
  - PFT Surveys
- **Deep MVA**
  - Reservoir Fluid sampling
  - Crosswell Seismic
  - Mechanical Integrity Test (MIT)
  - CO_2 Volume, Pressure, and Composition analysis
  - Injection, Temperature, and Spinner logs
  - Pulse Neutron Capture logs
  - Vertical Seismic Profile
- **MVA Experimental tools**

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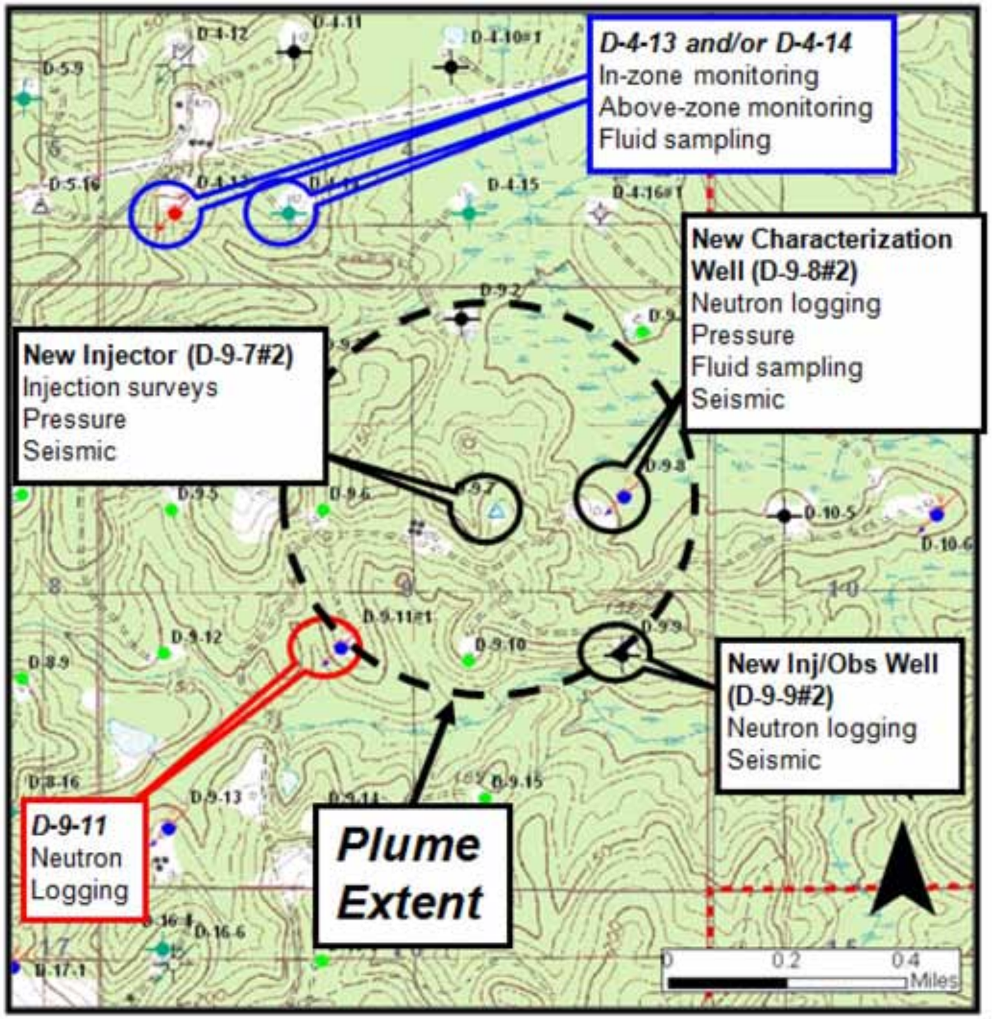
MVA Sample Locations



- One (1) Injector (D-9-7 #2)
- Two (2) deep Observation wells (D-9-8 #2 & D-9-9 #2)
- Two (2) in-zone Monitoring wells (D-4-13 & D-4-14)
- One (1) PNC logging well (D-9-11)
- Twelve (12) soil flux monitoring stations

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MVA Frequency

- **Shallow MVA**
  - Groundwater sampling (USDW Monitoring)
  - Soil Flux
  - PFT Surveys
- **Deep MVA**
  - Reservoir Fluid sampling
  - Crosswell Seismic
  - Mechanical Integrity Test (MIT)
  - CO_2 Volume, Pressure, and Composition analysis
  - Injection, Temperature, and Spinner logs
  - Pulse Neutron Capture logs
  - Vertical Seismic Profile
- **MVA Experimental tools**

Baseline	Injection	Post-injection
APR 2011 to AUG 2012	SEPT 2012 to SEPT 2014	OCT 2014 to SEPT 2017

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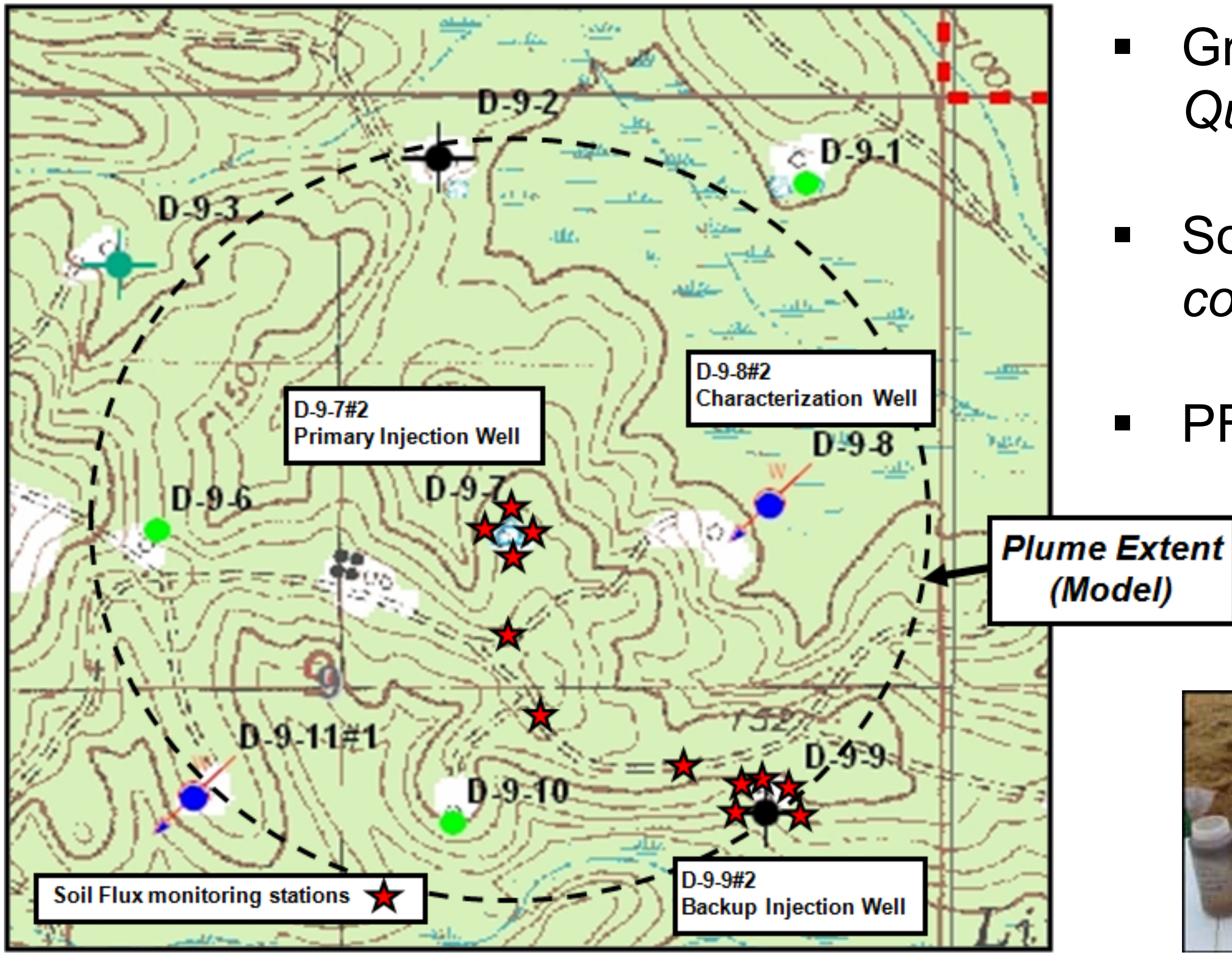
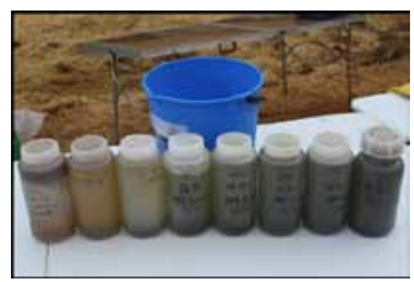
Shallow MVA



- Groundwater sampling – *Quarterly*
- Soil Flux sampling – *continuous*
- PFT Surveys – *annually*



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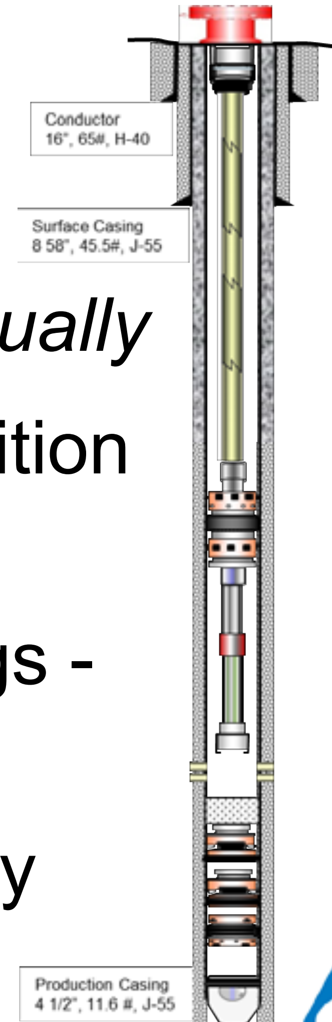
Deep MVA

- Reservoir Fluid sampling - *annually*
- Crosswell Seismic – *B/I/P-I*
- Mechanical Integrity Test (MIT) - *annually*
- CO_2 Volume, Pressure, and Composition analysis - *continuous*
- Injection, Temperature, & Spinner logs - *annually*
- Pulse Neutron Capture logs - annually
- Vertical Seismic Profile - *annually*



D 4-14 Observation Wellbore

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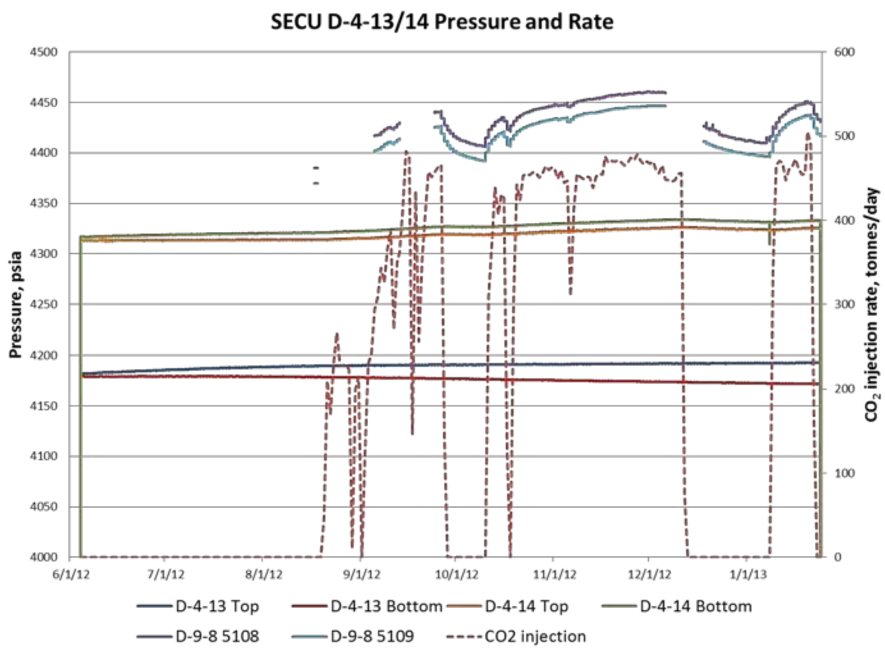
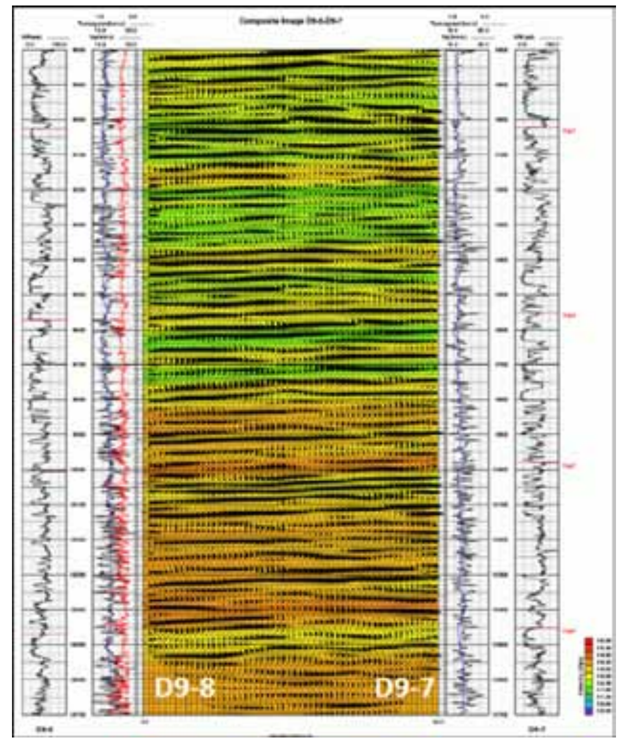
Key Results

- **Crosswell Seismic**
- **Reservoir Response**





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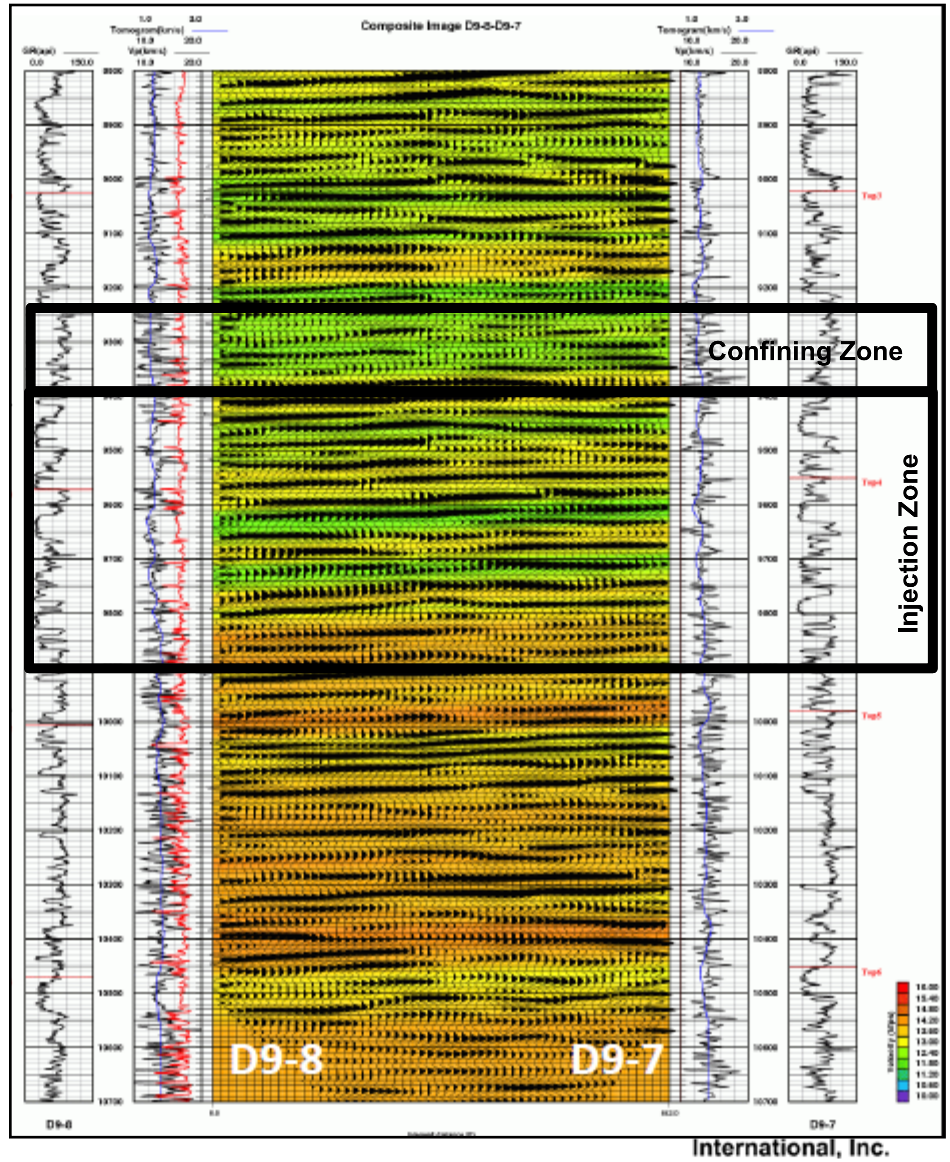
Seismic: Baseline Crosswell

Survey Parameters

- Source Type: Piezoelectric
- Receiver type: Hydrophone – 10 levels
- Source & Receiver interval: 10 feet
- Sweep length: 2.6 sec (record length 3 sec)
- Sweep: 100-1200 Hz
- Sample Rate: 0.25 ms
- Stack: 8

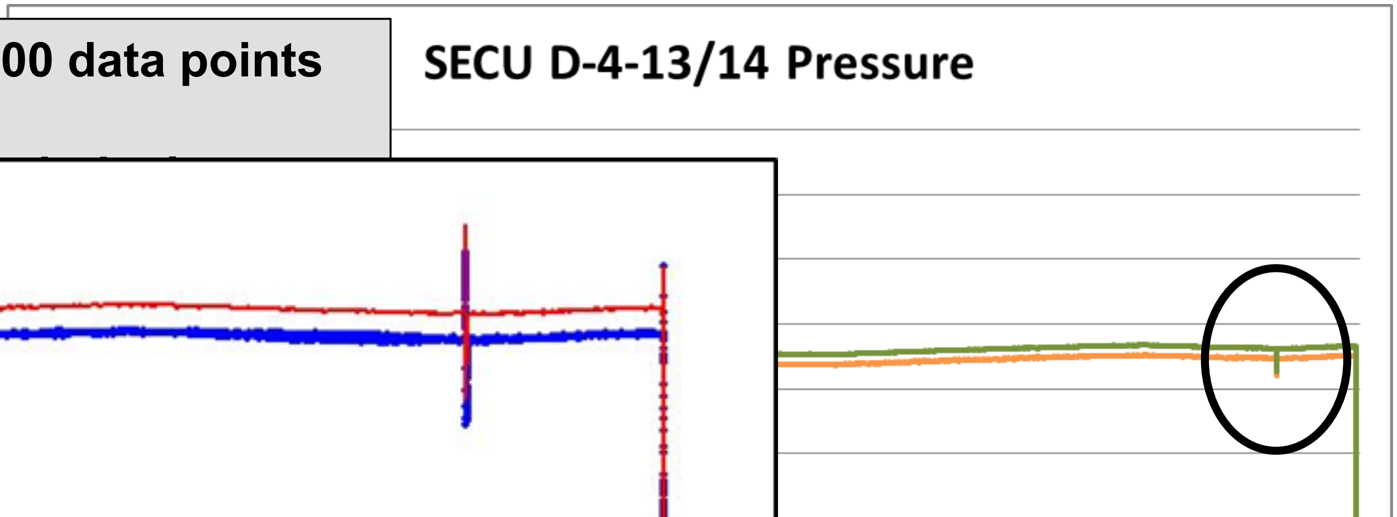
Survey Results

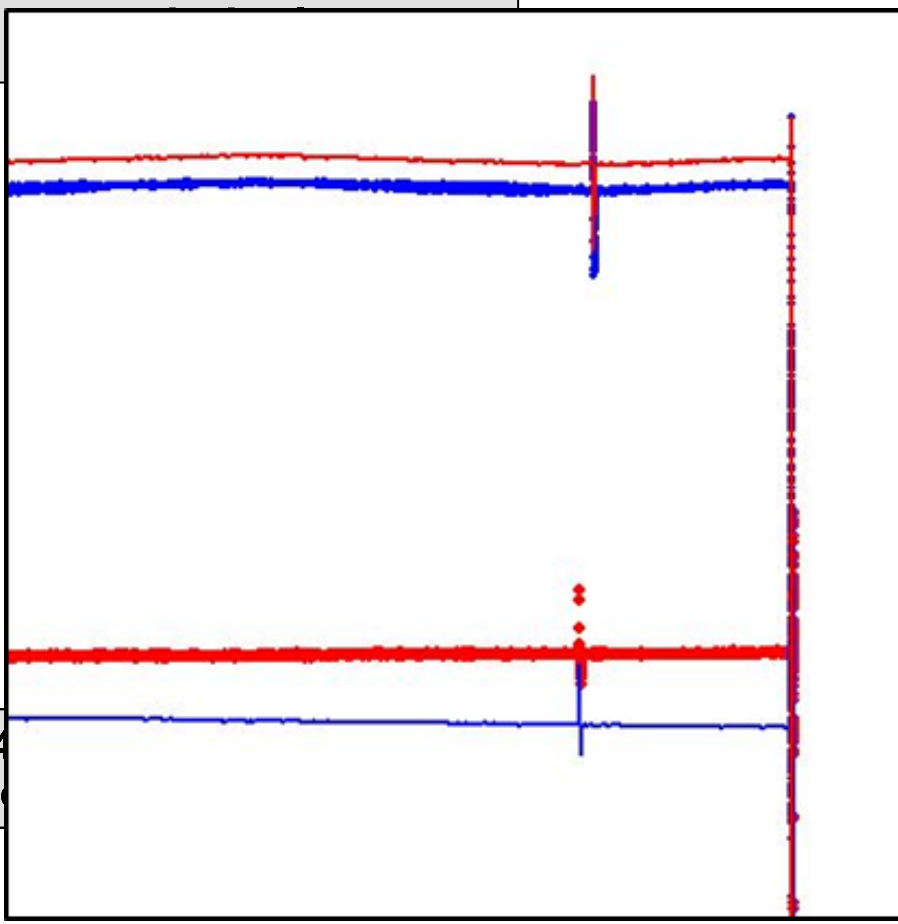
- High resolution image between injection well & observation well (~10 feet vertical resolution)
- No reservoir or confining unit discontinuities observed
- Good CO_2 confinement



D-4-13 & D-4-14 Pressure

- **630,000 data points**
-





D-4
re-

- 2nd anomoly in JAN 2012 across all 4 gauges
- Small pressure spike observed consistent with the MIT's
- Downhole pressure quickly stabilized to pre-test levels, indicating no residual effects & packer integrity.

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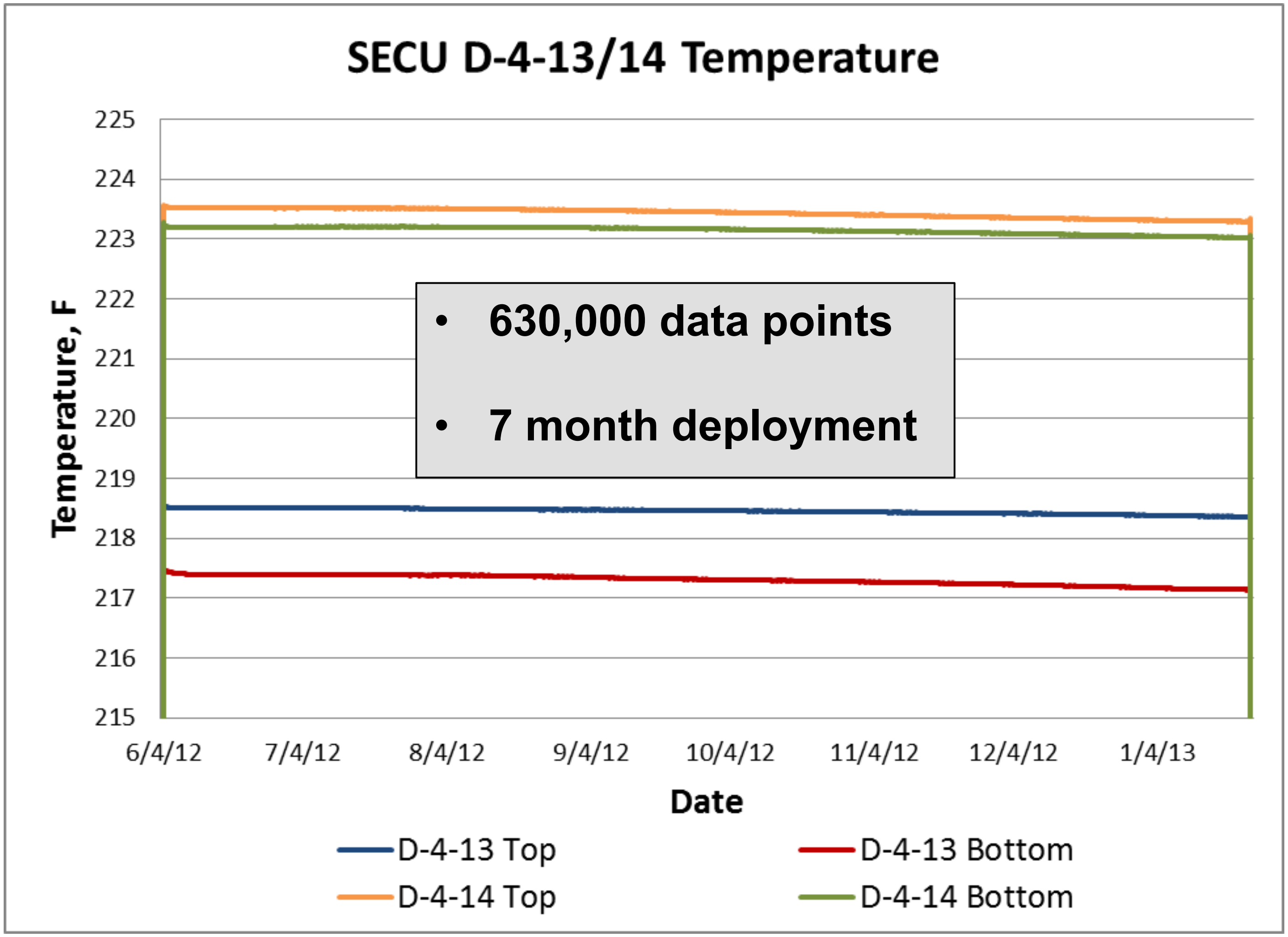
D-4-13 & D-4-14 Temperature



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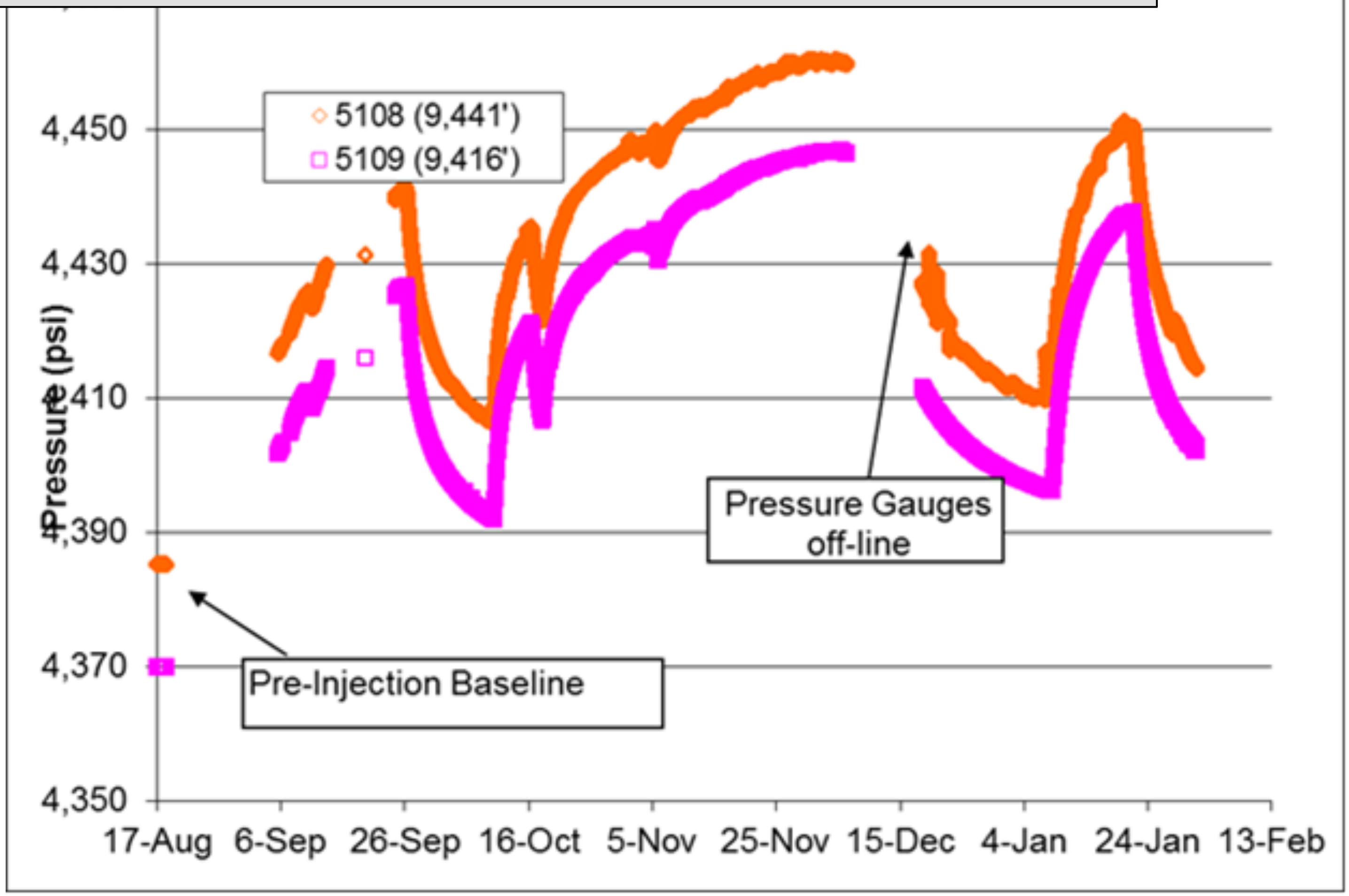
D-9-8#2 Downhole Pressure Gauge Data

- Consistent & expected pressure increases in zone
- At both 9,441 feet and at 9,416 feet



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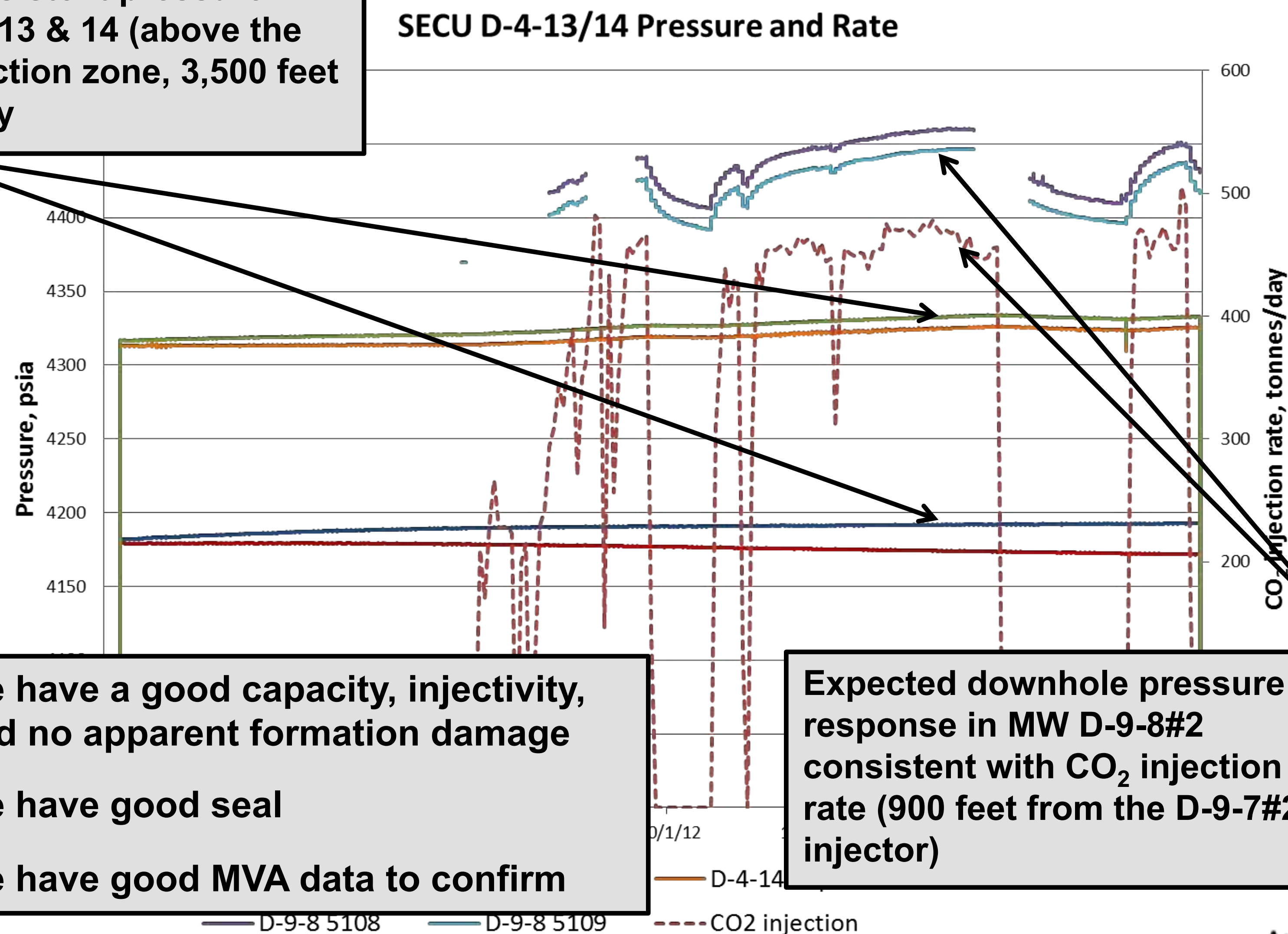
Pressure & Injection Rate Response

Consistent pressure in D-4-13 & 14 (above the injection zone, 3,500 feet away



- **We have a good capacity, injectivity, and no apparent formation damage**
- **We have good seal**
- **We have good MVA data to confirm**

Expected downhole pressure response in MW D-9-8#2 consistent with CO_2 injection rate (900 feet from the D-9-7#2 injector)

Advanced Resources International, Inc.

Thank you

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Advanced Resources
International, Inc.

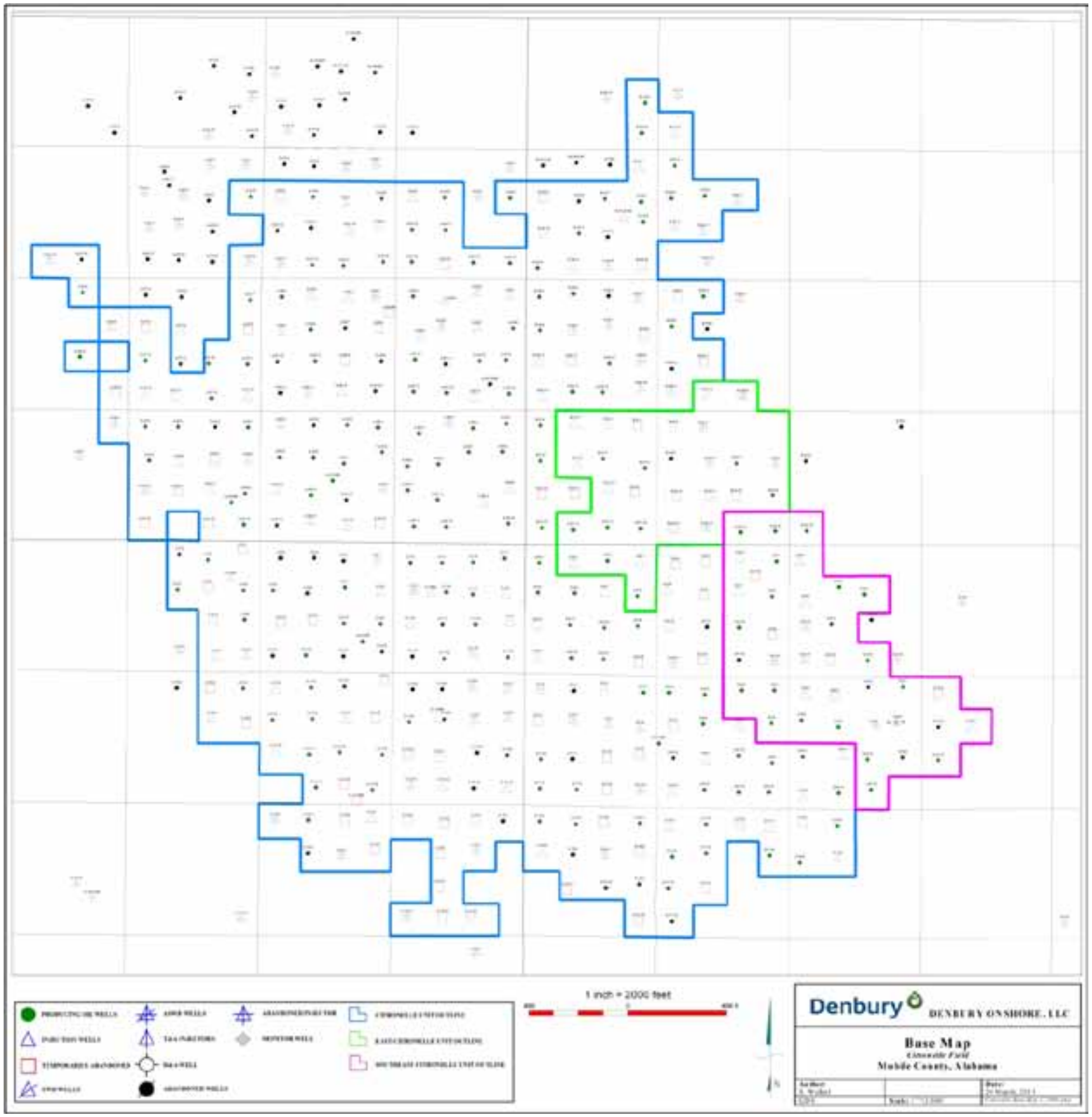
All Oil Companies Are Not Alike.

Denbury NYSE: DNR

SECARB – Plant Barry to Citronelle

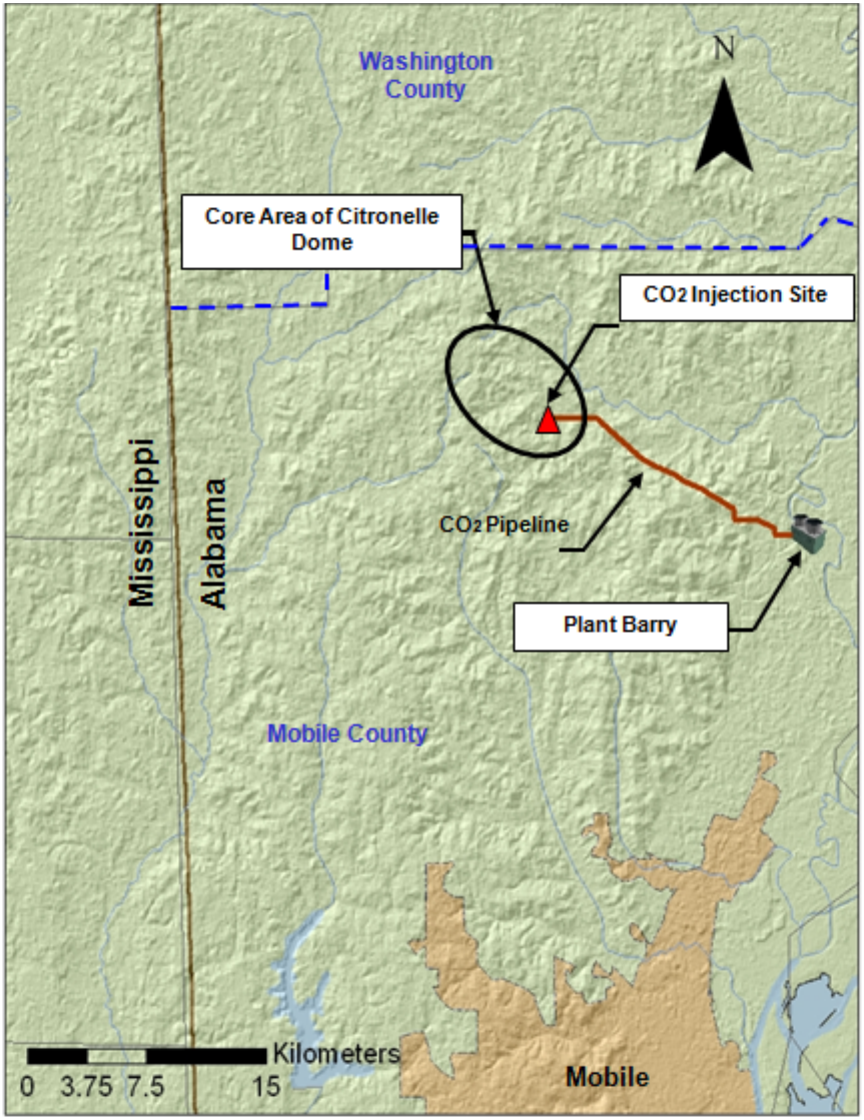
Stakeholder's Briefing - Atlanta - Mar 13, 2013

Citronelle Field – Basic Facts



- Citronelle Field located in & around the City of Citronelle
  - 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
  - 65 active injectors
  - 8 SWD wells
  - 88 TA/TP wells
  - 88 plugged
  - 5 SECARB
- Denbury took over operations on Feb. 1, 2006 from Merit Energy

SECARB Phase III Anthropogenic Test - Schedule



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 confirmed geology. Injection wells were drilled in 4Q 2011.

1st injection on Aug 20, 2012. Thru Feb 2013, have injected over 1 BCF or 50,800 metric tons.

100 to 300 thousand metric tons of CO_2 will be injected into a saline formation over 2 to 3 years beginning in 3Q 2012.

3 years of post-injection monitoring.

CO_2 Pipeline Right-of-Way

- Approx. 12 mi (19 km) to the SE Citronelle Unit in Citronelle Oil Field
- Right-of-Way
  - 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 commerical timber land
  - 3 mi (5 km) of emergent, shrub and forested wetlands
  - Endangered Gopher Tortoise habitat
    - 110 burrows in or adjacent to construction area
- Directional drilled 18 sections of the pipeline under roads, utilities, railroad tracks, tortoise colonies, and wetlands. (30 to 60 ft deep).
- Trenched remaining sections.

CO_2 Pipeline and Measurement Design

- 4-inch (10 cm) pipe diameter
- X42/52 carbon steel pipe
- MOP – 2,220 psig (flange limitation)
- Normal operating pressure: 1,500 psig (10.3 MPa) maximum
- Buried average of 5 ft (1.5 m) with surface re-vegetation and erosion control

Handling pipe for horizontal directional drill

CO_2 Pipeline and Measurement Design

- Denbury pipeline purity requirement is:
  - > 97% dry CO_2 at 115ºF (46ºC)
  - < 0.5% inerts (incl. N_2 & argon)
  - < 30 lb water per 1MMSCF
  - < 20 ppm H_2S
- A *Daniel* model 500 gas chromatograph is located at the pipeline metering and custody transfer station & continuously samples the gas leaving Plant Barry. Used for trace contaminant monitoring, pipeline integrity, or product quality / process control.

Custody meter station and building

Field-mount Gas Chromatograph

2012-13 Injection Stream Monitoring Results

(Percent by Volume).

	Sep	Oct	Nov	Dec	Jan
CO_2	99.979%	99.984%	99.984%	99.981%	99.977%
N_2	0.011%	0.002%	0.002%	0.003%	0.020%
O_2	0.010%	0.014%	0.014%	0.016%	0.003%

CO_2 Pipeline and Measurement Design

Mainline valve station & CP test station

Check meter station & building at Denbury Citronelle Field

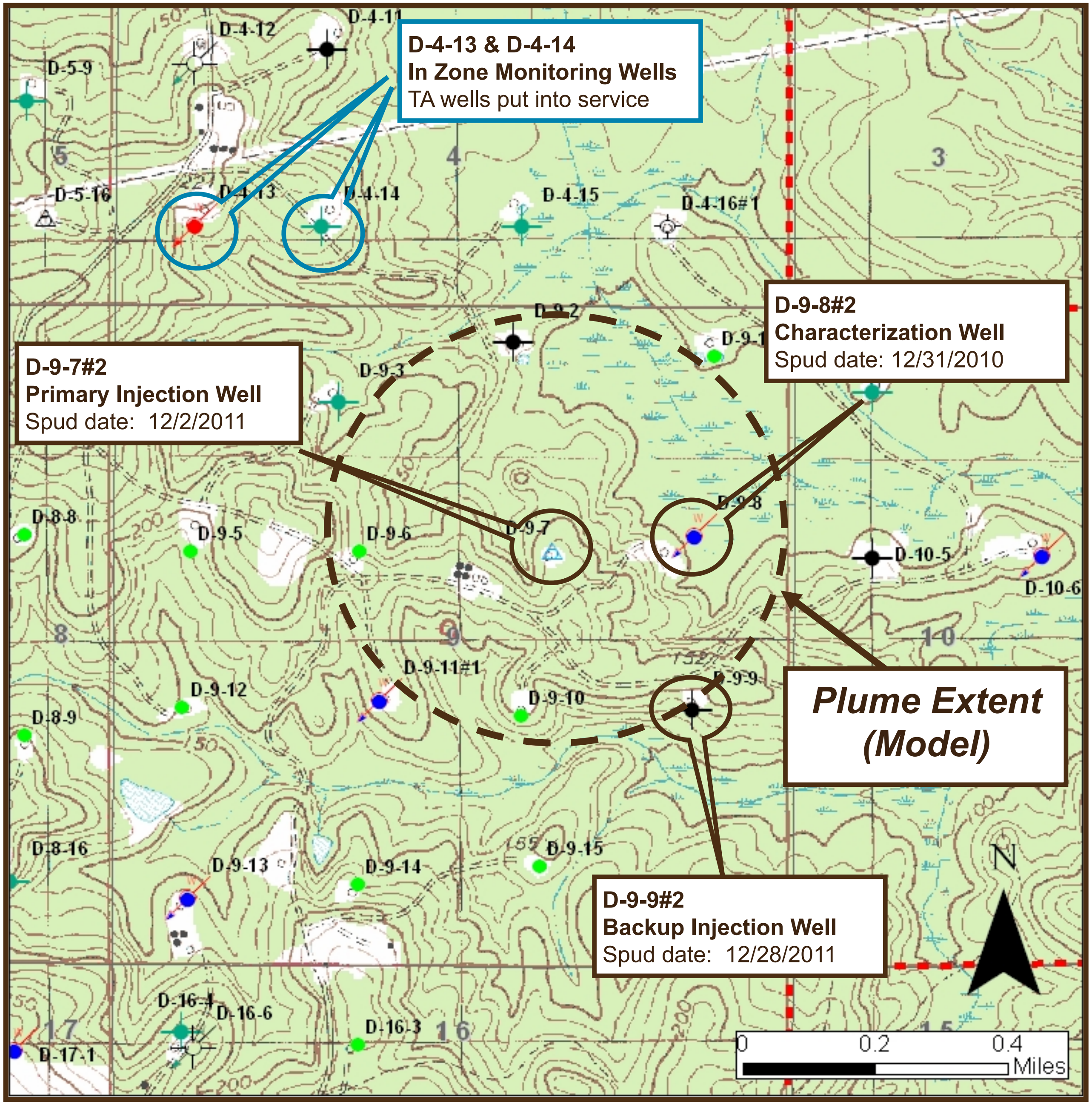
Check meter station to horizontal pump

Discharge side of horizontal pump

CO_2 Pipeline and Measurement Design

- Horizontal CO_2 Booster Pump @ D-9-7 #2 Wellsite
  - Designed & fabricated by Wood Group (GE)
  - 130 stages (impellers) / 44 ¾ ft long / 4” suction – 3” discharge
  - 300 HP electric motor – 3570 rpm w/ variable speed drive
  - Pneumatic shut downs (2), pneumatic control valves (2), manual shut down valves (2), vibration shut down switch (1), manual blow down valves (2), discharge check valve (1)
  - Inlet pressure 1300 psi – outlet pressure 3200 psi
  - Variable speed drive with recycle valve for near 100% turndown
  - Max rate approx. 14 MMCFD CO_2
  - Satellite link for communication
    - 2 pressure transmitters & 2 temperature transmitters
  - Stand alone air compressor system to operate valves & controls

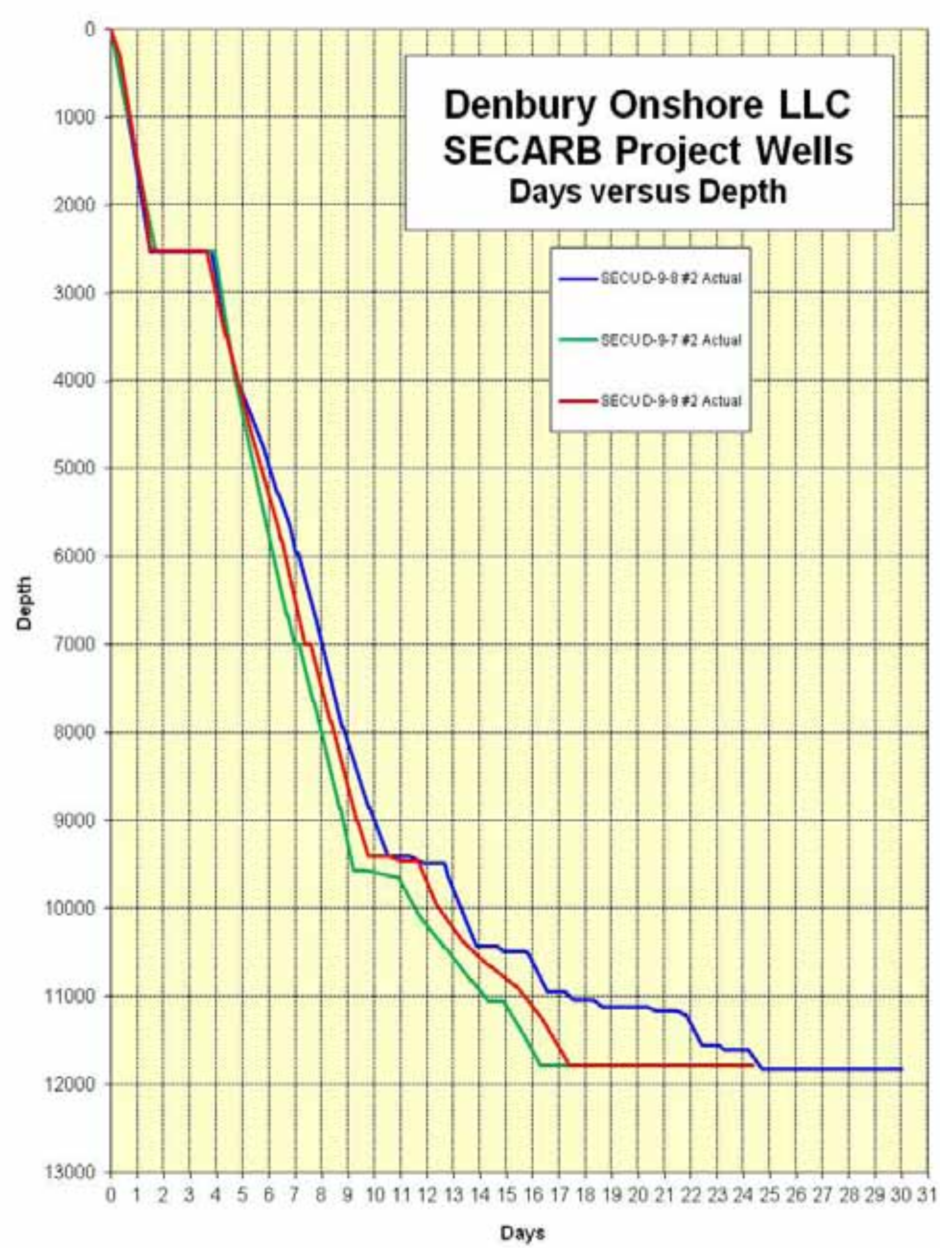
Deep Monitoring Activities



The 5 Wells Dedicated to the Project

- New wells - drilling order:
  - D-9-8 #2 characterization well
  - D-9-7 #2 primary injection well
  - D-9-9 #2 auxiliary injection well
- All 3 wells drilled to 11,800 ft.
- The distance from the D-9-7 #2 injector to the D-9-8 #2 observation well is only 825 ft.
- 2 SE Unit wells were converted from TA to be in & above zone monitoring wells:
  - D-4-13 perforated in the Tuscaloosa (above zone monitoring)
  - D-4-14 perforated in the Paluxy (in zone monitoring)

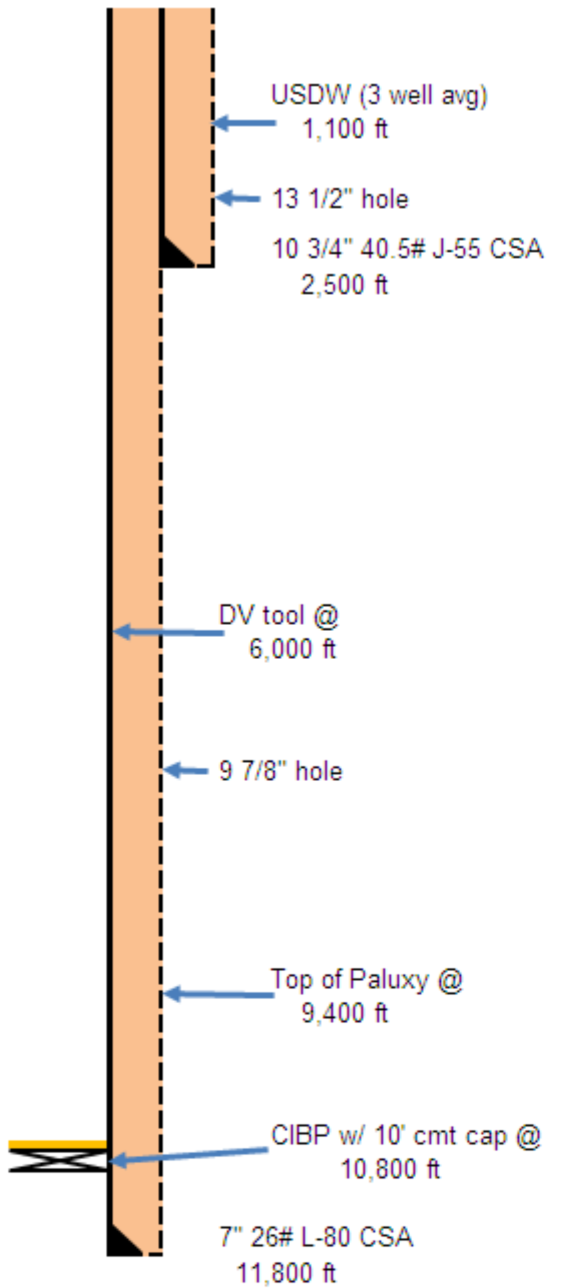
Drilling Time Curves



Wells Drilled for the Project

- All 3 wells drilled to same specifications except for coring program
- Closed loop mud system used on 2 of 3 wells
- Typical mud weight 9.2 to 9.5
- Typical Ph 9.5 to 10.0
- Projected drilling days on AFE
  - D-9-8 #2 = 41 days (30 days)
  - D-9-7 #2 = 33 days (22 days)
  - D-9-9 #2 = 33 days (25 days)
- Cores taken in Upper Paluxy for all 3 wells
- D-9-8 #2 had additional cores in lower Paluxy & upper & lower Donovan
- Deviation 1° or less on all wells
- Cost to drill & complete (less MBM) ranged from $2,200,000 to $2,400,000

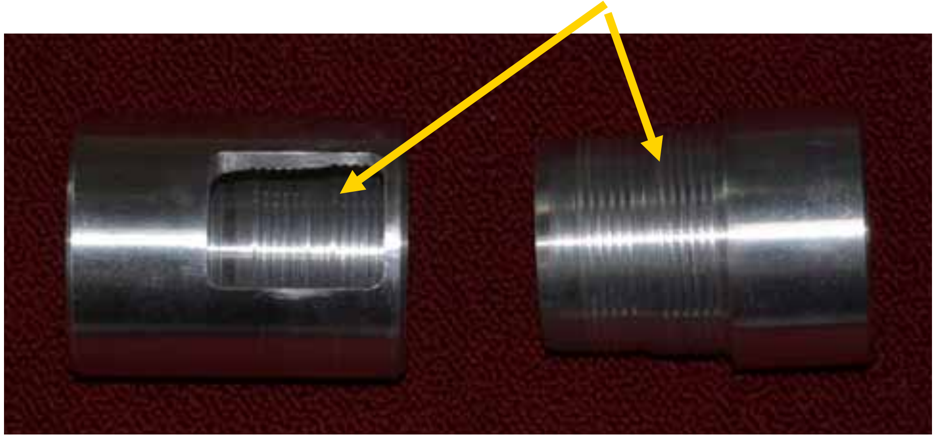
Wellbore Schematic



- The casing program for all 3 wells was identical
- Surface casing:
  - Drilled with 13 1/2" bit to 2500 ft
  - Set 10¾" casing & circulated cement to surface (D-9-7 #2)
    - Lead slurry = 805 sacks 35/65 Poz w/ yield of 1.81 ft^3/sack
    - Tail slurry = 320 sacks Type 1 cement w/ yield of 1.21 ft^3/sack
- Production casing:
  - Drilled with 9 7/8" bit to 11,800 ft
  - Set 7" casing with DV tool @ 6000 ft & circulated cement to surface (D-9-7 #2)
    - Spacer of Mud Clean II followed with a preflush of Sealbond
    - Lead slurry = 715 sacks 35/65 Poz w/ yield of 1.62 ft^3/sack
    - Tail slurry = 805 sacks Class H cement w/ yield of 1.43 ft^3/sack
    - Open DV tool, pump fresh water spacer followed with Sealbond preflush
    - Pumped 1515 sacks 35/65 Poz w/ yield of 1.62 ft^3/sack

Initial Completion

Tapered threads of RTS-8 connection

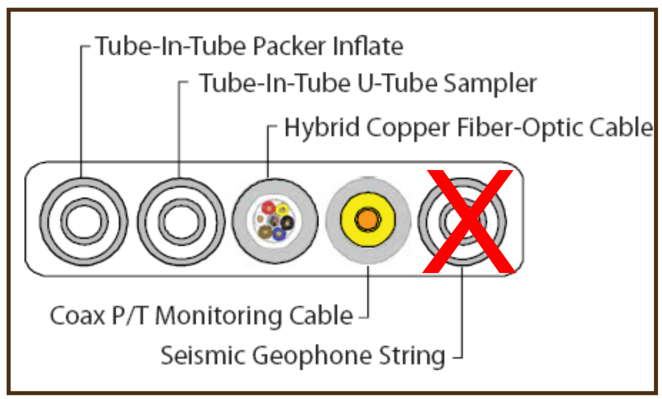


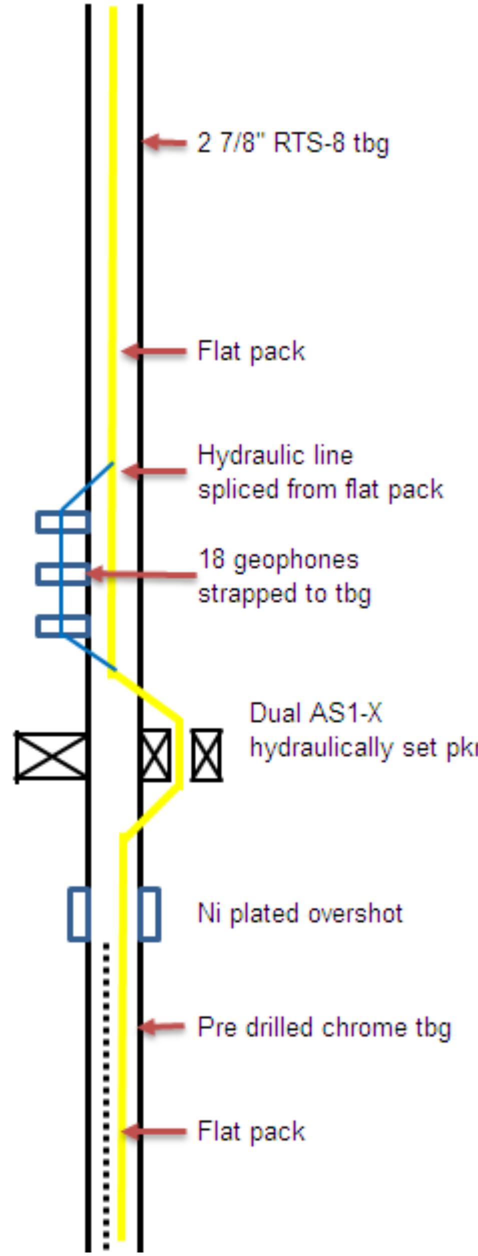
D-9-7 #2 Wellhead w/ Injection Line

- Casing was pressure tested to 1000 psi
- A bit & scraper was run to drill out the DV tool & any cement that may be on top of it.
- Continued in hole with bit & scraper to top of float collar near TD.
- Hole was left empty & rig was moved off.
- Rigs moved back in on both D-9-7 #2 & D-9-8 #2 for perforation & completion
- Perforations
  - D-9-7 #2 injector perfed 130' @ 2 spf
  - D-9-8 #2 obs well perfed 30' @ 2 spf
- Tubing
  - Basic tbg 2 7/8" 6.5 #/ft RTS-8 threads & coated w/ TK805 (rated to 300º F
- Packers
  - D-9-7 #2 Ni plated AS1-X ret
  - D-9-8 #2 Ni plated dual AS1-X ret
- Wellhead & Tree
  - Manufactured by GE
  - 9-5/8 x 5-1/2 x 2 7/8 5M

D-9-8 #2 MBM (Modular Borehole Monitoring) Deployment

Flat Pack
Weight = 1.089 #/ft
Total weight to packer depth of 9400 ft = 10,240 #'s





SECARB Awards

Anthropogenic Test

Richard Rhudy

Technical Executive

SECARB Annual Stakeholder's Briefing

March 4, 2014

Recent Awards

- Carbon Sequestration Leadership Forum (CSLF) endorsement of the anthropogenic project
  - The SECARB Anthropogenic Test is the largest pilot project of a fully-integrated pulverized coal-fired CCS project in the United States to date, pulling together components of capture, transportation, subsurface storage, and monitoring, verification, and accounting
  - As a first-of-its-kind project, this test will be very important for understanding the challenges power plant capture can present to the emerging field of geologic CO_2 storage
- Favorable review of the project by the IEAGHG Program
  - These included good co-operation between multiple parties in the public and private sectors and between different private entities, including a power plant operator, pipeline operator and the storage team.
  - This strong multi-party collaboration meant the project team had to handle a complex commercial arrangement to co-ordinate a fully integrated CCS chain.
- Entry of the project into the State of Alabama Engineering Hall of Fame
  - 25 Megawatt Carbon Capture and Storage Demonstration
- Chairman's Award from the Southeastern Electric Exchange 2014 Industry Excellence Awards Program
  - Non-profit, non-political trade association of investor owned electric utilities
  - Southern Company 25-Megawatt Carbon Capture Demonstration

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Advanced Monitoring Technologies SECARB Phase III CO_2 Storage Citronelle, Alabama

Rob Trautz, George Koperna, Steve Carpenter, and Dick Rhudy

SECARB Annual Business Meeting
March 4, 2014

Advance Monitoring Methods are Needed for Carbon Capture and Storage Projects

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

Goal: Develop a rugged, cost effective, modular, multi-sensor monitoring platform designed for a single-well

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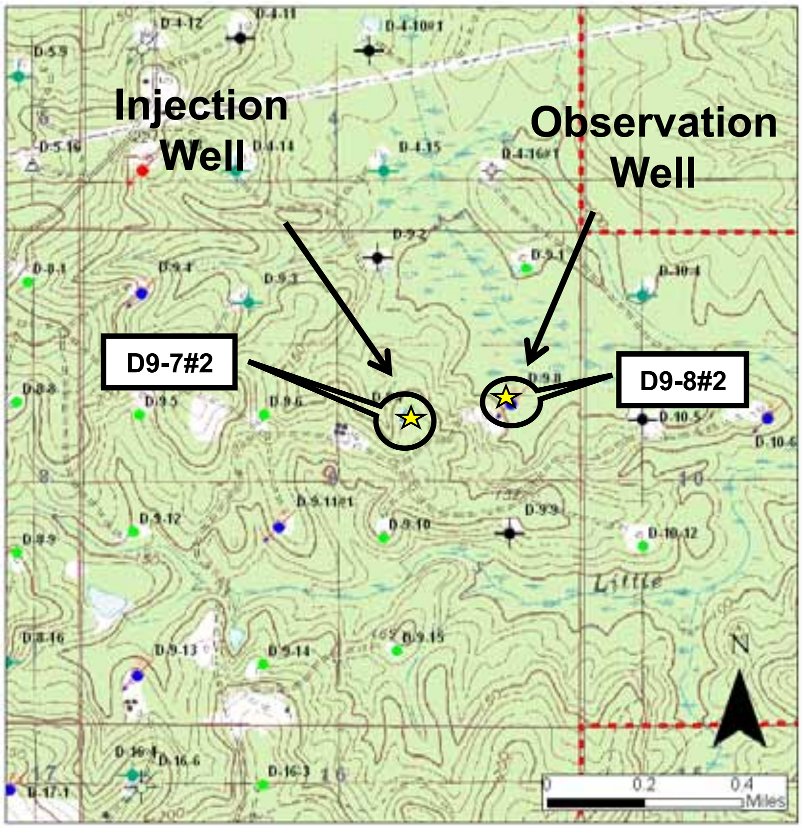
R&D Effort is Focused on Deployment of the Modular Borehole Monitoring (MBM) System in Observation Well (D9-8#2)



CO_2 injection well D9-7#2 and observation well D9-8#2

- Characterization well (D9-8#2) is:
  - ~850 ft east of the CO_2 injection well (D9-7)
  - Perforated at a depth of 9,394-9,424 ft (30 ft)
  - Completed in the upper-most sand in the Paluxy Formation

MBM System Sensor Configuration

- 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

Geophone pod and clamping assembly

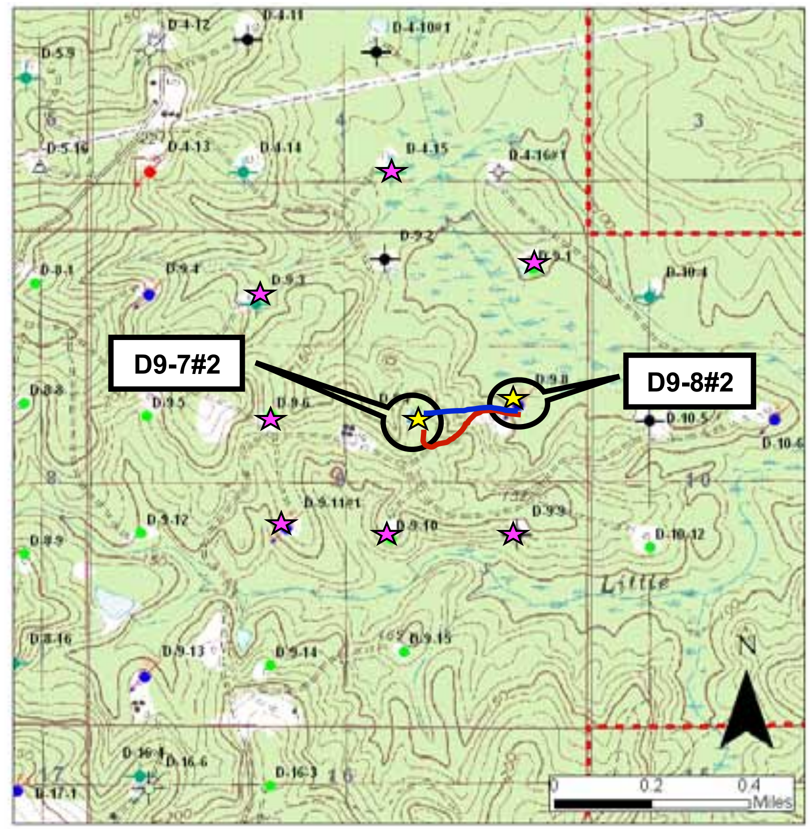
Cost Effective MBM Deployment

- Flat pack reduced run-in time & cost
- Unique bottom hole assembly (9,384 – 9,797 ft) simplified installation
  - Hydroset II packer
  - Overshot
  - Slotted tail pipe (structural support for DTS and heater)

1. Hydroset packer; 2. flat pack and control lines; 3. old deployment method with multiple spools; 4. newer, cleaner deployment with flat pack

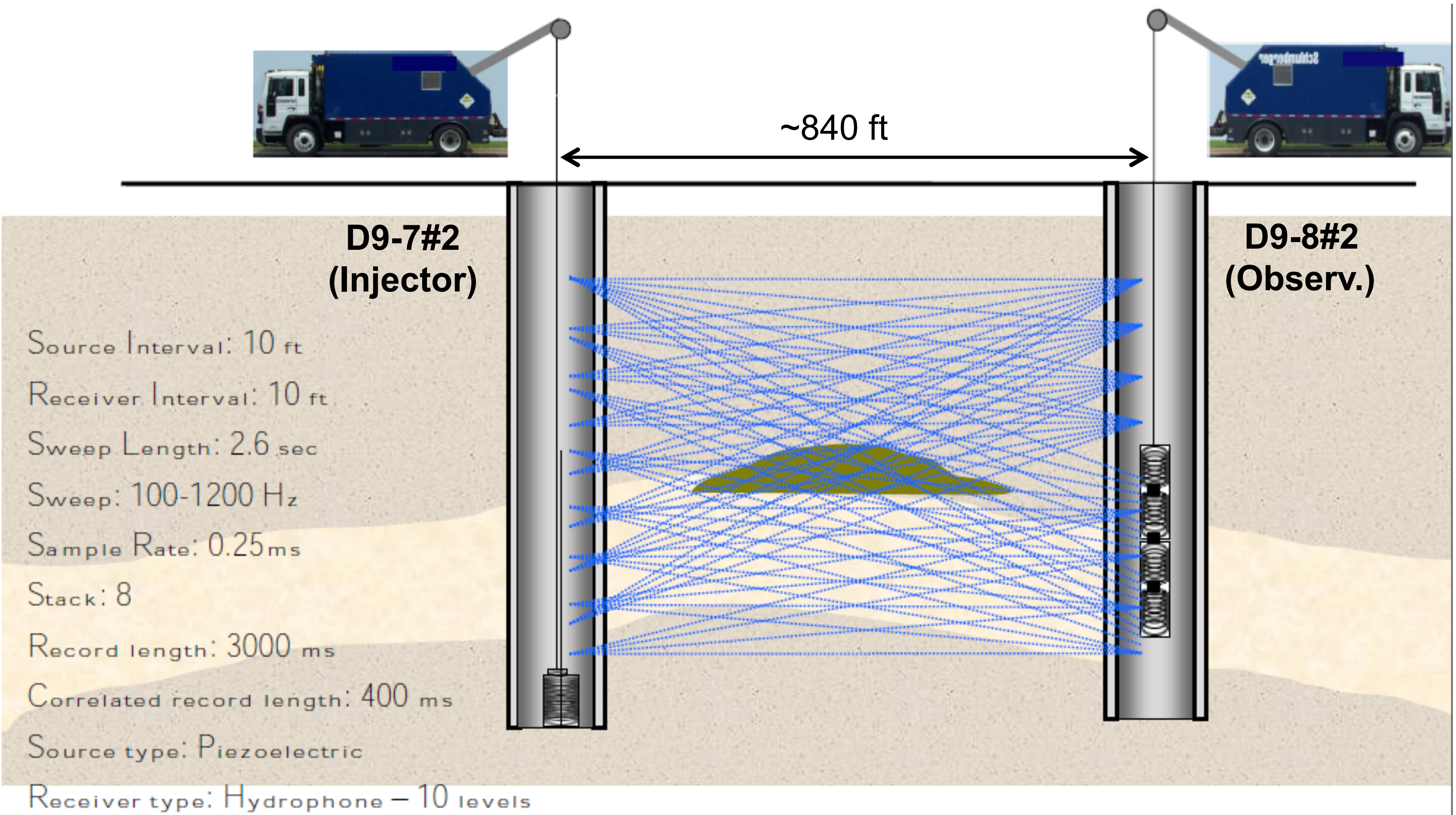
Citronelle Offers a Unique Opportunity to Compare Seismic Methods to Monitor CO_2 Plume Location

- Seismic surveys deployed at Citronelle include:
  - Cross-well seismic surveys
  - Offset vertical seismic profile (VSP) surveys using
  - Walk away VSPs
- Seismic Sources and Receivers
  - Mertz 35 vibrator
  - 80-level (long) geophone array deployed in the injector (D9-7#2) and observation well (D9-8#2)
  - 18-level (short) geophone MBM array in D9-8#2
  - Fiber-optic distributed acoustic sensor (DAS) array



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

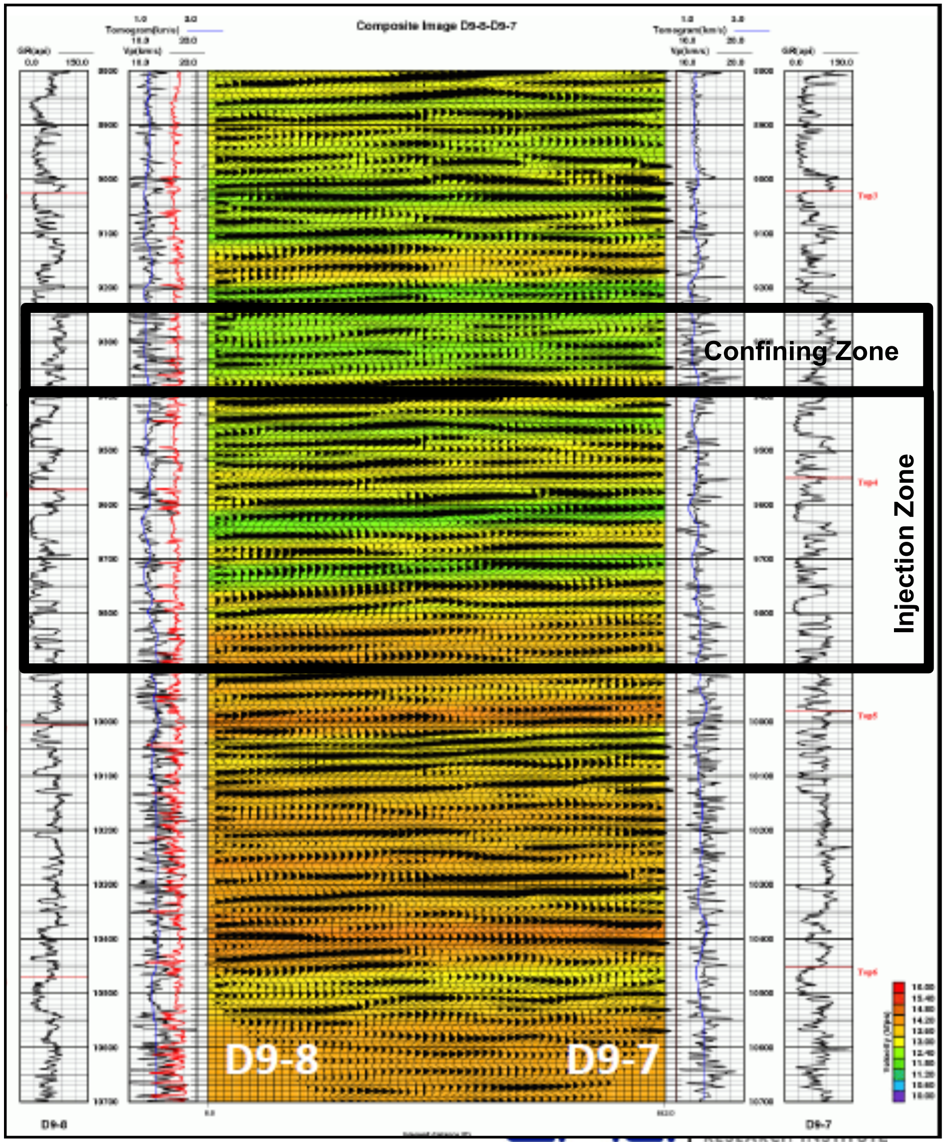
Cross-Well Seismic Survey Configuration (Baseline Jan. 2012)



Source Interval: 10 ft
Receiver Interval: 10 ft
Sweep Length: 2.6 sec
Sweep: 100-1200 Hz
Sample Rate: 0.25ms
Stack: 8
Record length: 3000 ms
Correlated record length: 400 ms
Source type: Piezoelectric
Receiver type: Hydrophone – 10 levels

Cross-Well Seismic Survey Results (Baseline Jan. 2012)

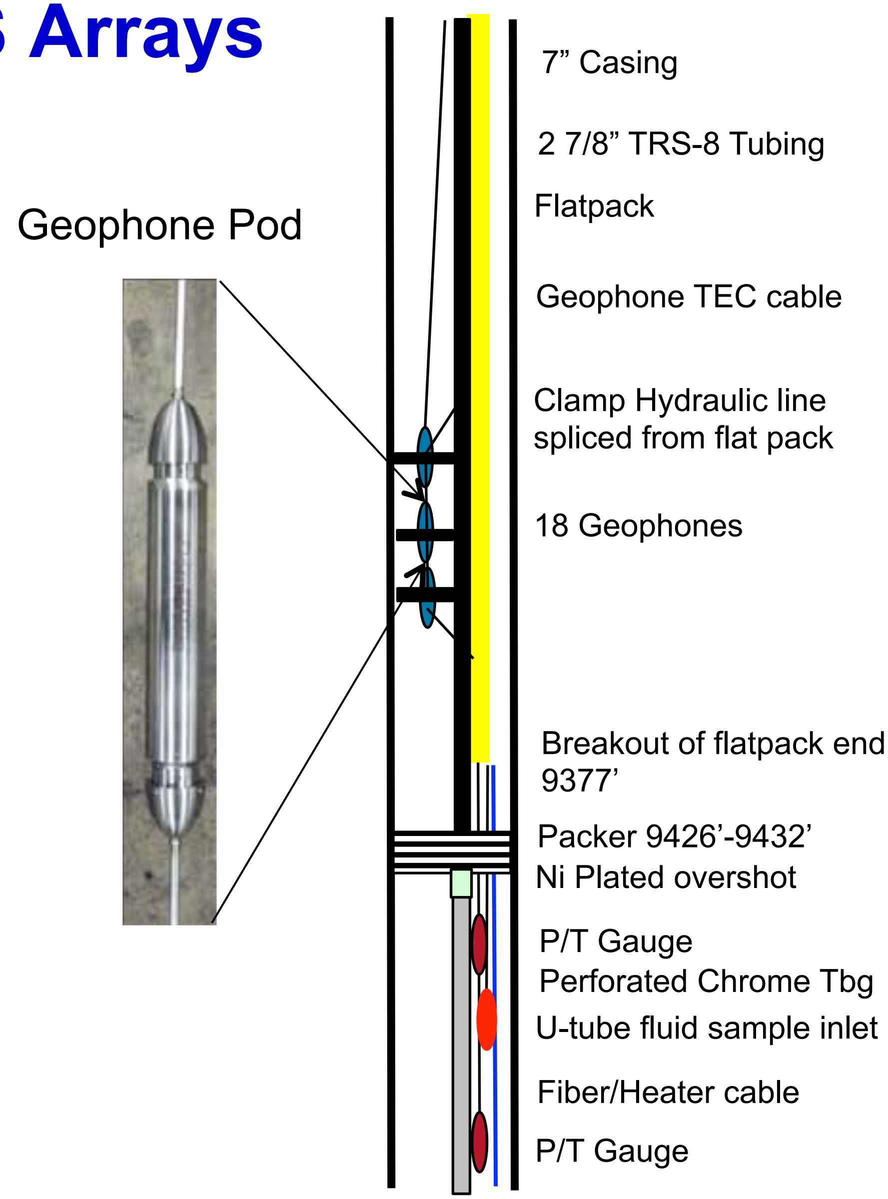
- High resolution image between injection well & observation well (~10 feet vertical resolution)
- No reservoir or confining unit discontinuities observed
- Expect good CO_2 confinement



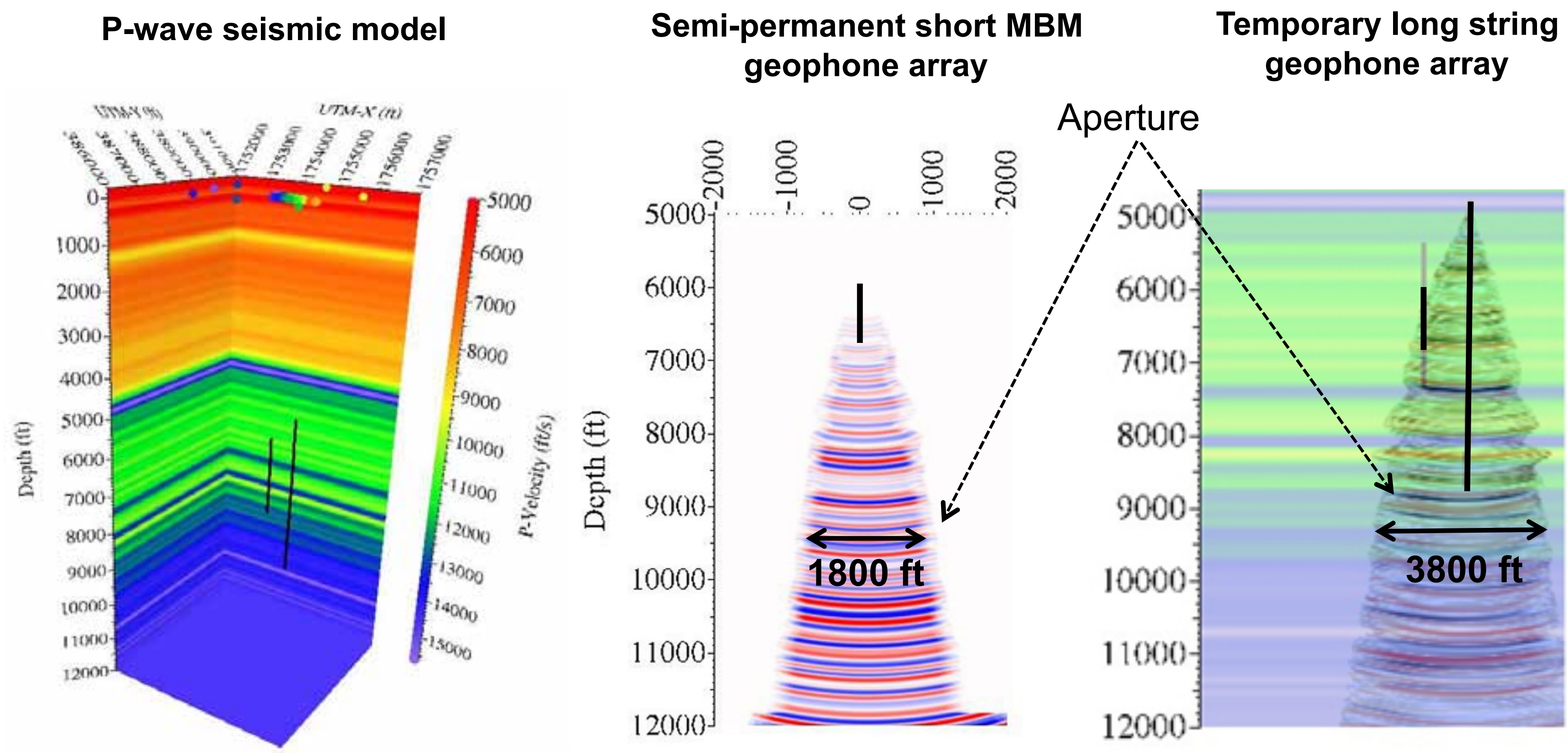
Vertical Seismic Profile (VSP) Surveys using the MBM Geophone and DAS Arrays

- MBM Receivers: 18 geophone pods
  - 3 x,y,z component geophones (top, mid and bottom)
  - 15 vertical component phones
  - Hydraulically clamped to casing
- Over 3,100 DAS “receivers”

Photo courtesy of D. Miller, Silixa



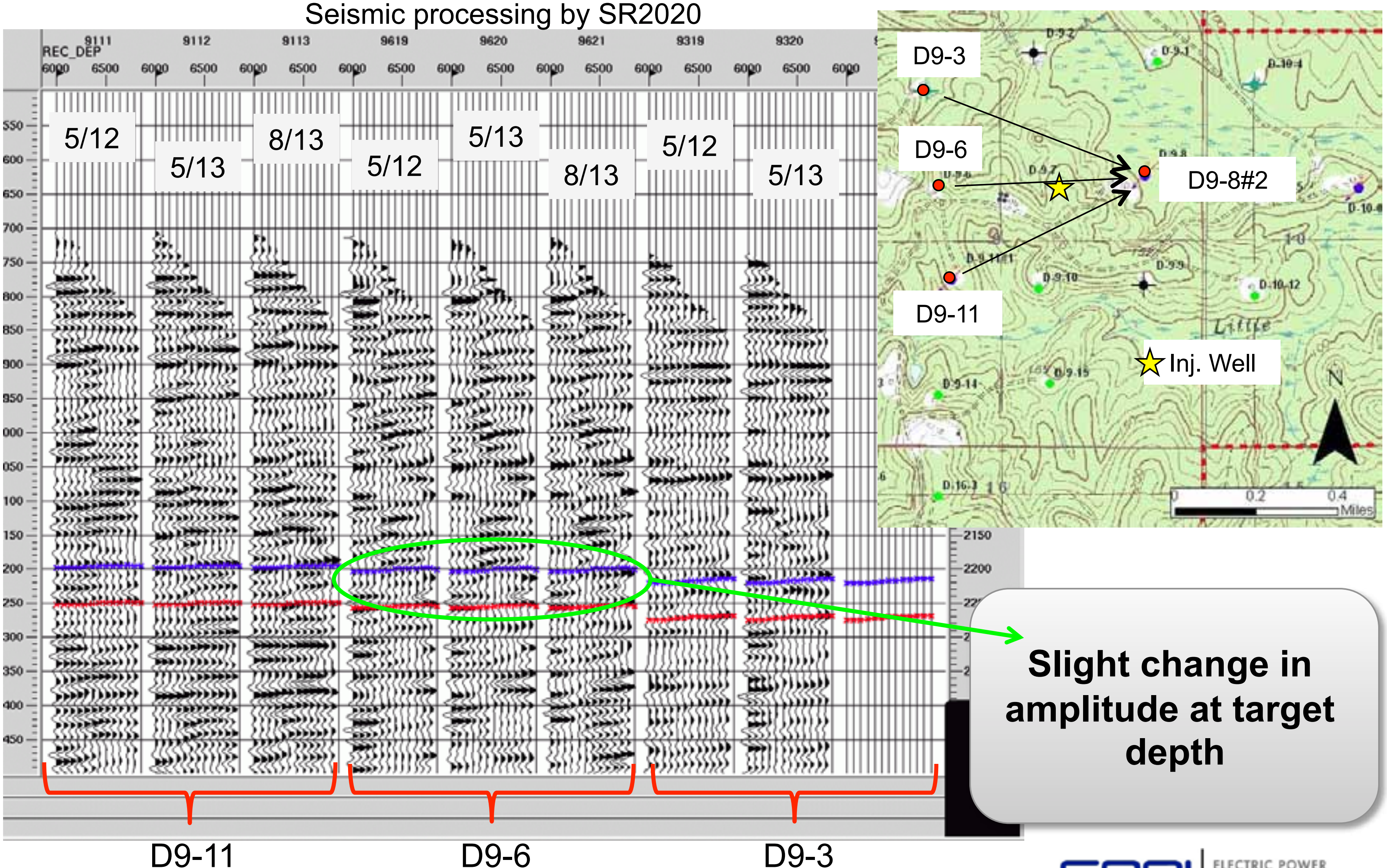
Comparison of Baseline VSP Surveys using the Long Array and Shorter MBM Array



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

Time Lapse Comparison of Baseline (5-2012) to May and August 2013 VSP Surveys using MBM

Seismic processing by SR2020



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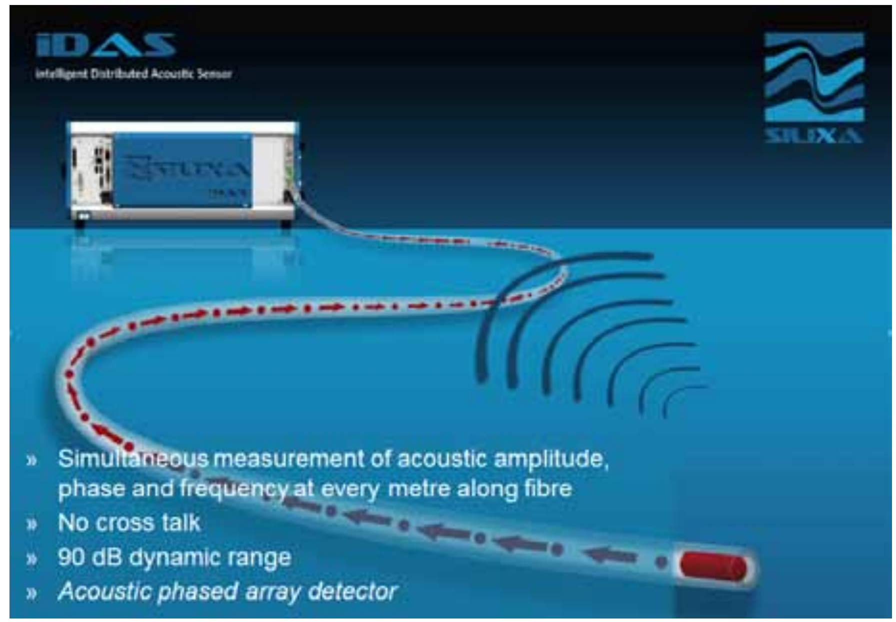
Distributed Acoustic Sensing (DAS)

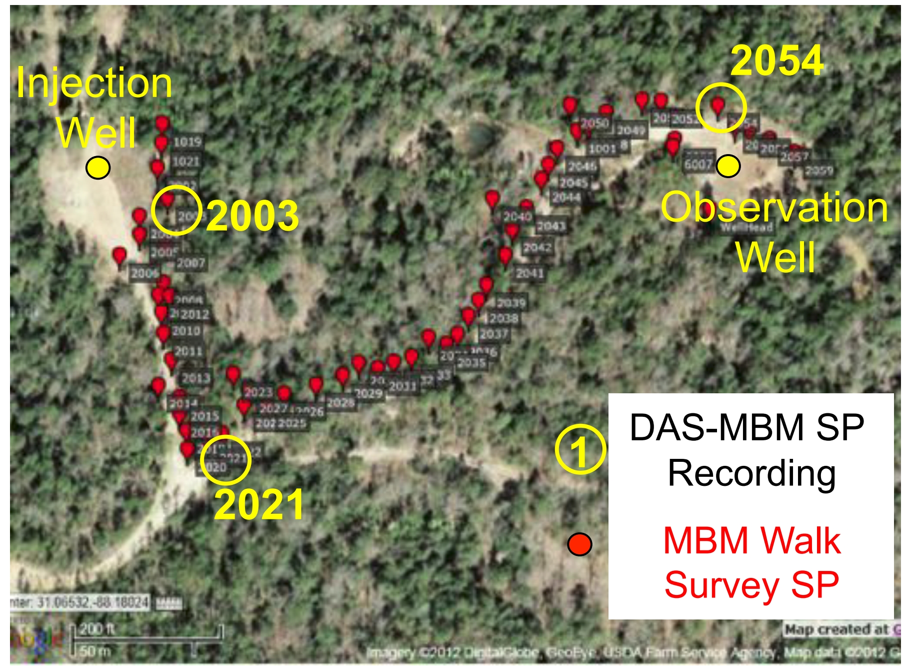
- Light emitted into a fiber is reflected throughout the fiber's length by Rayleigh scattering
- DAS system measures the modulation of the backscattered light
- An acoustic field around the fiber exerts tiny pressure/strain changes on the fiber, resulting in changes to the backscattered light
- The DAS measures these changes by generating a repeated light pulse every 100 μs and continuously processing the returned optical signal, thus interrogating each meter of fiber up to 10 km in length at a 10 kHz sample rate
- Unlike other methods, the system records the full acoustic signal, including amplitude and phase



A 10 km single mode fiber becomes a high density acoustic array with 10,000 linear sensors with 1 m spatial resolution!

VSP Walkaway Surveys Were Performed in June 2012 and August 2013

- Walkaway surveys provide detailed coverage between the injection & observation wells
- Source: vibroseis truck
  - ~60 shot points
  - 4–6 sweeps per location
  - Sweep duration: 16 s, recording 4 s
  - Sweep frequency range: 10–160 Hz
- Simultaneous recording of receivers:
  - 18-level MBM geophone array in D9-8#2
  - DAS in D9-8#2



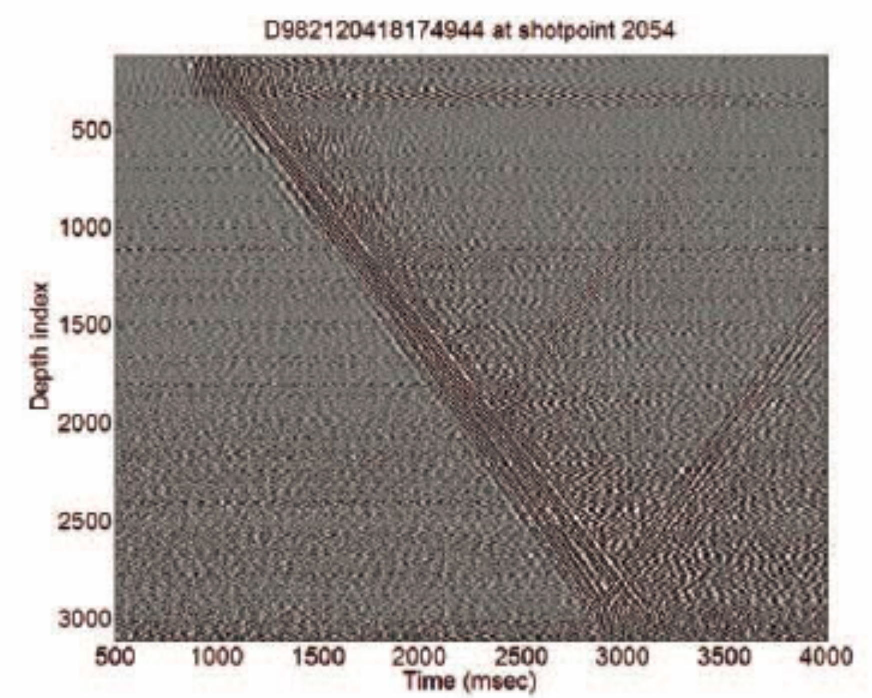
Map showing position of the individual shot points (red dots) for walkaway VSP 2012

SECARB Southeast Regional Carbon Sequestration Partnership

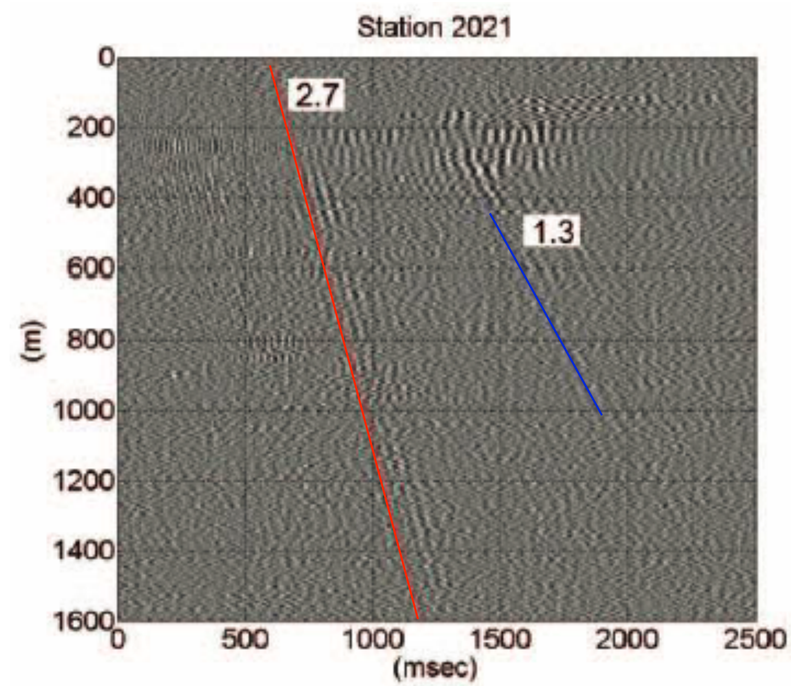
CO_2 Capture Project

June 2012 DAS Results

T. Daley et al., "Field testing of fiber optic acoustic sensing (DAS) for subsurface seismic monitoring," The Leading Edge, June 2013



SP 2054 located ~100 ft offset from the D-9-8 sensor borehole. Observed two tube waves.

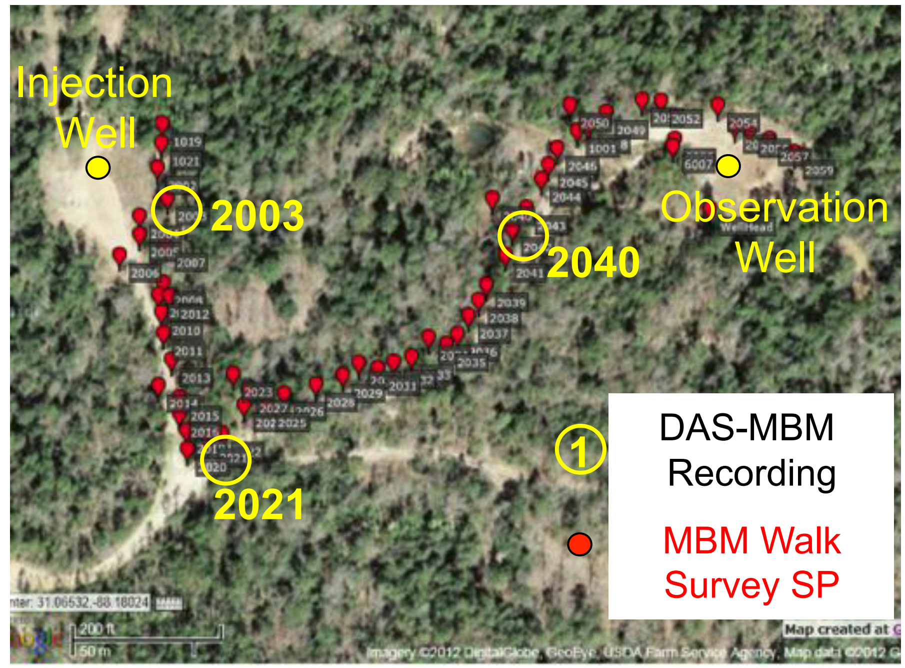


SP 2021 located ~700 ft offset from the D-9-8 sensor borehole. Estimated wave speeds for two events (red and blue lines) are labeled in km/s.

Seismic energy was recorded by DAS but the signal-to-noise ratio (SNR) was not sufficient to observe P-waves below approximately 1600 m (i.e., 2.7 km/s event)

Recorded Simultaneous Response of the MBM Geophones and DAS at 3 Walkaway Stations in August 2013

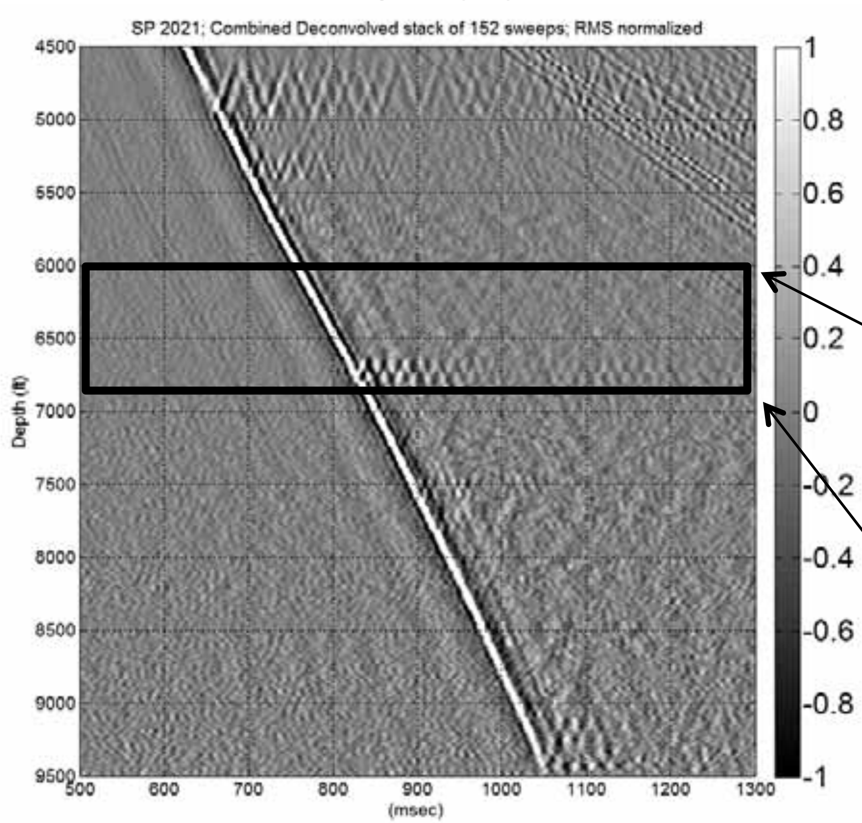
- Purpose: Try to improve the DAS signal by acquiring stacked data
- Source: vibroseis truck
  - 3 shot locations
  - 128 sweeps per location
- Receivers:
  - 18-level MBM geophone array in D9-8#2
  - DAS in D9-8#2



Map showing the shot locations (yellow circles) where seismic data were simultaneously recorded using both the MBM geophones and DAS installed in the observation well

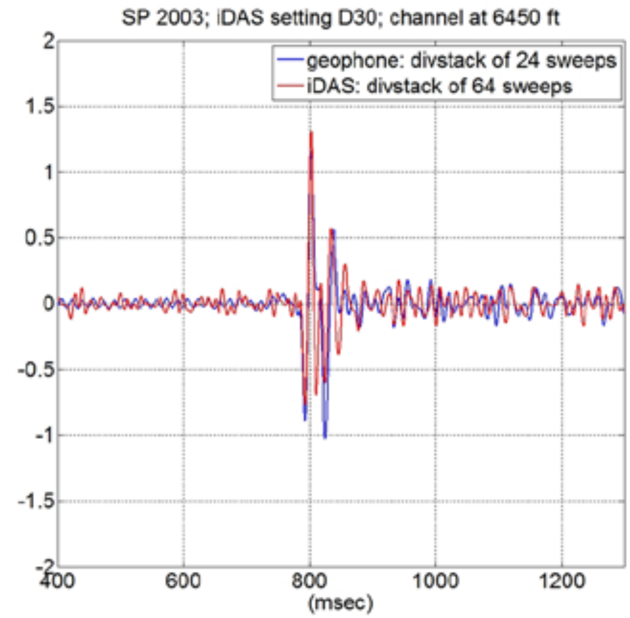
Citronelle DAS-Geophone Comparison from Walkaway Shot Point 2021

DAS Data

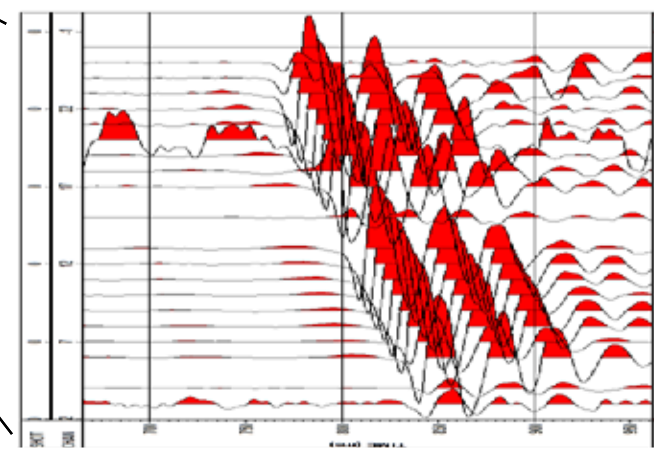


Processed by D. Miller, Silixa

DAS vs. Geophone

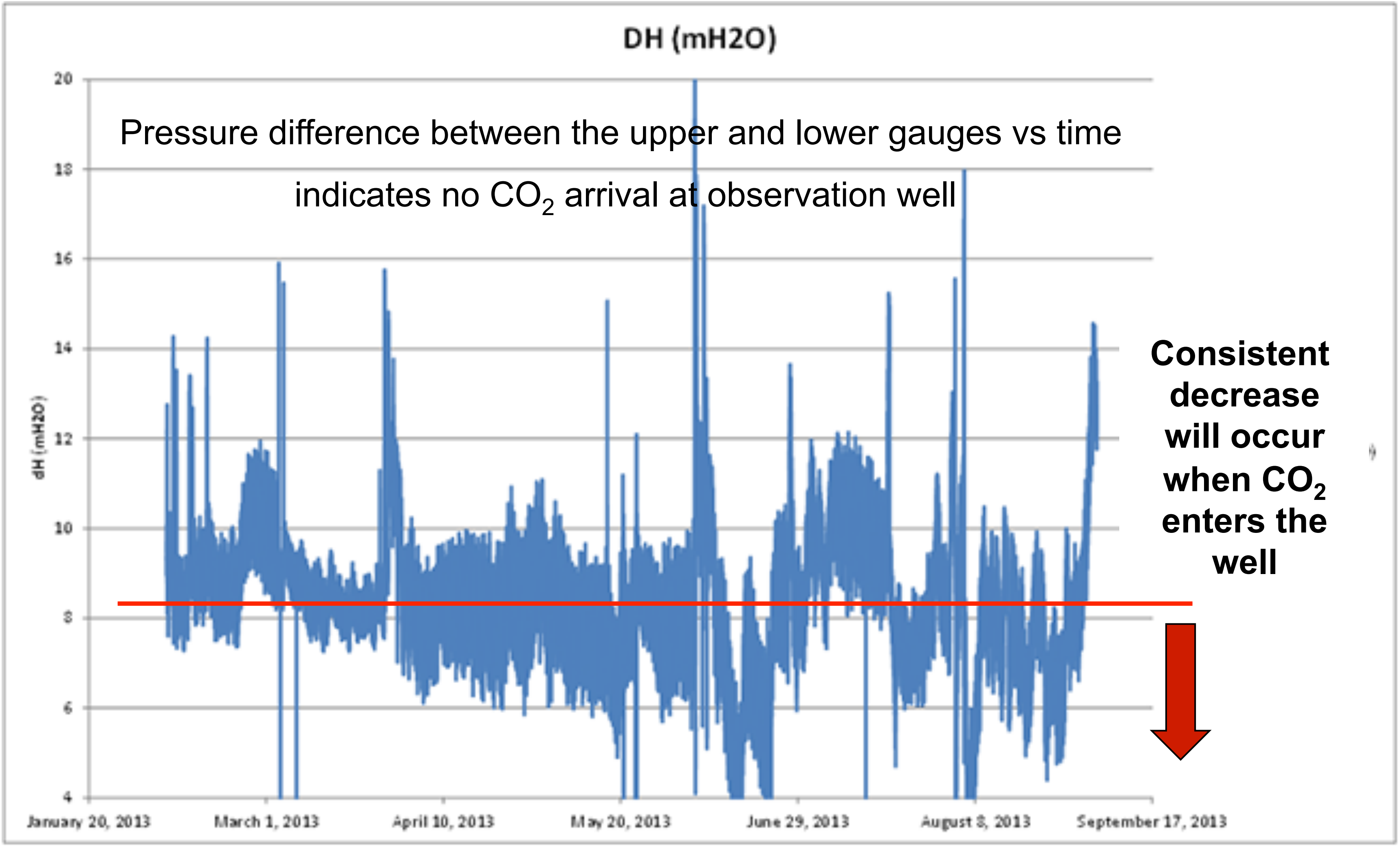


Geophone Data



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

Two Quartz P&T Gauges for Redundancy and Real-Time Measurement of Fluid Density Changes



Consistent decrease will occur when CO_2 enters the well

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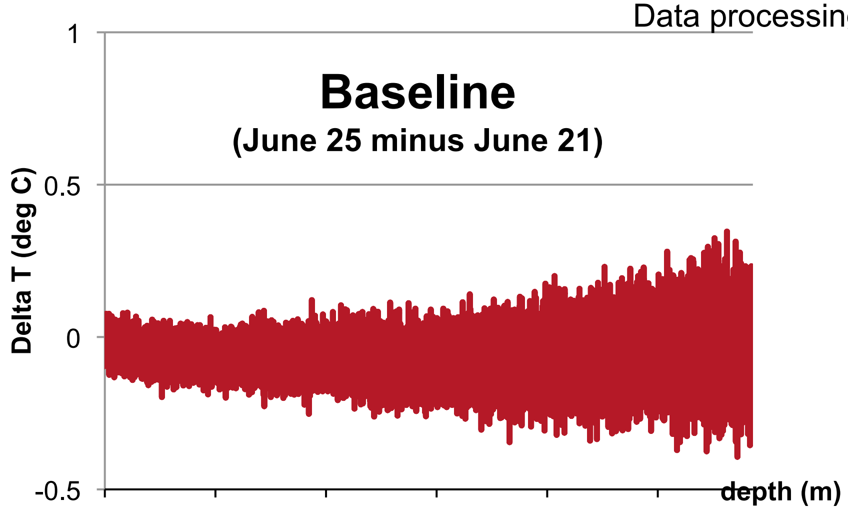
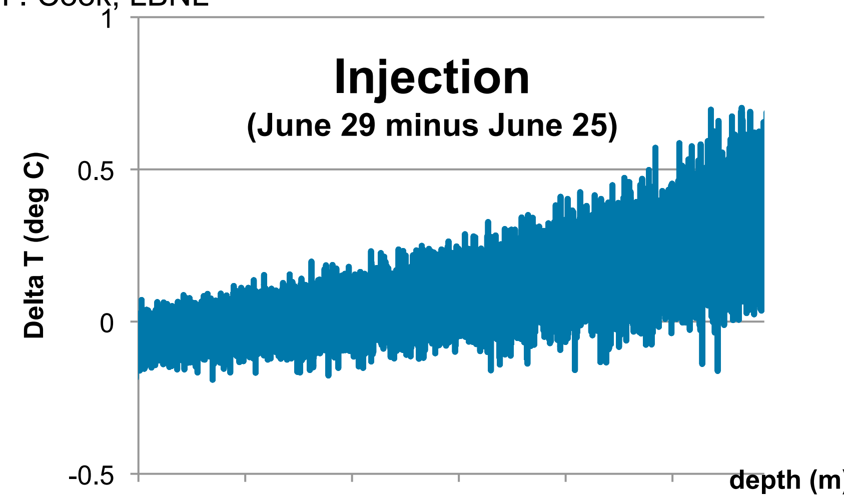
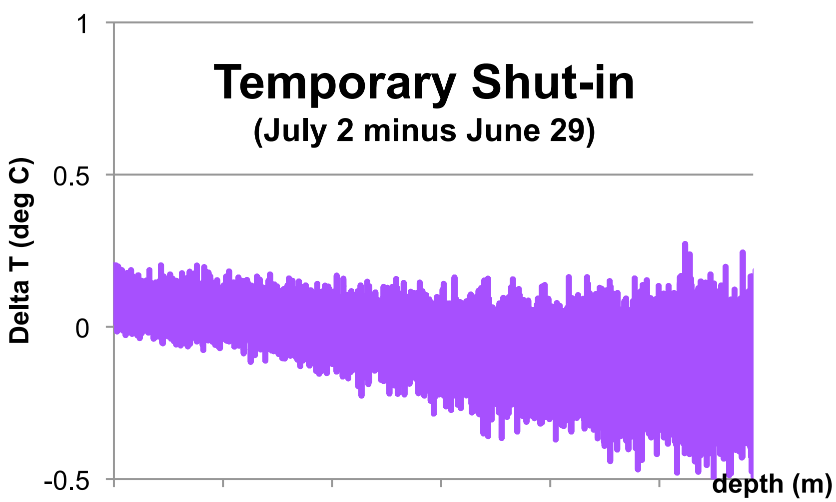
Distributed Temperature Sensing (DTS) using Downhole Fiber Optic Monitoring at D9-8#2

Data processing by P. Cook, LBNL







DTS responded to changes in fluid levels in the observation well caused by CO_2 injection at D9-7#2 located 850 ft (260 m) away

Confidential

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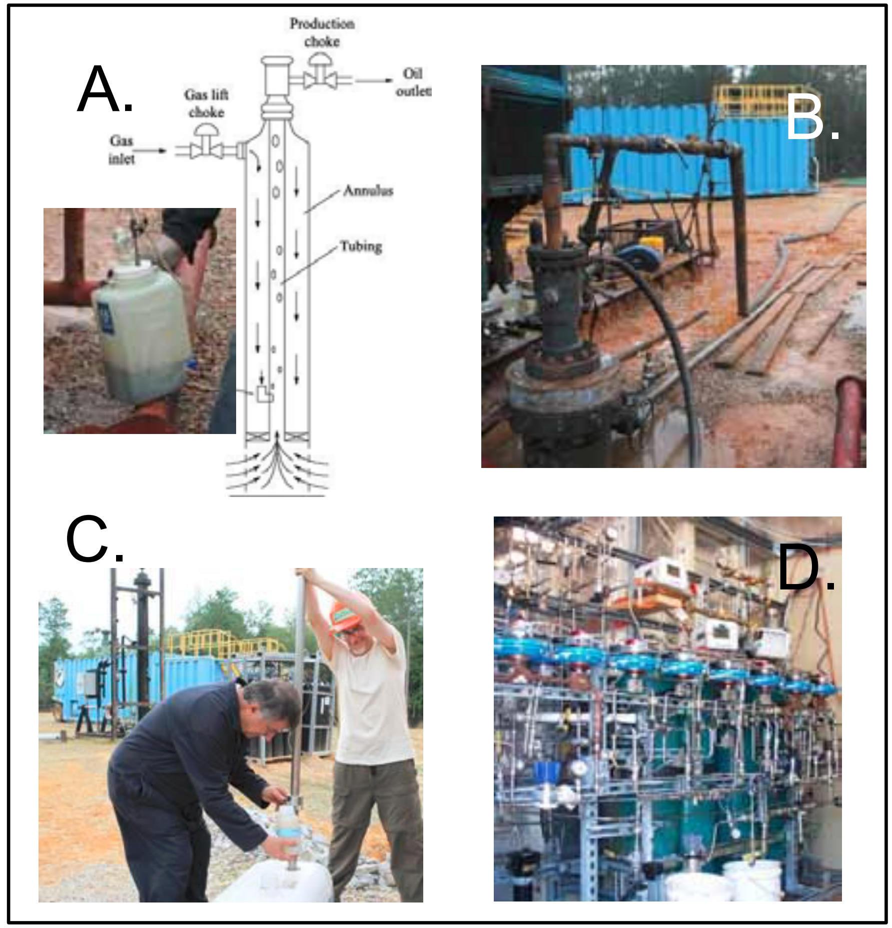
In-zone Comparison of Fluid Sampling Methods (U-tube, Gas lift, Pumping, Kuster Sampler)

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

Kuster and U-tube sampling methods provide the best water quality results

Summary

- Continuous SRO Pressure and Temperature
  - Provides reliable and ongoing injection performance data
  - Eliminates MRO gauge runs ($10K)
- Permanent Geophone Installation
  - Provides opportunity for time-lapse seismic
  - Eliminates need to deploy geophone strings ($150K)
- Distributed Acoustic Sensing (DAS)
  - Provides opportunity for seismic across wellbore
  - Eliminates need for geophone deployment ($150K)
- Distributed Temperature Sensing (DTS)
  - Provides temperature profile across wellbore
  - Eliminates need for temperature surveys ($10K)
- U-tube Fluid Sampling
  - Provides access to reservoir fluid sampling as needed ($12K)

Project has recouped >$500K and counting using MBM

Together…Shaping the Future of Electricity



SECARB Anthropogenic Test Project Assessment

Prepared For:

SOUTHEAST REGIONAL CARBON SEQUSTRATION PARTNERSHIP MEETING

Prepared By:

GEORGE J KOPERNA JR

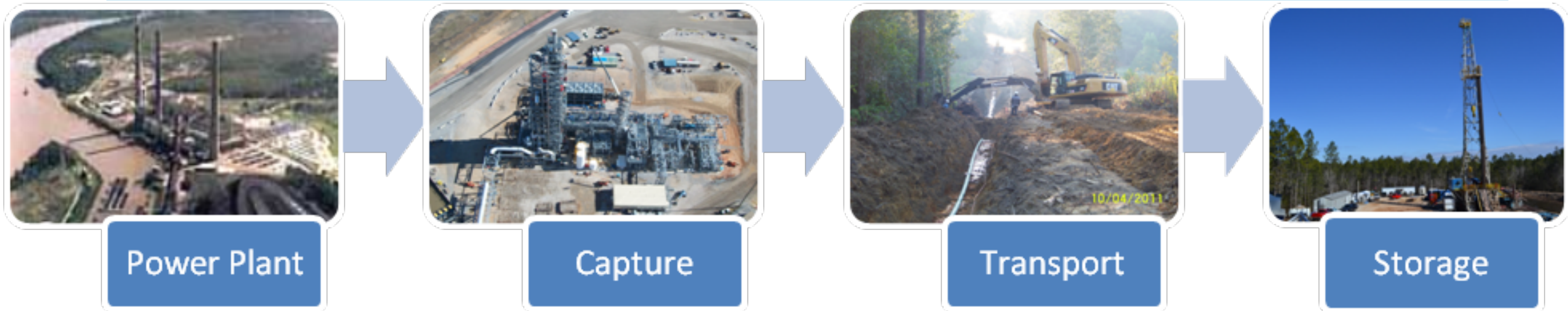
ADVANCED RESOURCES INTERNATIONAL, INC.

March 4-5, 2014

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.

Regulatory Objectives



1. Assess the AoR for the CO_2 injection determined by modeling and monitoring results;
2. Extensive monitoring for CO_2 at deep, shallow and surface locations;
3. Monitoring of the injection stream composition;
4. Maintain a pressurized annulus of 200 psig or less;
5. Periodic update of a Corrective Action Plan for the AoR; and
6. Demonstration of USDW non-endangerment for site closure.

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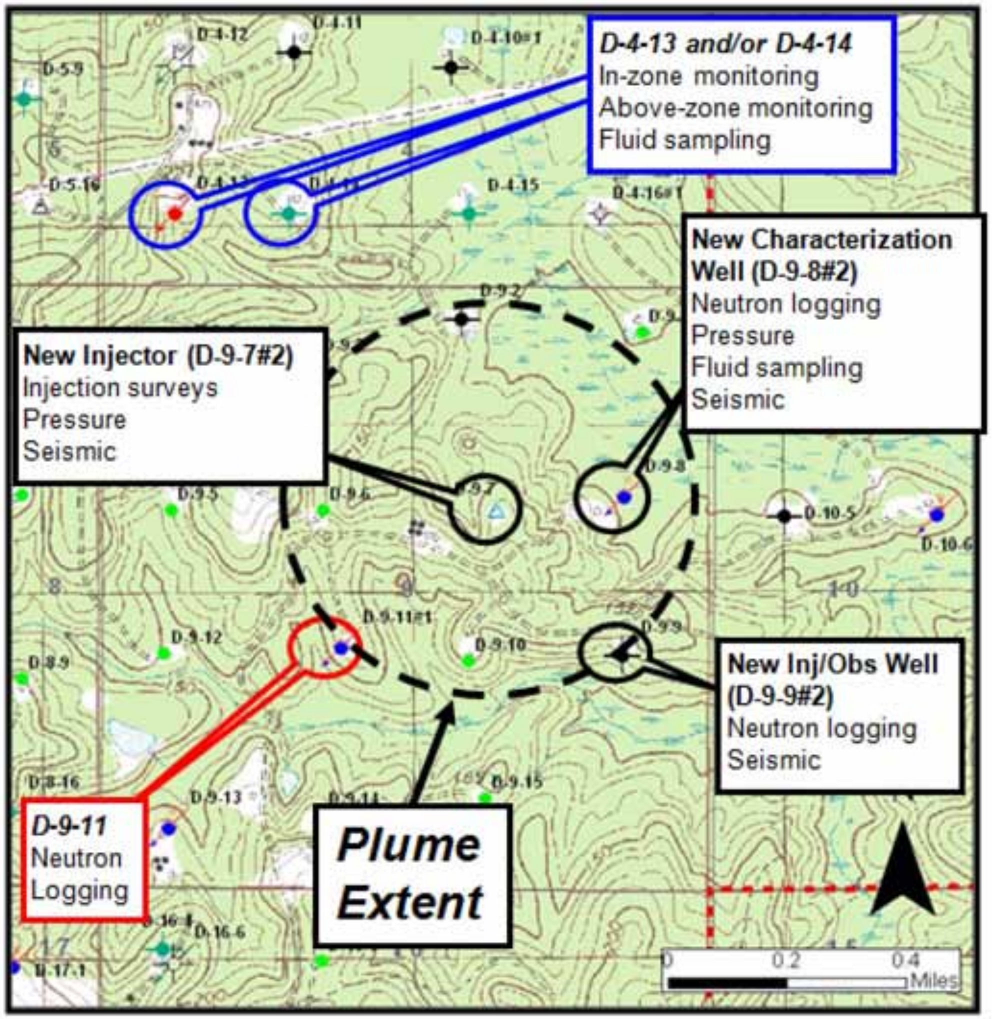
Initial AoR Estimation



Pre-project modeling assumptions:

- 3 years of continuous injection at 500 tonnes per day;
- A cumulative injection of 547,500 tonnes;
- Confinement of the CO_2 within the Upper Paluxy, and
- No significant pressure buildup (high perm),
- 1,700 ft. radial dispersion

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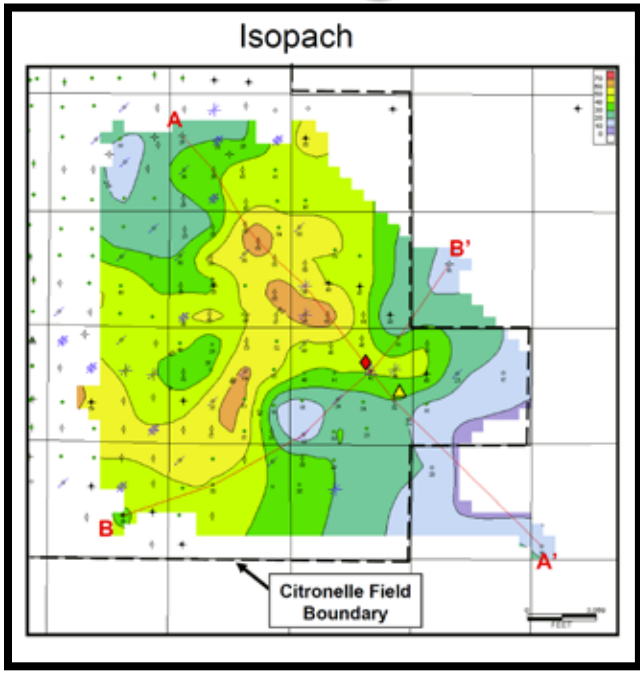
Geologic Characterization



Baseline Reservoir Characterization:

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

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

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Whole Core Analyses & Confining Unit Characterization

Core Analysis	D 9-7 #2	D 9-8 #2	D 9-9#2
Spectral Gamma Ray	X	X	X
Routine Porosity, Permeability, Grain Density	X	X	X
Vertical and Orthogonal Permeability	X	X	X
Relative Permeability		X	
X-ray Diffraction Mineralogy	X	X	X
Fluid Sensitivity – Permeability vs. Throughput		X	
Thin-Section Petrography	X	X	X
Mercury Injection Capillary Pressure		X	
Total Organic Carbon		X	X
Source Rock Analysis		X	X
Shale Rock Properties		X	X
Methane Adsorption Isotherm		X	X

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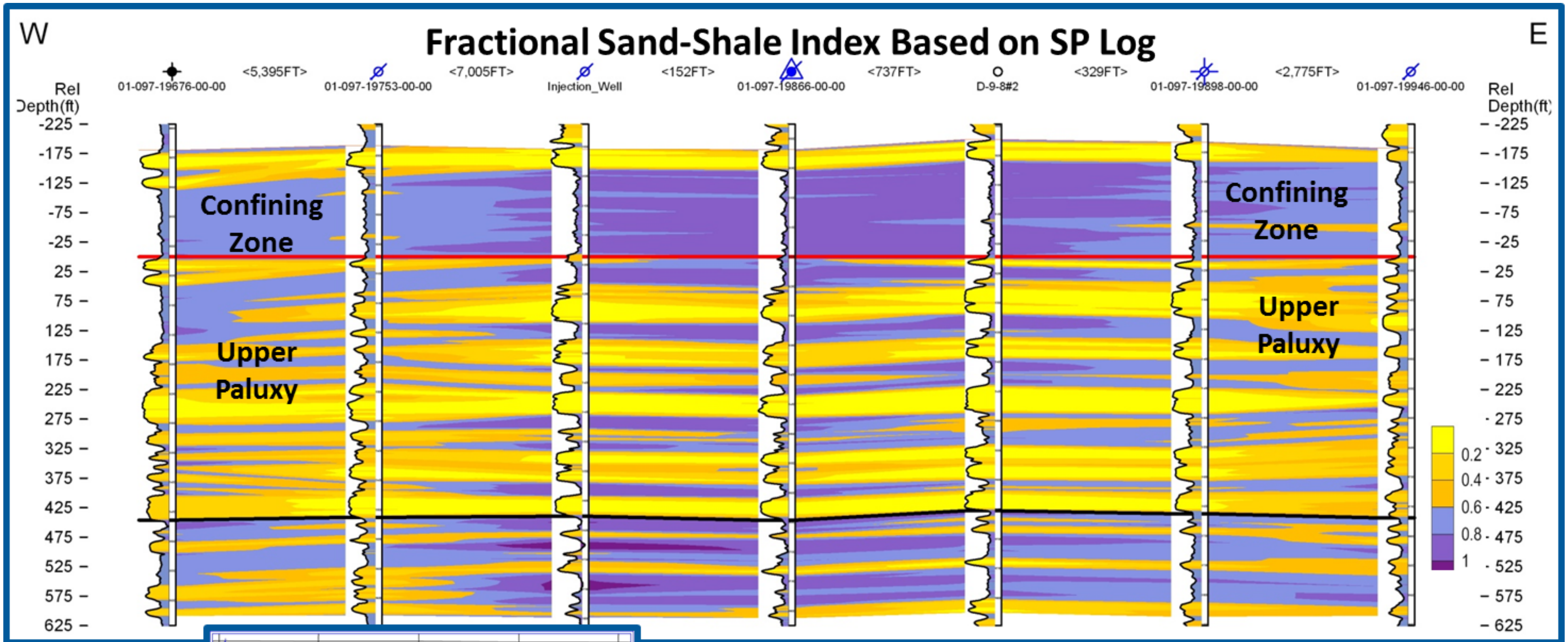

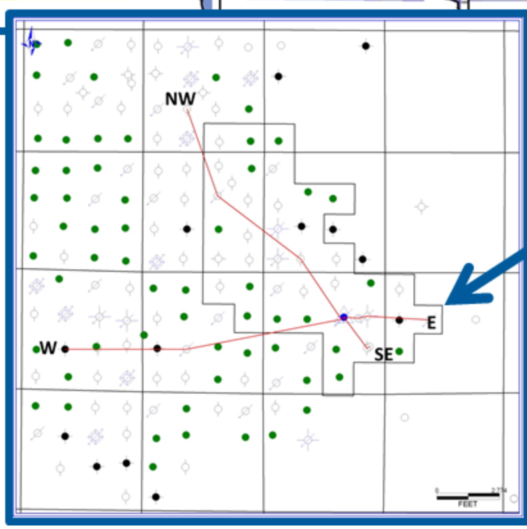

Extrapolated Continuity of Upper Paluxy Sandstones At Citronelle Southeast Unit West - East

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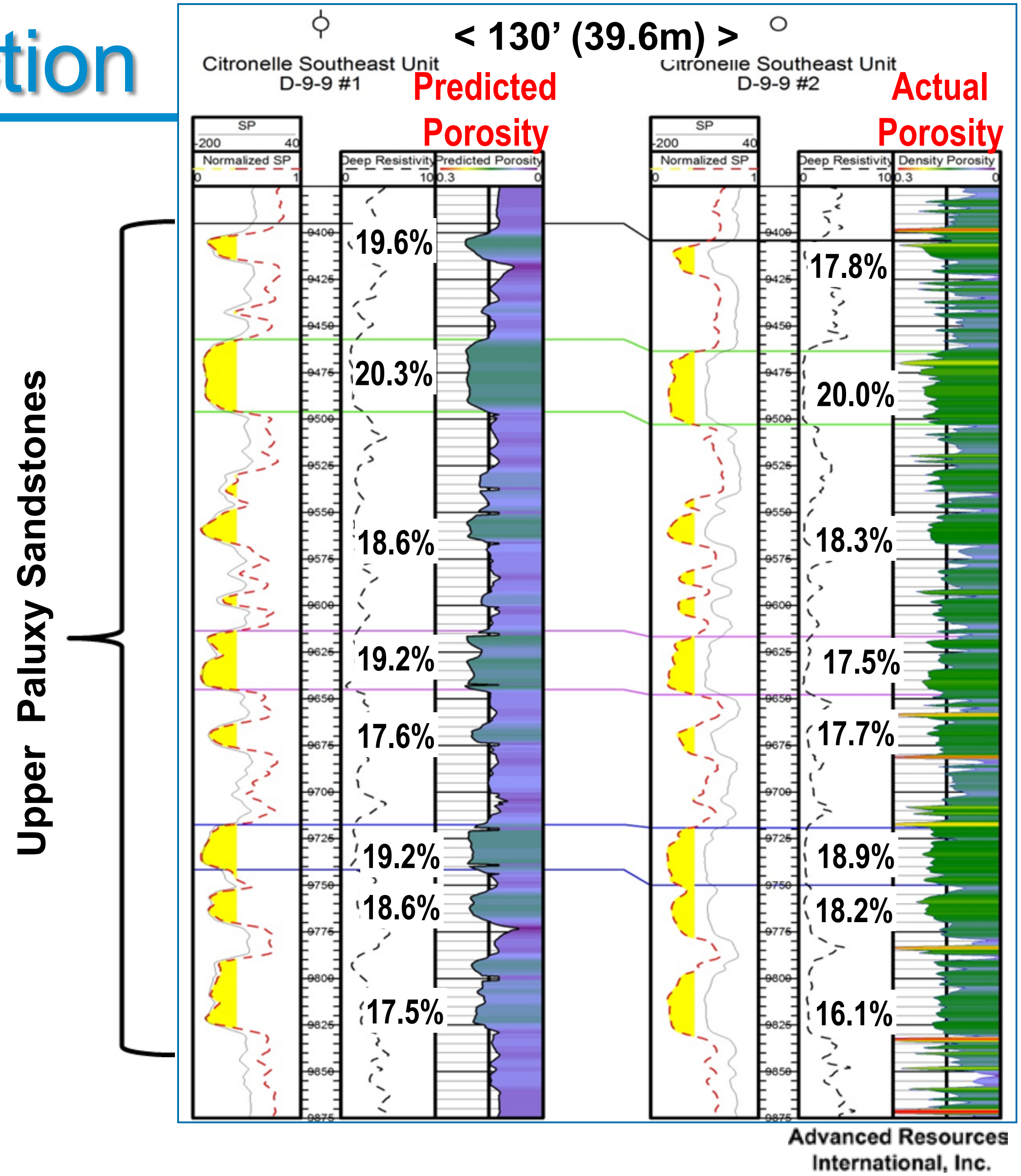
Neural Network Porosity Prediction

- The three new wells provided modern and very detailed geophysical well logs.
- These wells were drilled on pre-existing well pads.
- New well logs were compared to vintage well logs using Neural Network protocols.
- Predicted porosity for D-9-9 #1 compared to actual density porosity from D-9-9 #2 well for Upper Paluxy Sandstones.
- This relationship was then rolled out to remaining vintage well logs to generate synthetic porosity logs for the remainder of the field.



Project Timeline

The MVA Program is a continuum:

- *Shallow MVA*
- *Deep MVA*
- *Experimental MVA*

Will be in place for six (6) years throughout the three phases of the project

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

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Defined Elements of the MVA Program

- **Shallow MVA**
  - Groundwater sampling (USDW Monitoring)
  - Soil Flux
  - PFT Surveys
- **Deep MVA**
  - Reservoir Fluid sampling
  - Crosswell Seismic
  - CO_2 Volume, Pressure, and Composition analysis
  - Injection, Temperature, and Spinner logs
  - Pulse Neutron Capture logs
  - Vertical Seismic Profile
- **MVA Experimental tools**

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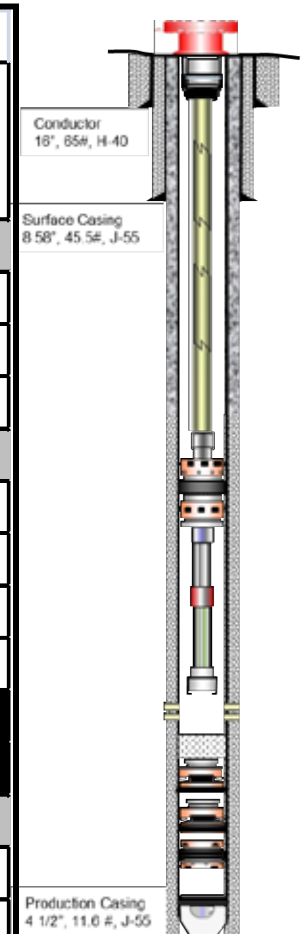
SECARB Anthropogenic MVA Frequency

MVA Method	Frequency				
	Continuous	Monthly	Quarterly	Annual	Milestone *(Baseline, Injection, Post)*
Shallow					
Soil flux		■			
Groundwater sampling (USDW)			■		
PFT survey				■	
Deep					
CO_2 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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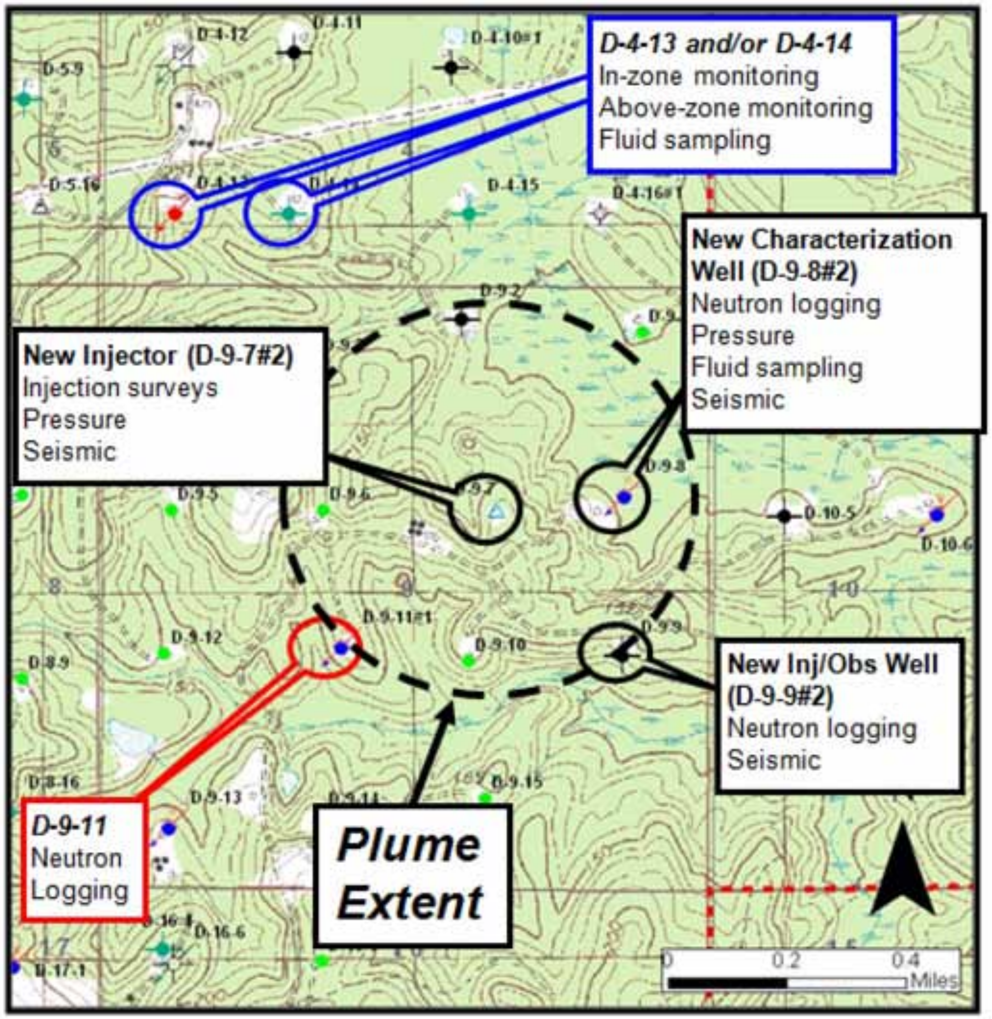
MVA Sample Locations



- 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)
- Twelve soil flux monitoring stations

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CO_2 Stream Composition

	CO2 Stream composition data (%)			
	CO_2	O_2	N_2	Total
Jan-14	99.944	0.004	0.052	100
Dec-13	99.968	0.003	0.029	100
Nov-13	99.968	0.003	0.029	100
Oct-13	99.971	0.002	0.027	100
Sep-13	99.950	0.007	0.043	100
Aug-13	99.984	0.003	0.013	100
Jul-13	99.893	0.031	0.076	100
Jun-13	99.893	0.031	0.076	100
May-13	99.976	0.003	0.021	100
Apr-13	99.977	0.003	0.020	100
Mar-13	99.977	0.003	0.020	100
Feb-13	99.977	0.003	0.020	100
Jan-13	99.978	0.004	0.018	100
Dec-12	99.981	0.016	0.003	100
Nov-12	99.984	0.014	0.002	100
Oct-12	99.984	0.014	0.002	100
Sep-12	99.979	0.011	0.010	100
Aug-12	99.975	0.004	0.021	100
average	***99.964***	***0.009***	***0.027***	

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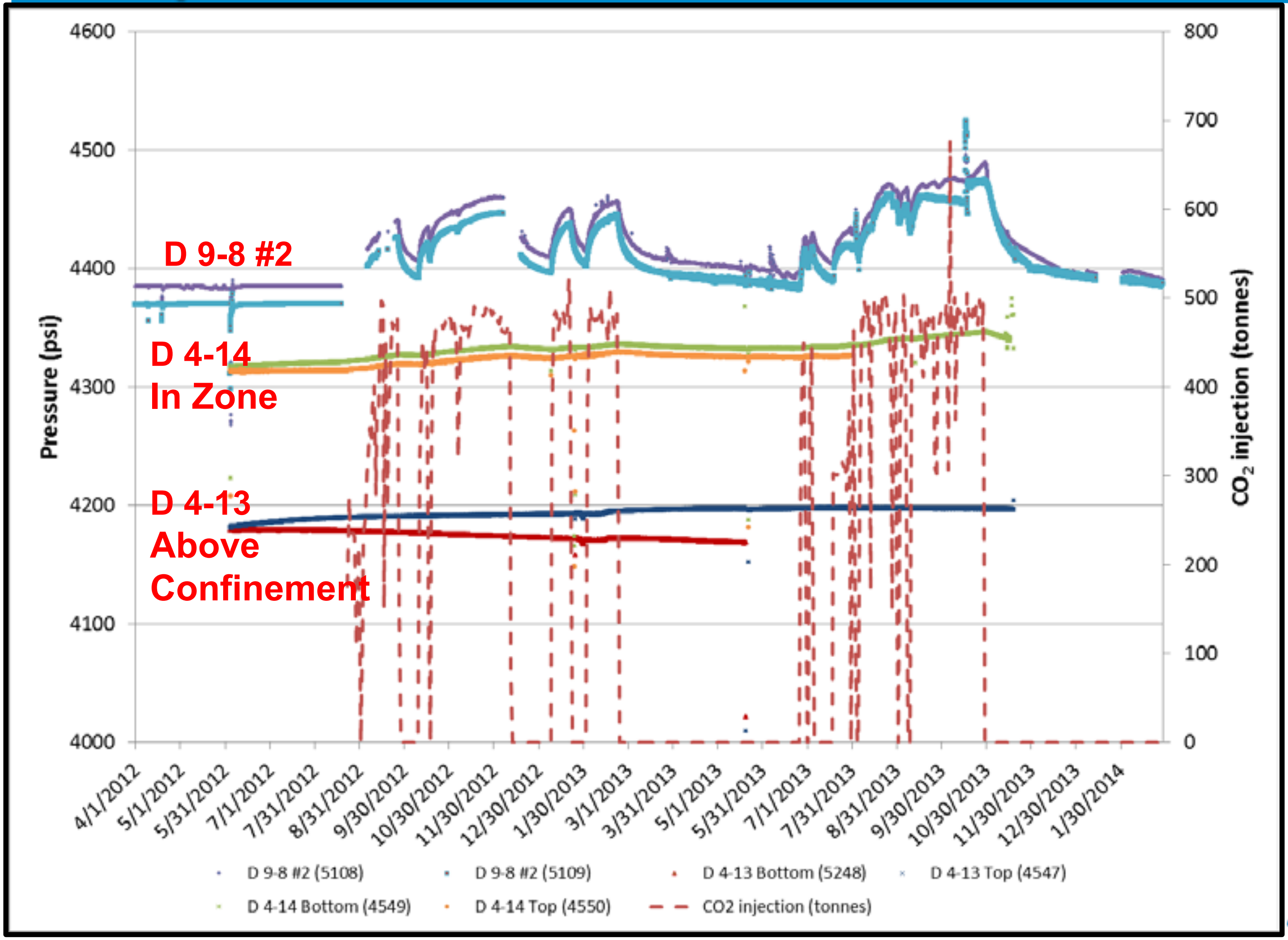
Pressure & Injection Rate Response



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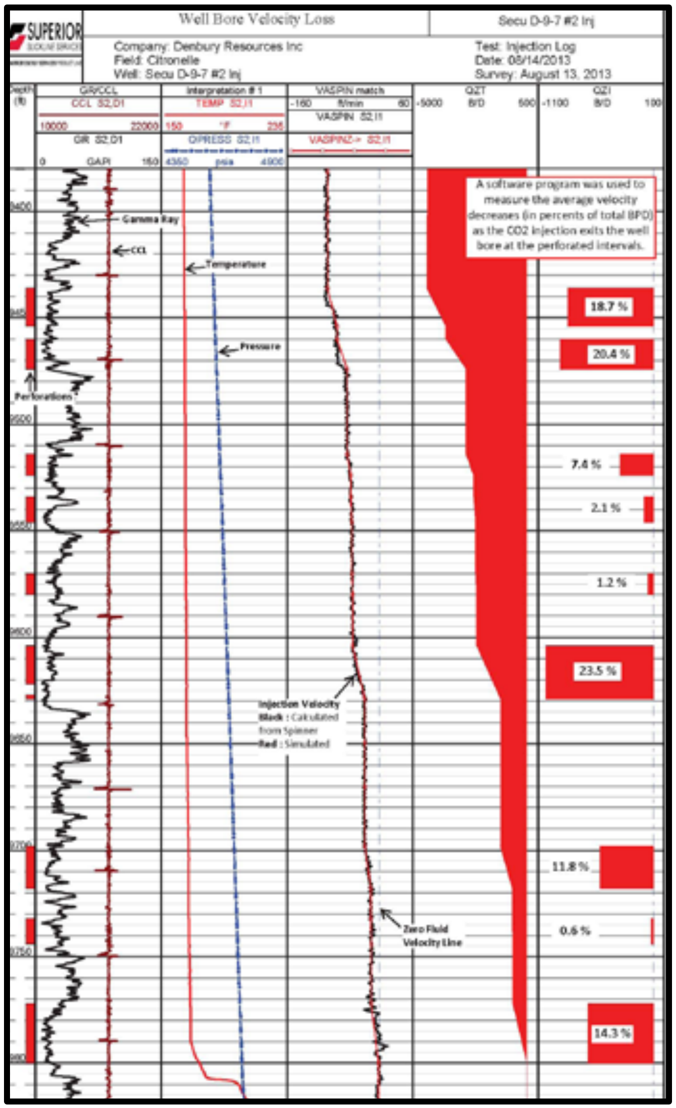
Spinner Surveys



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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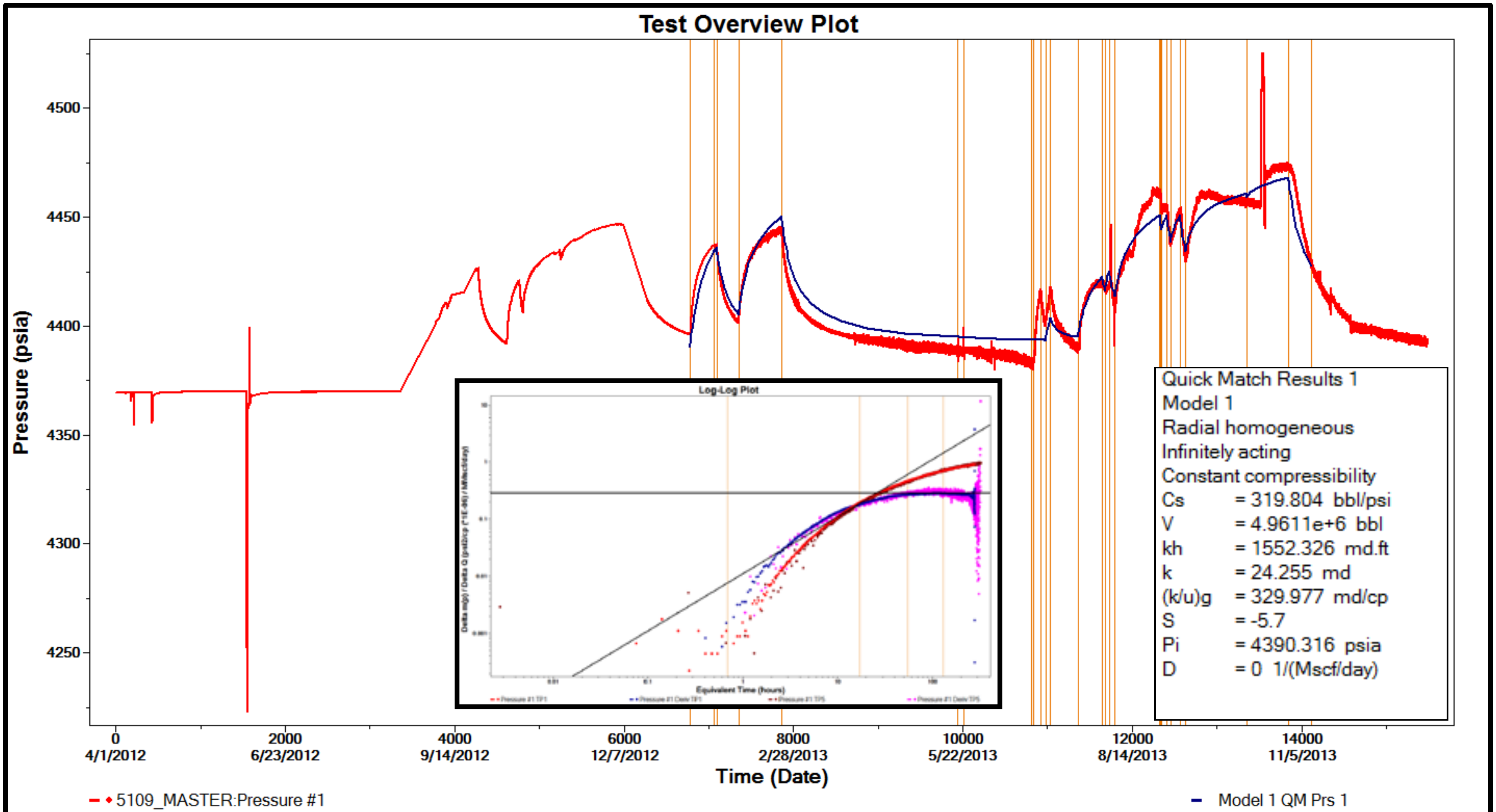
Upper Paluxy (9460 Sand)



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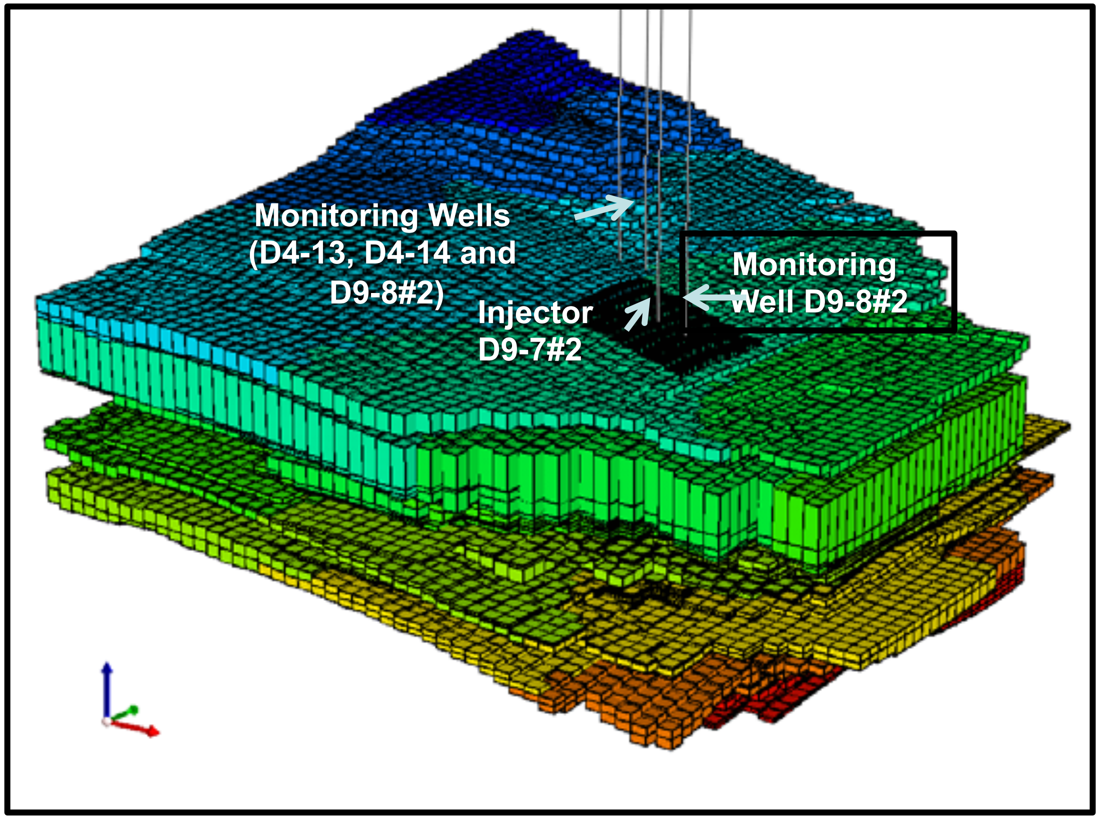
Model 3D View



Note: Vertical to Horizontal Ratio Exaggeration of 10

- Elevation and thickness maps generated using Petra software based on available logs
  - Divided the interval between the various sand flow units and their associated shaly interburden units
  - Layers further subdivided to adequately represent the injection well perforations and heterogeneity
- Grid blocks are 400’ by 400’ (before refinement)
- 52 layers

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Perforation Data

Sand Name	Perforated Intervals (ft)	Total Perf Footage
9460	**9436 - 9454, 9460 -9474**	**28**
9520	**9514 -9524**	**10**
9540	**9534 - 9546**	**12**
9570	**9570 - 9580**	**10**
9620	**9604 - 9622, 9627 - 9629**	**20**
9670	N/A	N/A
9710	**9698 - 9718**	**20**
9740	**9732 - 9744**	**12**
9800	**9772 - 9800**	**28**
9840	N/A	N/A
9900	N/A	N/A
9970	N/A	N/A
10030	N/A	N/A
10040	N/A	N/A
10100	N/A	N/A
10130	N/A	N/A
10310	N/A	N/A
10370	N/A	N/A
10400	N/A	N/A
10470	N/A	N/A
10500	N/A	N/A

Perforated intervals respected in the model

	Depth from Model	Thickness from Model	Model Layer	Perforated Layer
9460 A1	9420.1	7.93	6	
9460 A2	9428.0	7.93	7	
9460 A3	9436.0	7.93	8	X
9460 B	9443.9	9.5	9	X
9460 C	9453.4	7.7	10	
9460 D	9461.1	11.8	11	X
9460 E	9472.9	9.6	12	
Interburden 9460 to 9520	9482.5	22.9	13	
9520 A1	9505.4	7.45	14	
9520 A2	9512.9	7.45	15	X
9520 B1	9520.3	4.5	16	X
9520 B2	9524.8	4.5	17	
9520 C	9529.3	4.1	18	
Interburden 9520 to 9540	9533.4	3.3	19	
9540 A	9536.7	5	20	X
9540 B1	9541.7	5.6	21	X
9540 B2	9547.3	5.6	22	
9540 C	9552.9	4.4	23	
Interburden 9540 to 9570	9557.3	12.5	24	
9570 Top	9569.8	6.2	25	X
9570 B	9576	8.7	26	
9570 C	9584.7	4.1	27	
Interburden 9570 to 9620	9588.8	8.6	28	
9620 A1	9597.4	5.5	29	
9620 A2	9602.9	5.5	30	X
9620 B	9608.4	8.3	31	X
9620 C1	9616.7	4.2	32	X
9620 C2	9620.9	4.2	33	
9620 C3	9625.2	4.2	34	X
9620 D	9629.4	8.7	35	
9620 E	9638.1	5.7	36	
Interburden 9620 to 9670	9643.8	16.4	37	
9670	9660.2	27.3	38	
Interburden 9670-9710	9687.5	12.6	39	
9710 A	9700.1	18	40	X
9710 B	9718.1	3.2	41	
9710 C	9721.3	5.1	42	
Interburden 9710 to 9740	9726.4	6.8	43	
9740 A	9733.2	6.7	44	X
9740 B	9739.9	4	45	X
9740 C	9743.9	16.3	46	
Interburden 9740 to 9800	9760.2	20.6	47	
9800 A	9780.8	4.6	48	X
9800 B	9785.4	4.7	49	X
9800 C	9790.1	13.3	50	X
9800 D	9803.4	9.6	51	
9800 E	9813.0		52	

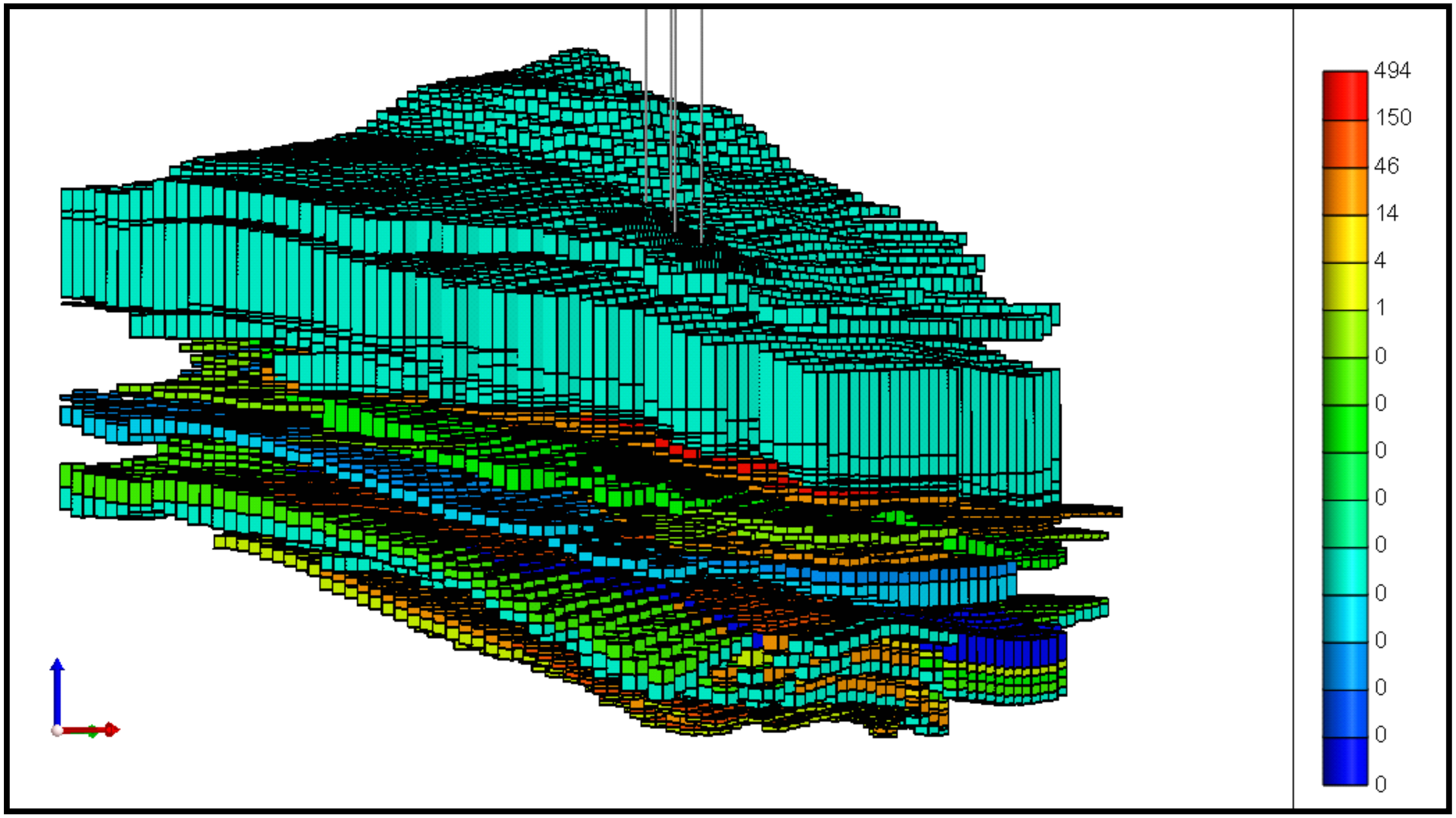
Vertical & Directional Permeability

- Vertical permeability measured on 9 samples was found to be on average 4 times smaller than horizontal permeability: ratio implemented in the model.
- Directional core data on 7 samples showed an average horizontal anisotropy of 2 but with an unknown direction: will be varied in the model.

Sample Number	Depth	Net Confining Stress (psig)	Porosity (%)	Permeability Klinkenberg (md)
8H	9577.20	1200.00	17.38	34.71
8V	9577.4 - 9577.50	1200.00	17.21	17.78
28H	9597.35	1200.00	21.62	496.23
28V	9597.45 - 9597.65	1200.00	22.04	462.93
29H	9598.35	1200.00	20.20	74.82
29V	9598.45 - 9598.70	1200.00	19.90	14.14
46H	9614.65	1200.00	20.27	167.32
46V	9615.05 - 9615.30	1200.00	18.07	32.27
49H	9617.65	1200.00	17.71	52.28
49V	9618.1 - 9618.25	1200.00	16.83	6.98
52V	9621.2 - 9621.35	1200.00	20.83	756.16
55V	9624.25 - 9624.45	1200.00	20.42	535.71
59H	9627.65	1200.00	13.70	26.50
59V	9627.8 - 9628.10	1200.00	20.74	612.96
61H	9629.75	1200.00	17.06	223.67
61V	9630.05 -	1200.00	12.37	0.80

Permeability 3D View

- Logarithmic scale used to facilitate viewing of the full permeability range



Note: Vertical to Horizontal Exaggeration Ratio of 15

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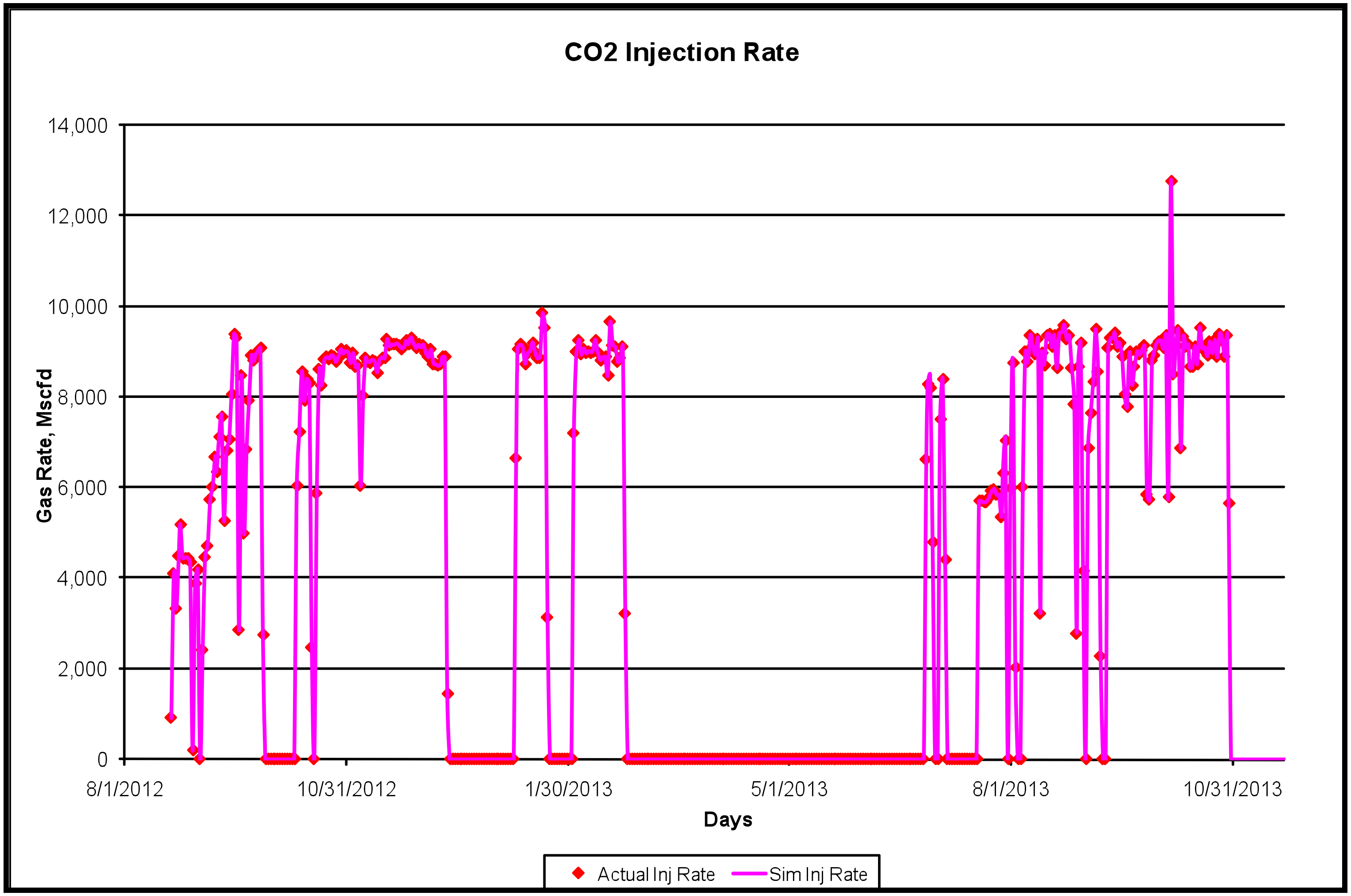
Injection Rate Match



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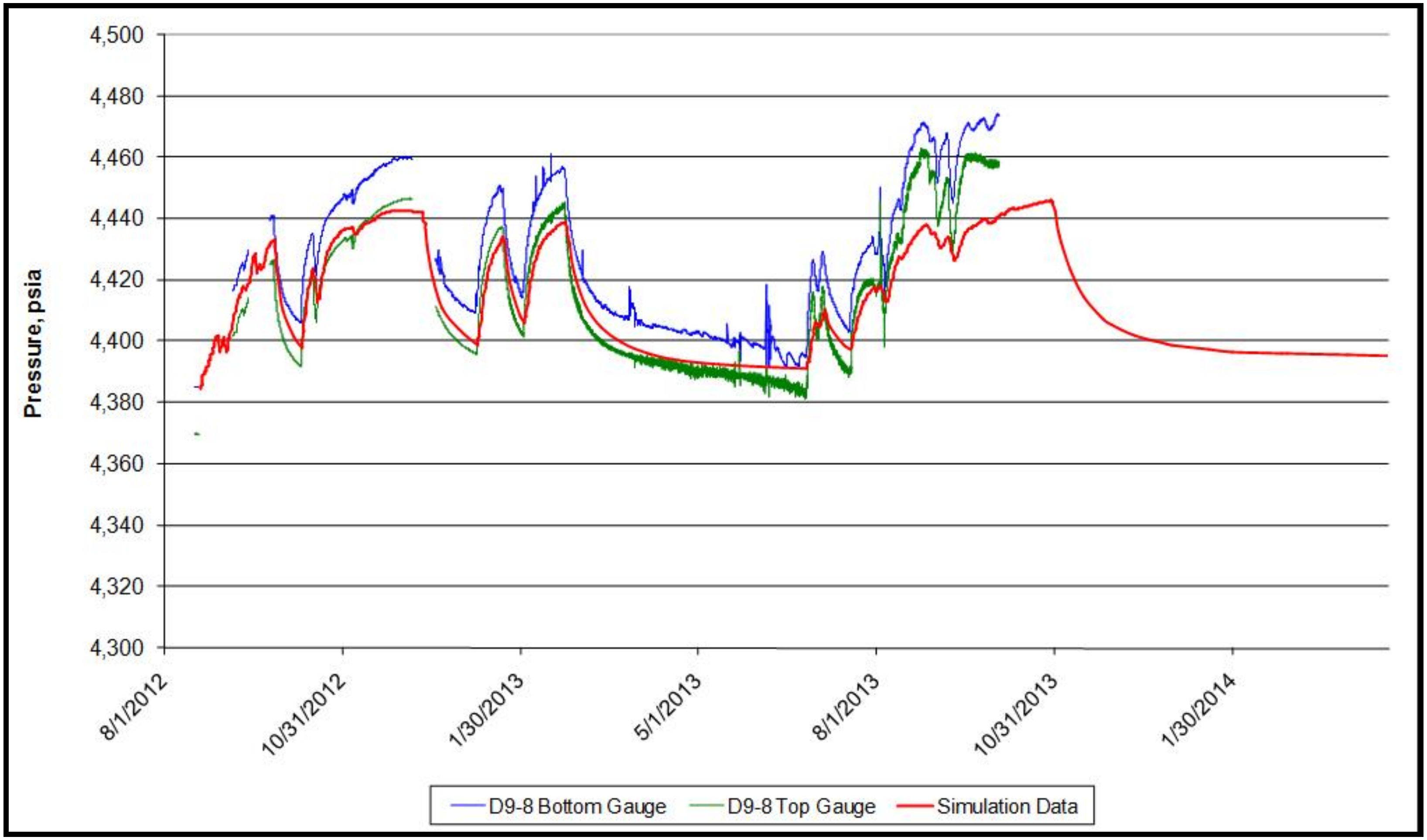
Pressure at Monitoring Well D 9-8



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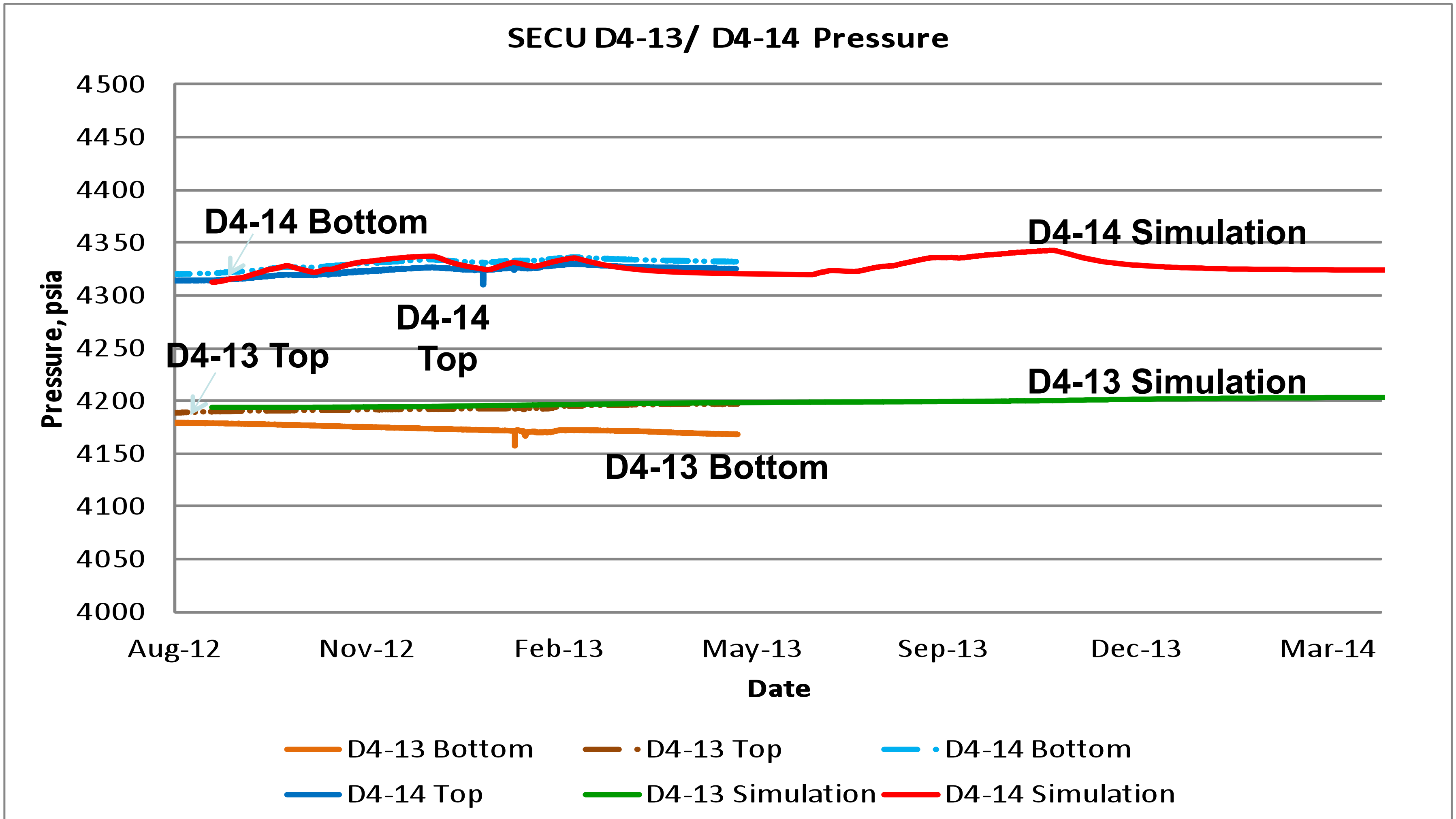
Pressure at Monitoring Wells D 4-13 and D 4-14



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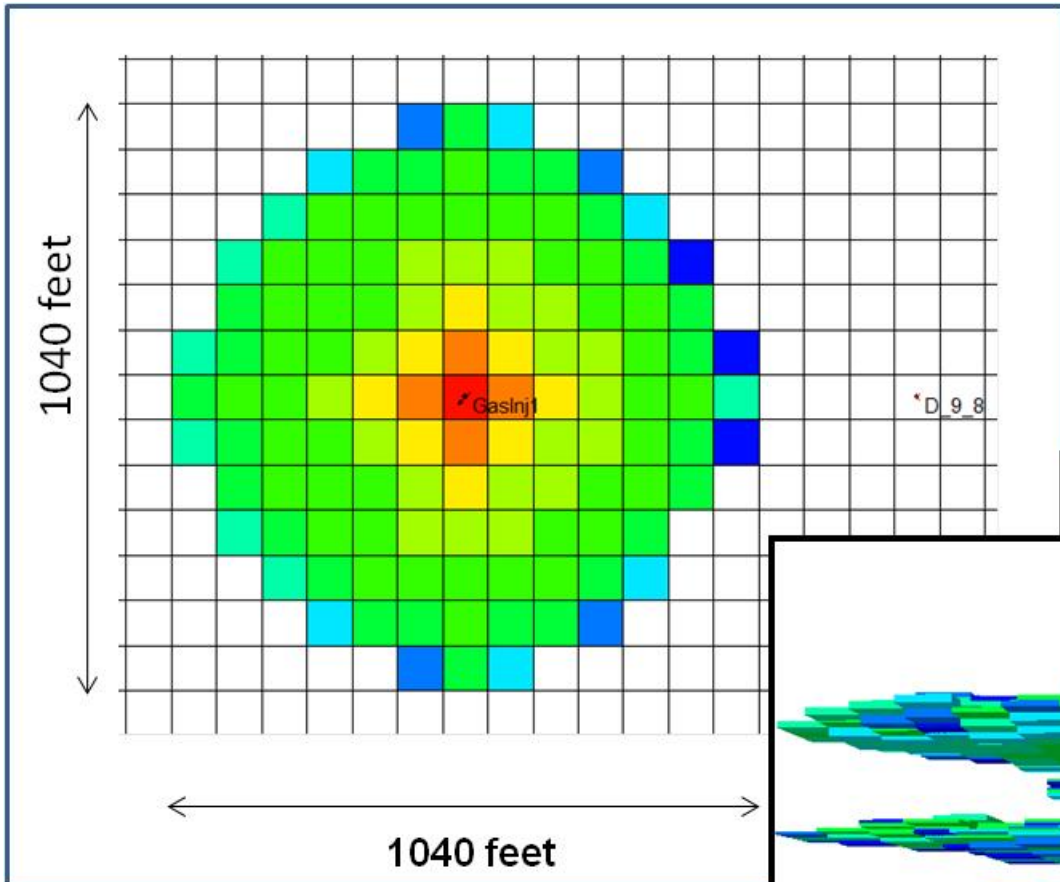
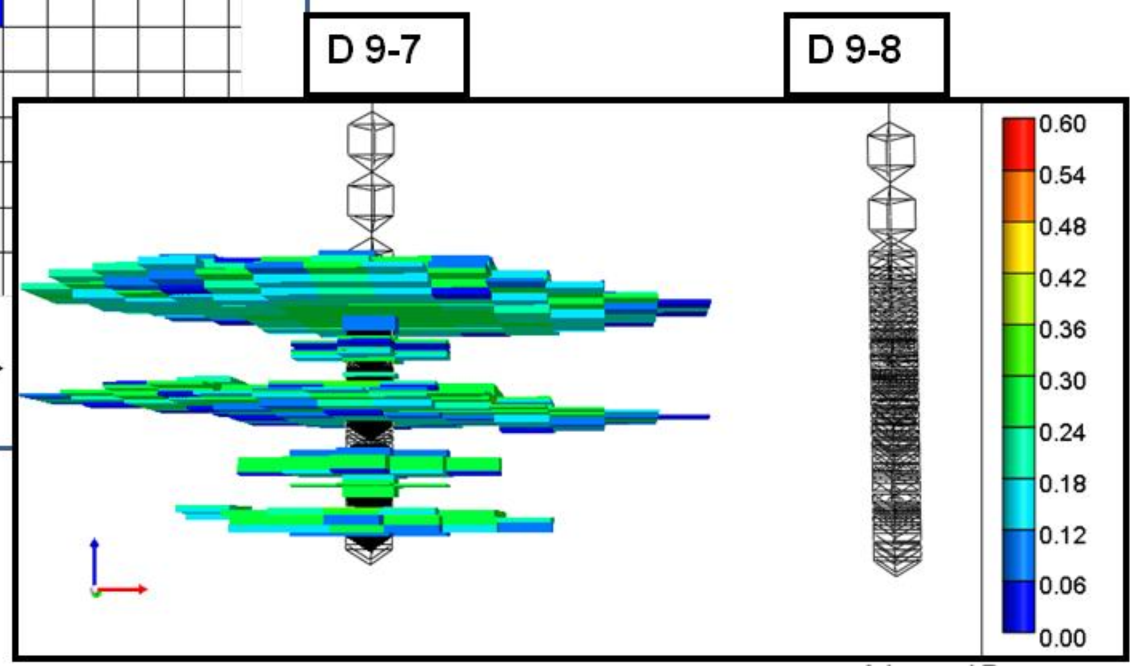
CO_2 Plume View Gas Saturation as of October 31st, 2013



Note: grid refined
grid blocks are 80' by 80'



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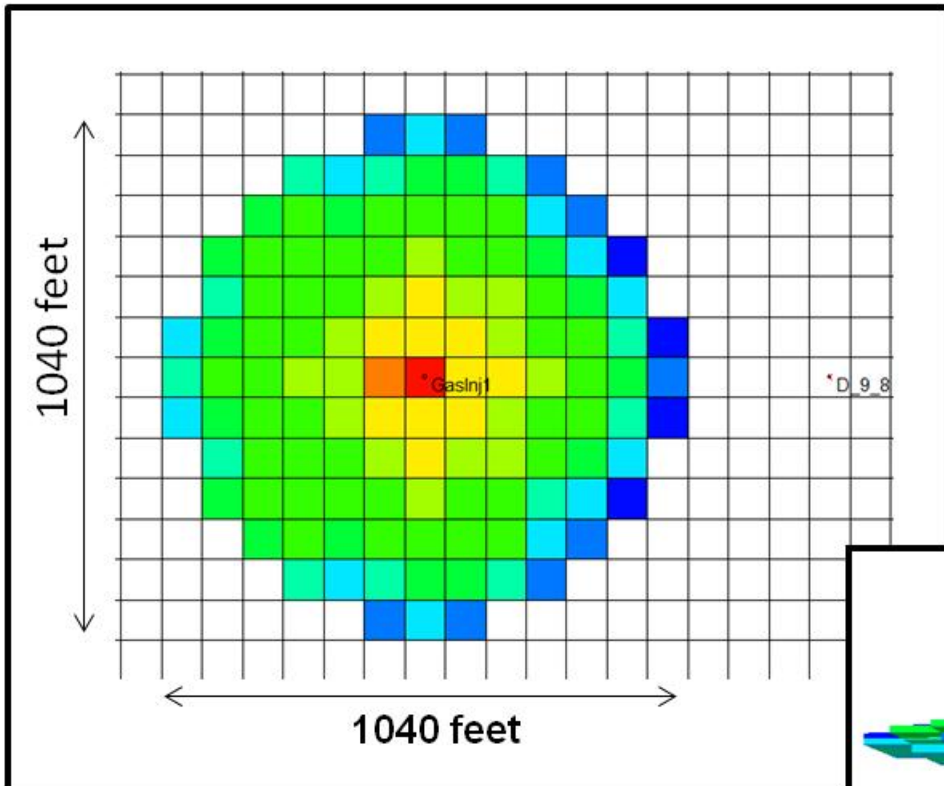
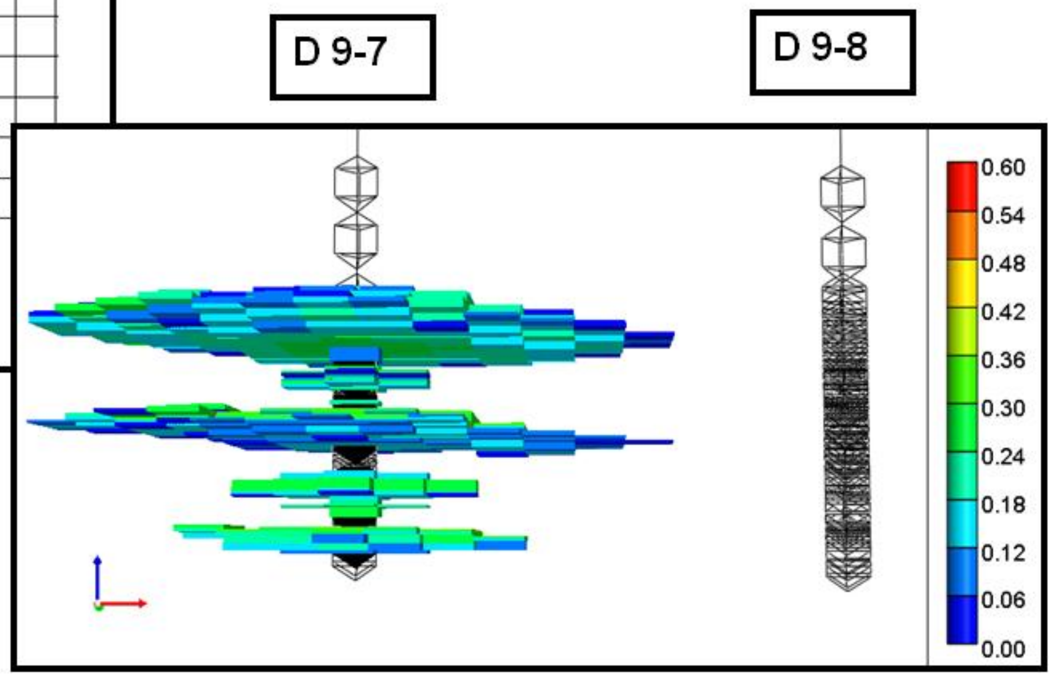
CO_2 Plume View Gas Saturation as of February 28th, 2014





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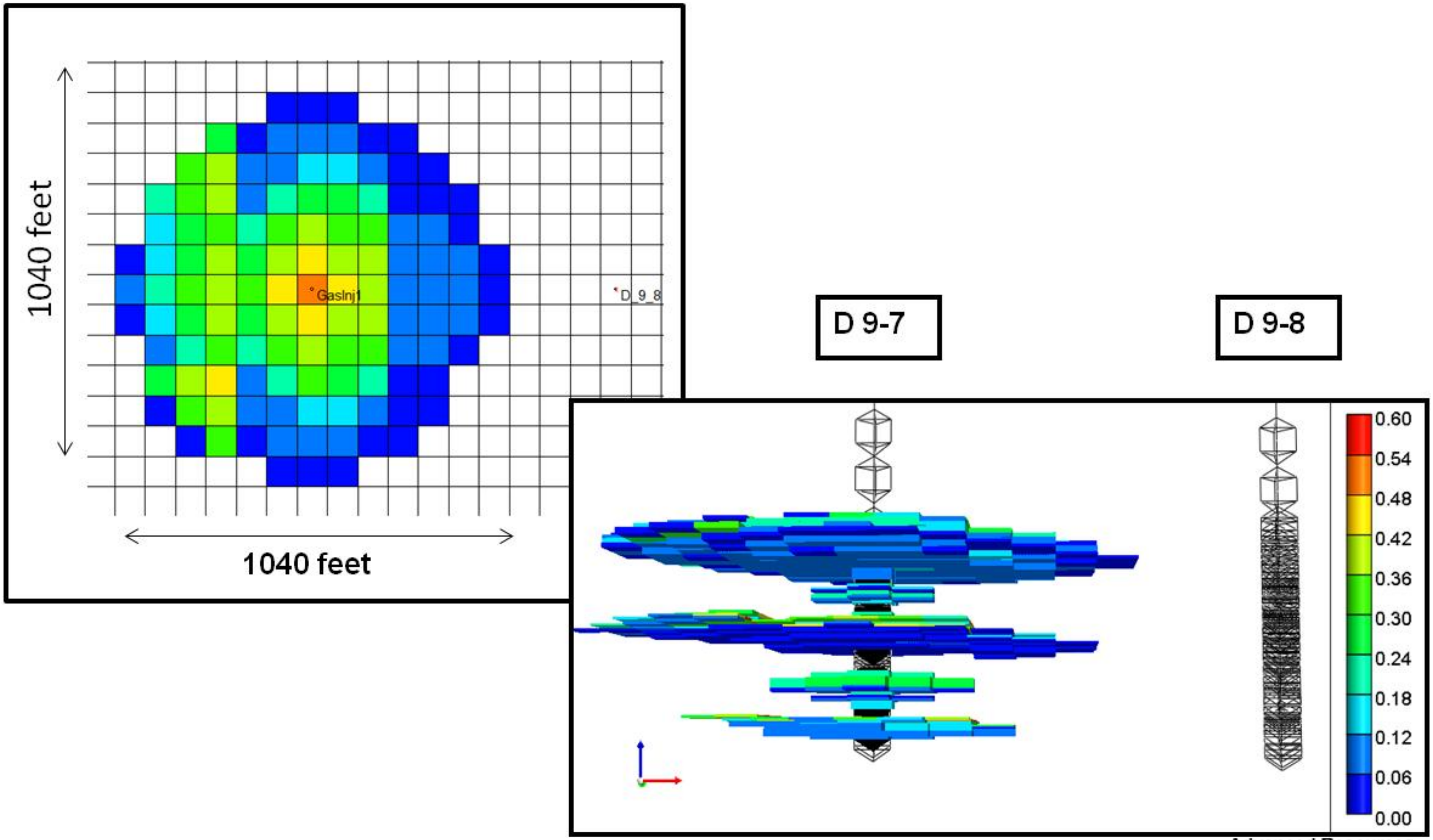
CO_2 Plume View Gas Saturation as of February 28th, 2017



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Summary

The initial AoR estimate was 1,700 ft

- Based on 3 years and 547,500 tonnes injected

Through the end of the current injection, the AoR is 520 feet.

- Injection through Nov 2013 is100,616 tonnes.

The only well within the AoR is the injection well, itself.

- No Corrective Action Plan adjustment necessary.

Advanced Resources International, Inc.

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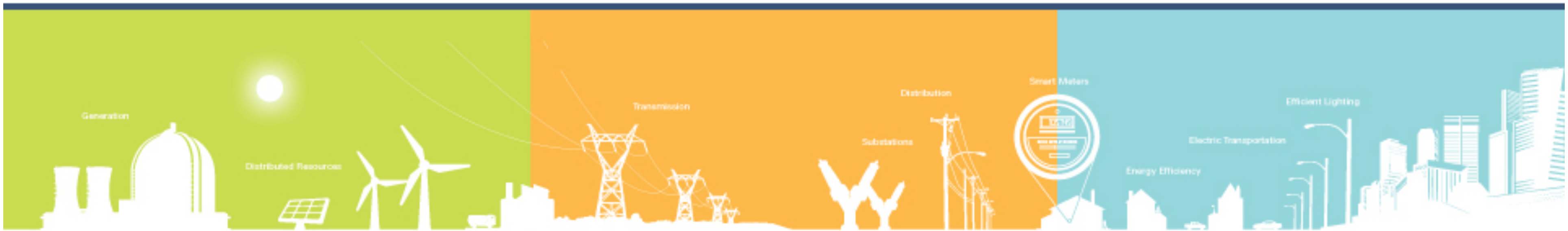
Advanced Resources International, Inc.

Southern Company/MHI Ltd.
500 TPD CCS Demonstration

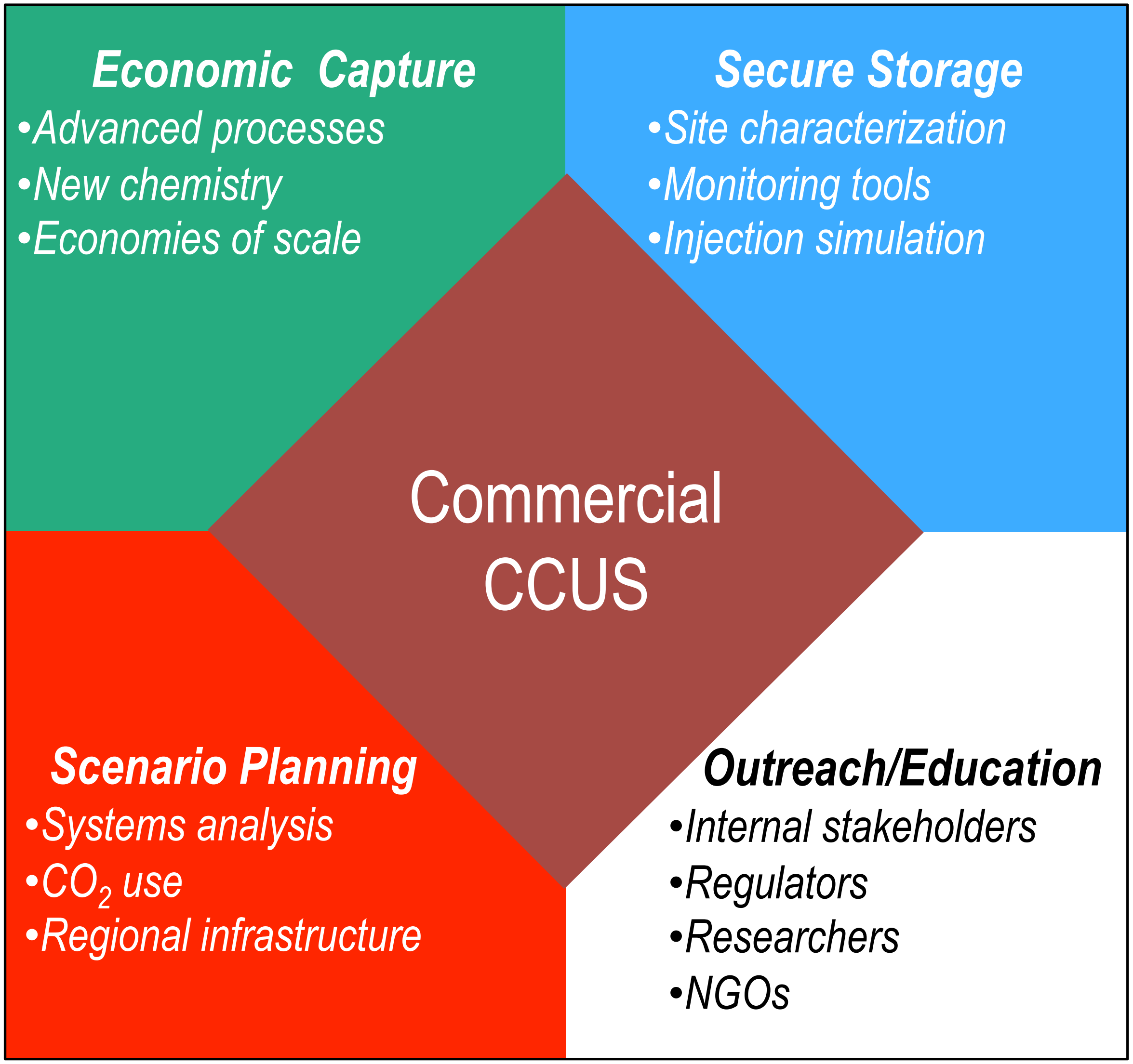
Jerrad Thomas | Research Engineer

Southern Company Services, Inc.



SOUTHERN COMPANY

The Commercialization Puzzle



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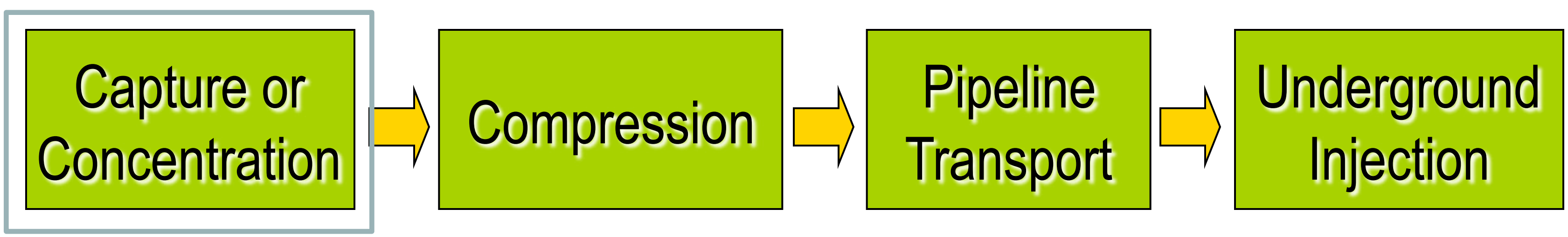
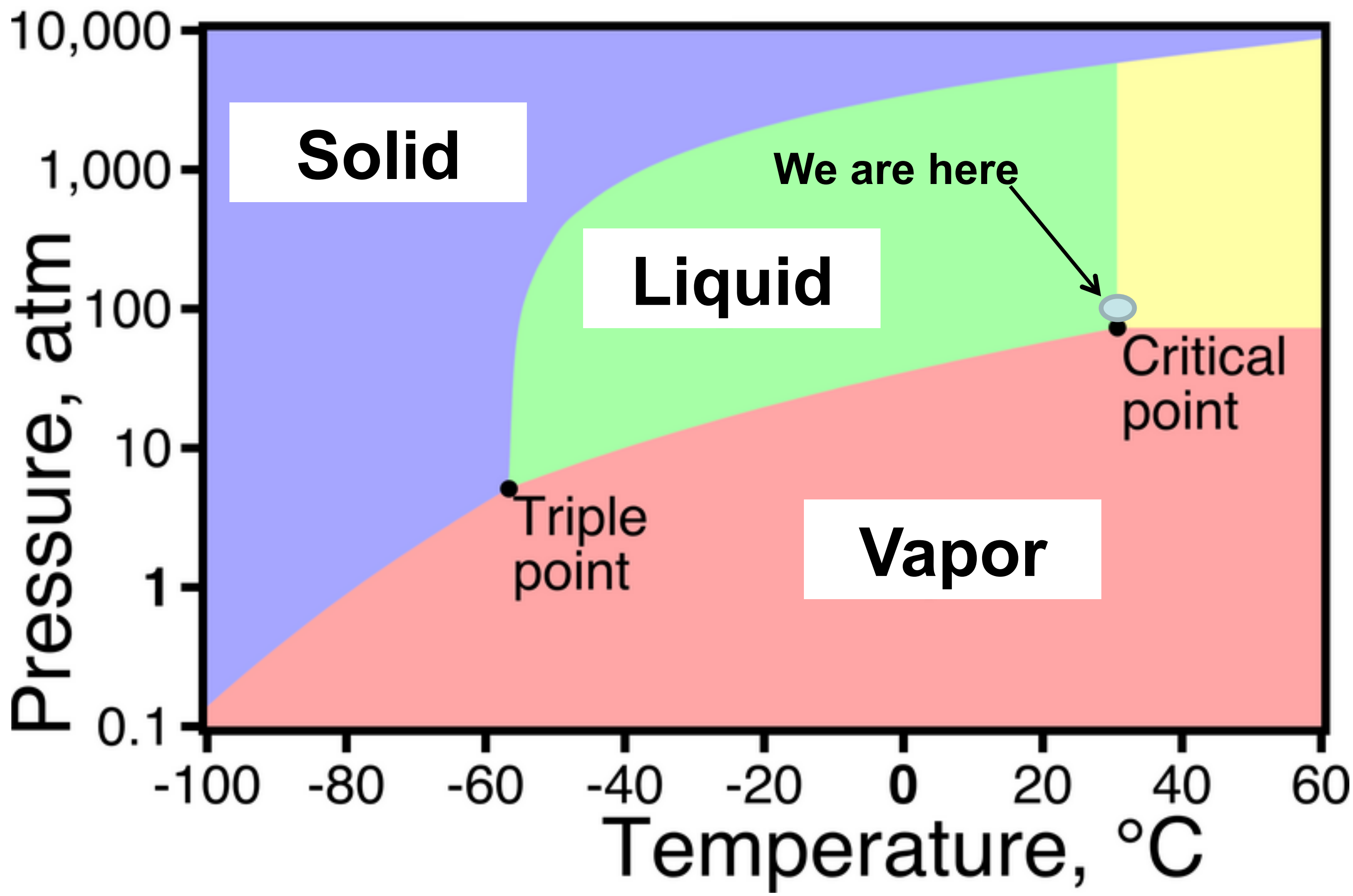
Four Steps

- **CCS is a four-step process**
  - CO_2 captured or concentrated
  - Compressed to ~100-150 atm (~1500-2250 psi)
  - Transported to injection site
  - Injected deep underground into geological formations and sequestered safely for thousands of years



Phase Changes in Carbon Dioxide



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Basics of Carbon Capture

- **3 Categories**
  1) **Post-Combustion**
     Solvent, Solid Sorbent, Membrane, Cryogenic
  2) **Pre-Combustion**
     Integrated Gasification Combined Cycle
  3) **Oxy-Combustion**

Alabama Power Plant Miller
Solid Sorbent Process
1 MW = 20 tonnes / day

Alabama Power Plant Barry
Solvent Process
25 MW = 500 tonnes / day

1 MW ADA-ES Pilot at Alabama Power Plant Miller

SOUTHERN COMPANY

1 MW ADA-ES Pilot at Plant Miller

Project Goals

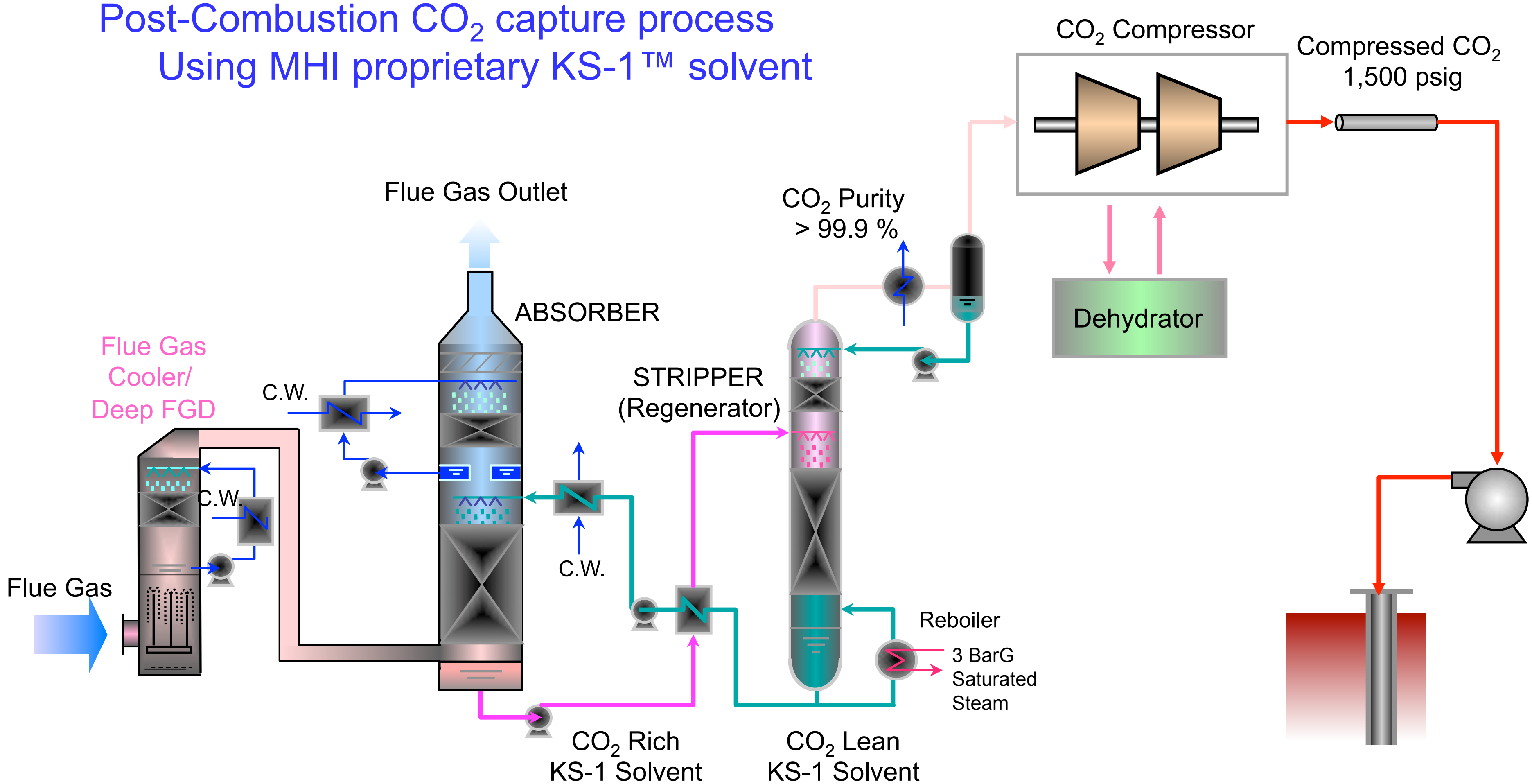
- The overall objective is to validate solid sorbent-based post combustion CO_2 capture through slipstream pilot testing.
- Project Goals:
  - Achieve 90% CO_2 Capture
  - LCOE increase less than <35%
  - Generate a high purity CO_2 stream
  - Successfully scale sorbents

Federal Funding provided by the DOE National Energy Technology Laboratory's Carbon Capture Program

25 MW CCS Demonstration at Alabama Power Plant Barry

Flow Diagram

Post-Combustion CO_2 capture process
Using MHI proprietary KS-1™ solvent



World's Largest Integrated CCS of Coal-fired Power Plant

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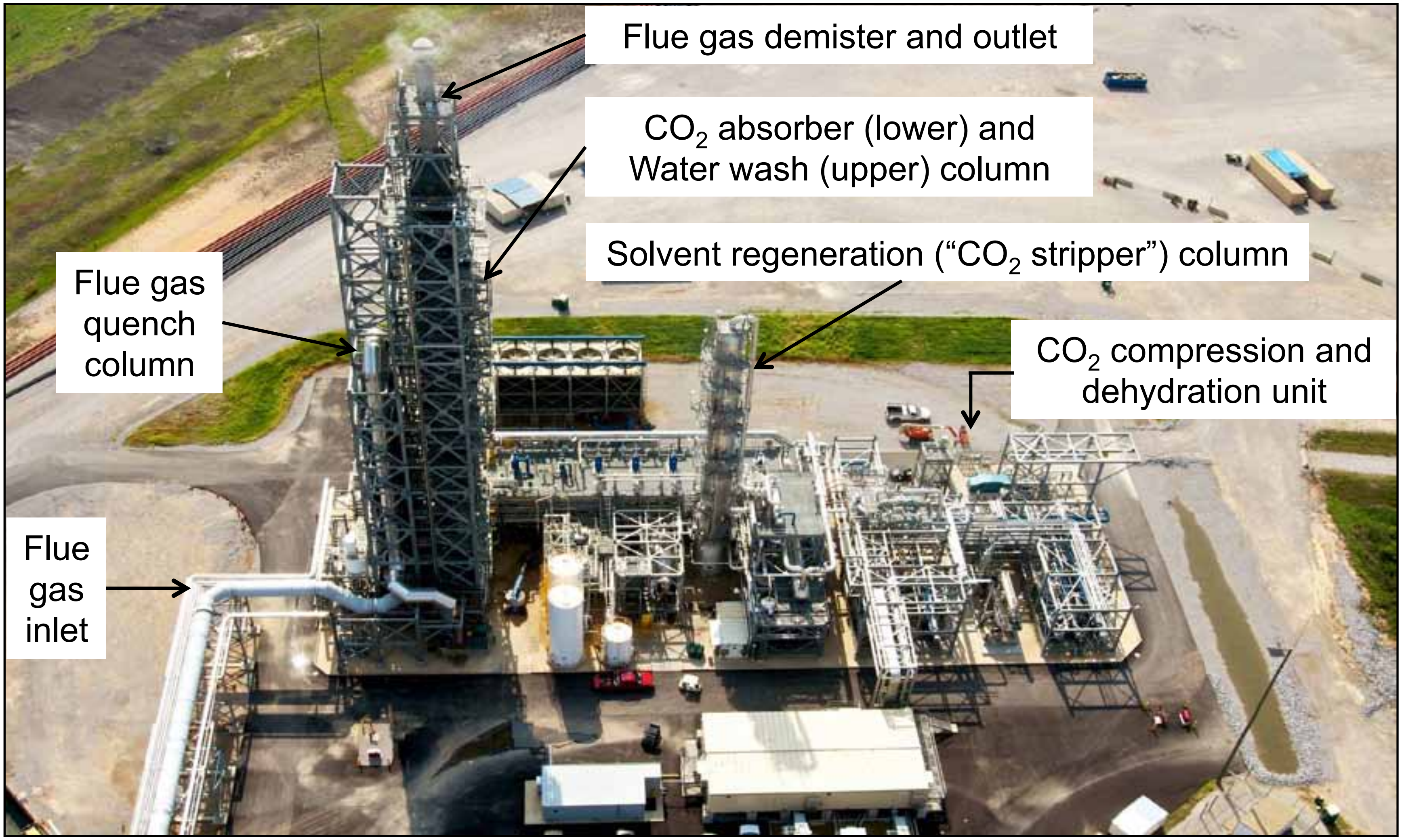
CO2 Capture Plant



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

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
  (World's Largest Integrated CCS from a Coal-fired Power Plant)

Items		Results
Total Operation Time *	**hrs**	**10,600**
Total Amount of Captured CO_2 *	**metric tons**	**198,100**
Total Amount of Injected CO_2 *	**metric tons**	**100,600**
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**

*As of October 31th, 2013

Operational Update of 500 TPD CCS Demo

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)
Dynamic response test for load following	Carried out continuous control testing to optimize the operation condition with self-developed dynamic simulator. The system successfully controlled the operation condition. (Oct. 2013)
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

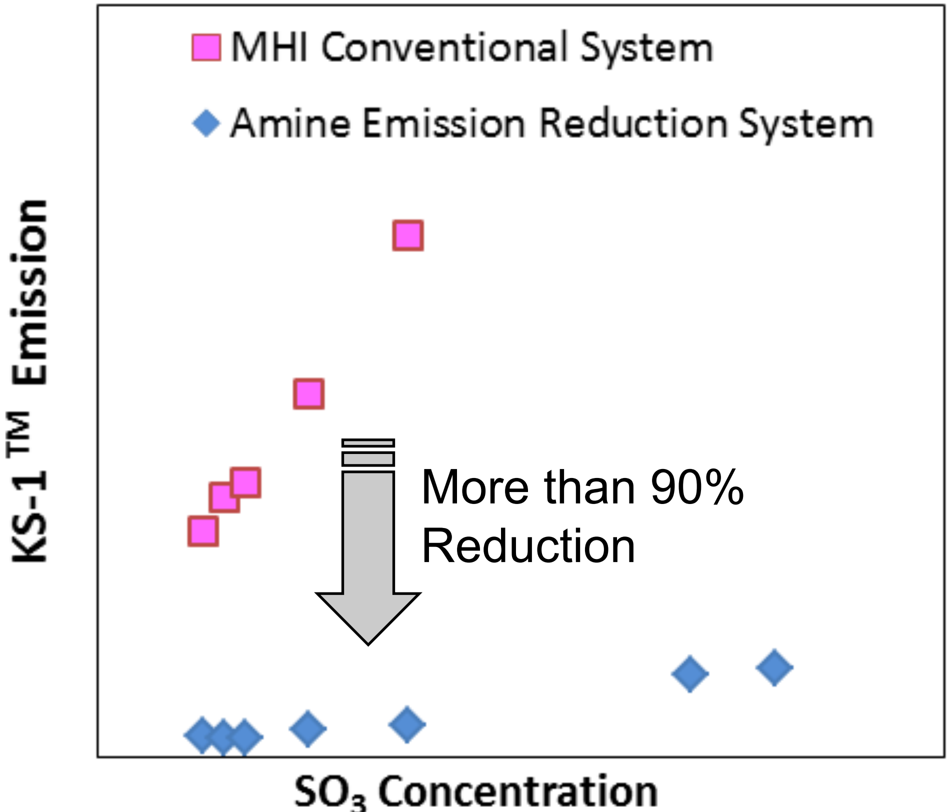


Fig. Relationship between SO_3 conc. and solvent emission

(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)

Heat Integration System

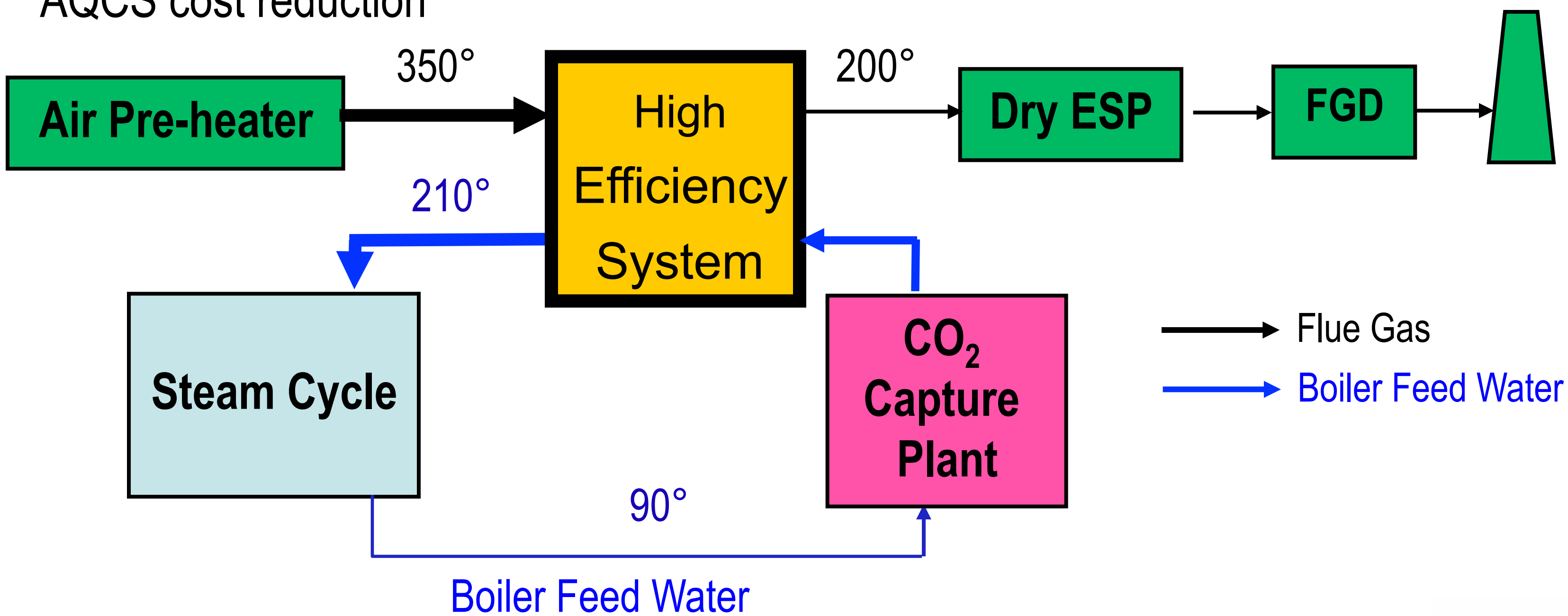
High Efficiency System (HES)

- Project Overview
  - Integrate waste heat recovery technology to 500MTPD Demo Plant at Plant Barry
  - Evaluate improvements in the energy performance of the integrated plant
- Objectives
  - Quantify the energy efficiency improvements to the CO2 capture process when integrated with High Efficiency System (HES) and the host power plant
  - Quantify the tangential benefits of the HES technology
  - ESP performance improvement
  - SO3 and trace elements removal
  - Solvent consumption reduction
  - Water consumption reduction
- Project Schedule
  - BP 1: FEED and Permitting through Sep. 2013
  - BP 2: EPC Oct. 2013 – Sep. 2014
  - BP 3: Field Testing Oct. 2014– Feb. 2016

DOE funded project, "Development and Demonstration of Waste Heat Integration with Solvent Process for More Efficient CO_2 Removal from Coal-Fired Flue Gas" DE-FE0007525

Process Flow & Technology Benefits

- **Improve efficiencies of host steam cycle and CO_2 recovery plant**
- Reduce water consumption in FGD by lowering flue gas inlet temperature
- Improve ESP performance
- Remove SO3 and heavy metals (mercury and selenium) in ESP
- AQCS cost reduction

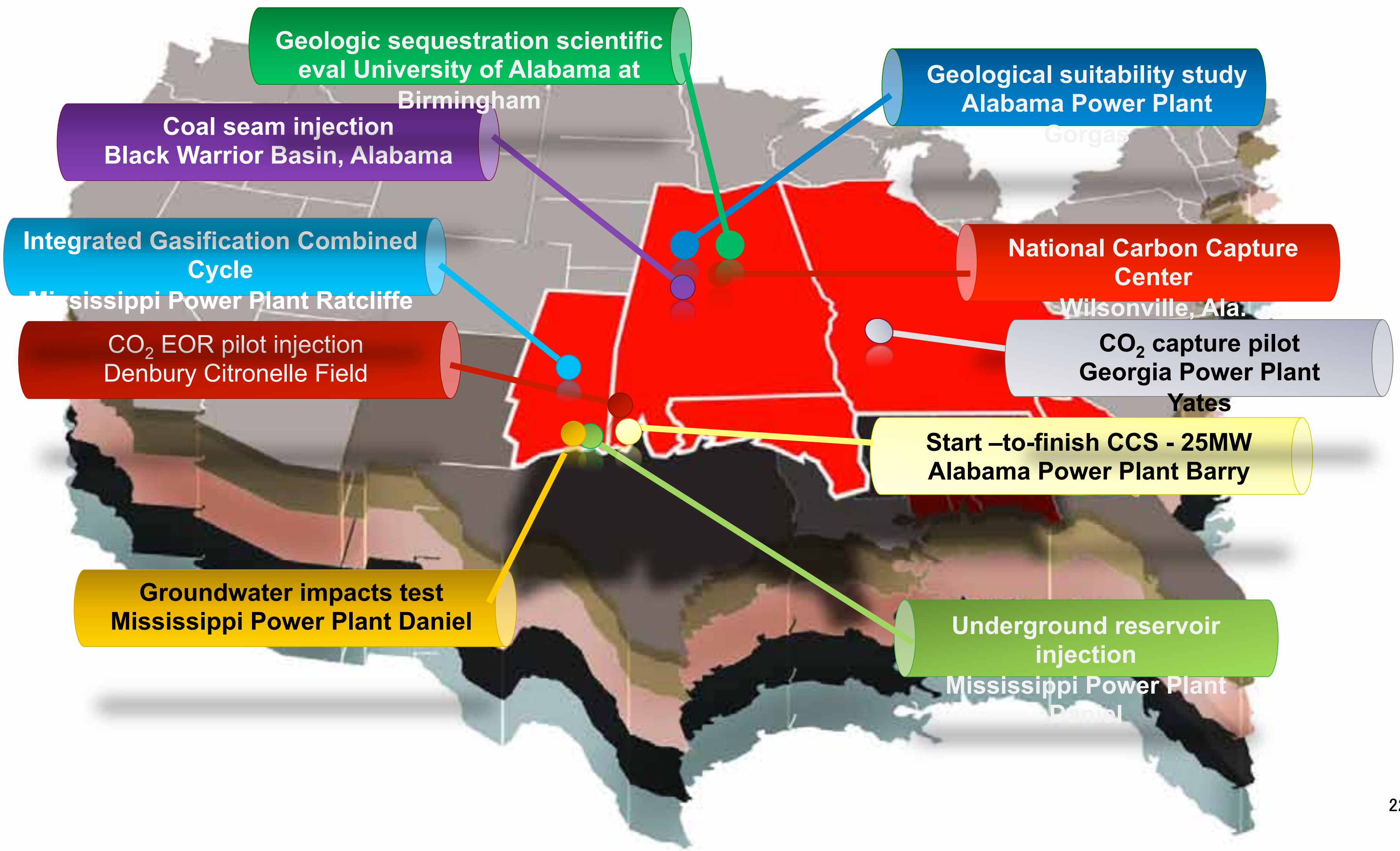


Summary

- Alabama Power's Plant Barry 500 TPD CCS plant has successfully completed its 2nd year of operation
- Total 198,100 metric tons of CO2 were captured, and total 100,600 metric tons of CO2 were injected (10/31/2013)
- Plant performance is very stable at full load condition with CO_2 capture rate of 500 TPD at 90% CO_2 removal and lower steam consumption than the conventional process
- Operation by Southern Company staff has been very successful
- Collaboration between Southern Company and MHI has lead to significant process improvements and enhanced operability demonstrated in the following:
  - New amine emission reduction technologies achieved significant reduction (More than 90% reduction).
  - The spray type distributer achieved significant weight reduction in comparison to the trough type. (Approx. 50% reduction)
  - MHI Dynamic Simulator stably and continuously optimized operation based on the flue gas condition or CO2 production demand.

Southern Company

Leading the Industry in CCS



Thank You!

Questions?

For more information please contact:

Jerrad Thomas – Southern Company Services
Project Manager for CCUS and Research Engineer
Email: JERRTHOM@southernco.com
Tel: 205-257-2425

SECARB 10th Annual Stakeholders' Briefing

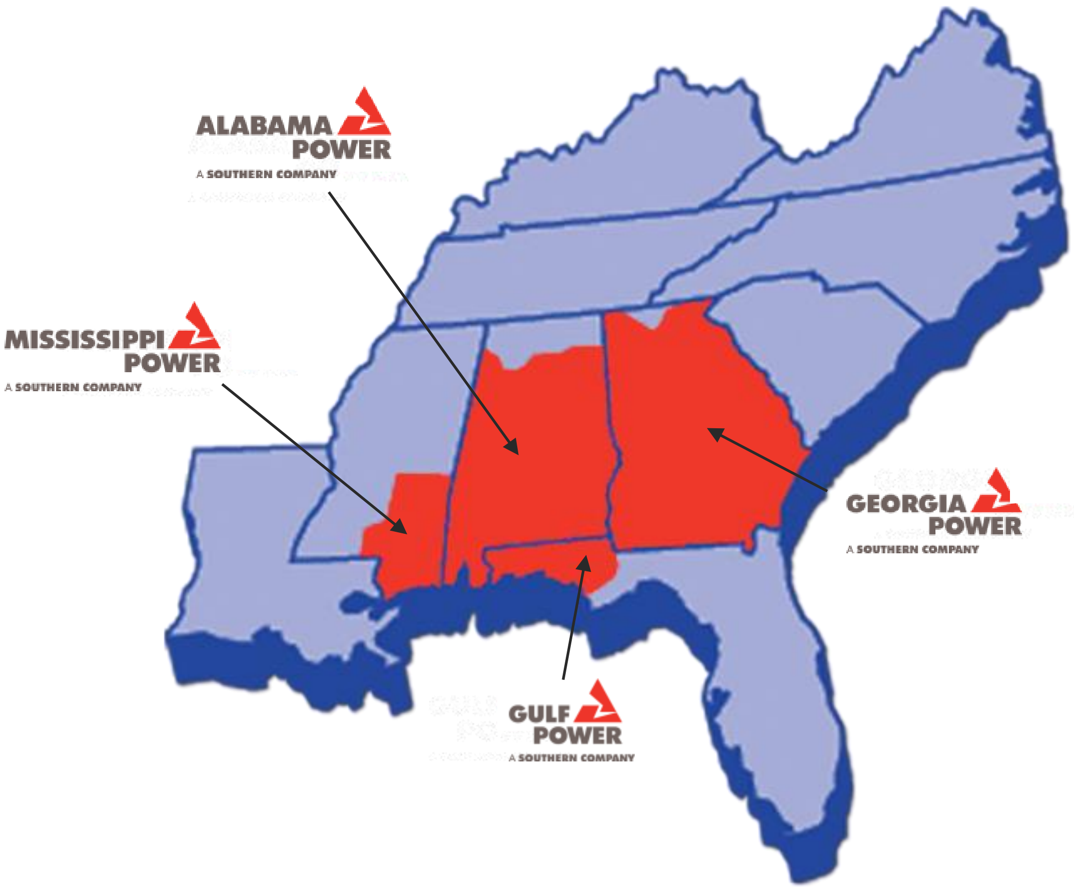
Southern Company CCS R&D: Plant Barry CCS Demo

Dr. Richard A. Esposito
Southern Company

March 12, 2015

Introduction to Southern Company

Regulated Utility Franchises



Regulated Utilities

- Alabama Power
- Georgia Power
- Gulf Power
- Mississippi Power
- Southern Nuclear

Competitive Power

- Southern Power
- Southern Generation Technology

Core Service Area

- 120,000 sq. miles in four states
- 4.4 million retail customers
- 26,000 employees
- 46 GW generation capacity

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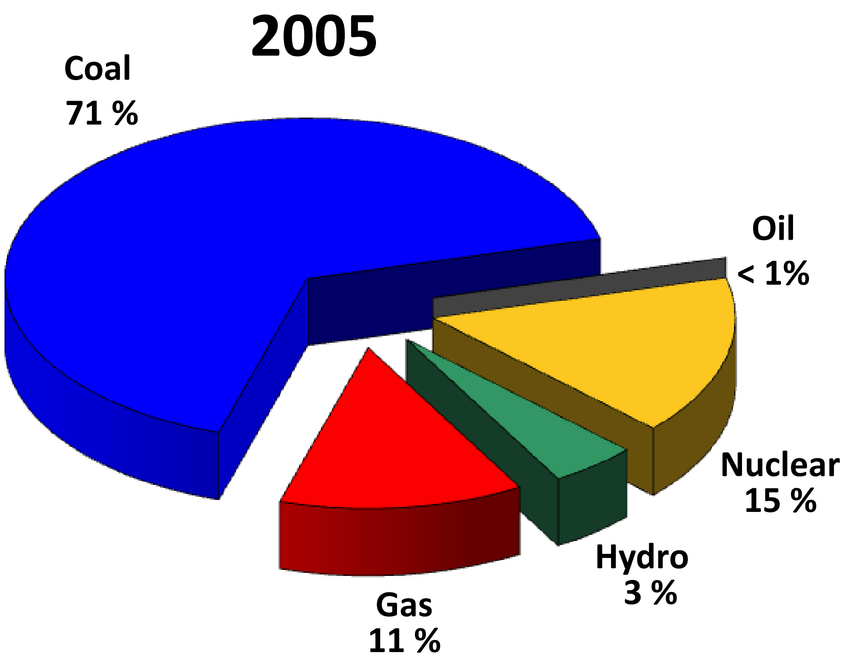
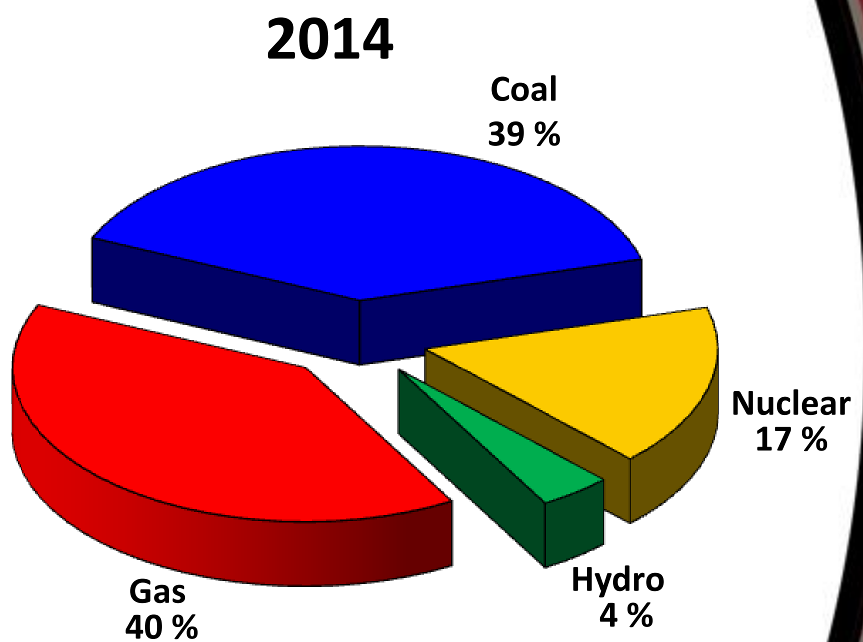
Southern Company Generation Mix 2005 and 2014



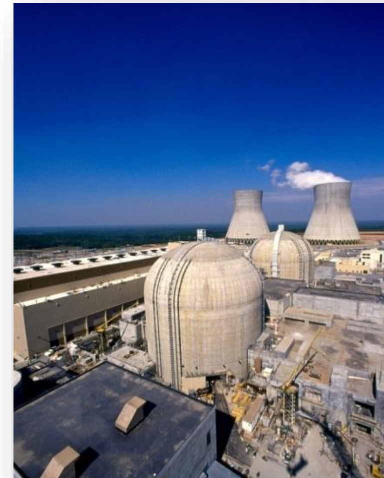


Source: Southern Company Form 10K filings

All of the Below Energy Strategy

New Natural Gas

21^{st} Century Coal



New Nuclear

Energy Efficiency

Biomass

Wind

PV Solar

Recent and Planned Additions

Plant McDonough-Atkinson
2,520 MW Natural Gas CC
Among of the most efficient in the nation

Utility Scale Solar at Southern Power and initiatives at Georgia Power

Vogtle Units 3 & 4
~1,005MW Ownership
AP1000 technology

Multiple Wind Energy PPAs

One of the Largest Biomass Facilities in North America

Kemper County IGCC
~495MW Ownership
Proprietary TRIG technology

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Southern Company R&D

- Only U.S. electric power company with internal R&D organization
- Approximately 150 engineers and scientists in laboratories and facilities dispersed across operating assets
- Active collaboration with other power companies; domestic and international
- Primary goal of research portfolio is to provide technology options to power operating business

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U.S. DEPARTMENT OF ENERGY

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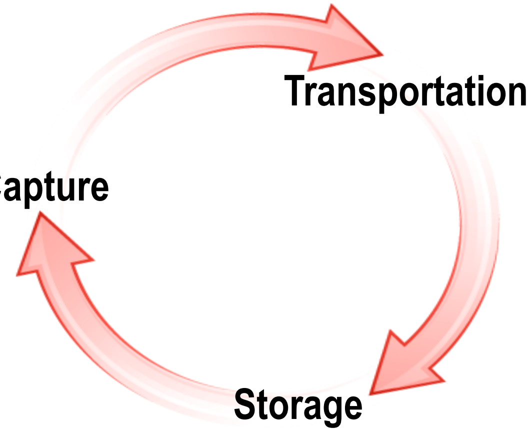
Carbon Capture & Storage R&D Program

"Efforts key to our long-term program success"

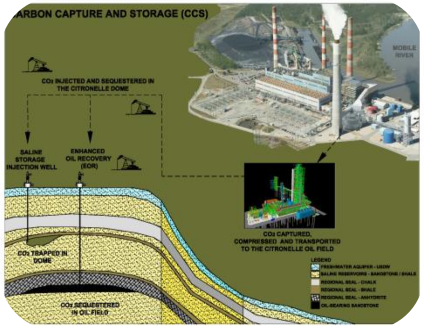
Pilot Scale

Carbon Capture Utilization Storage

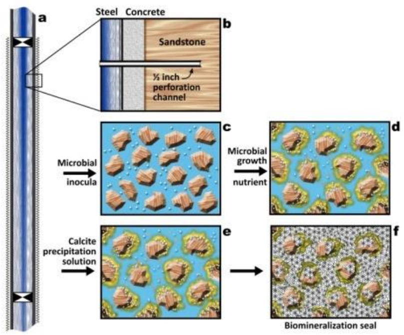


Laboratory Testing

Demonstration Scale



Applied Science

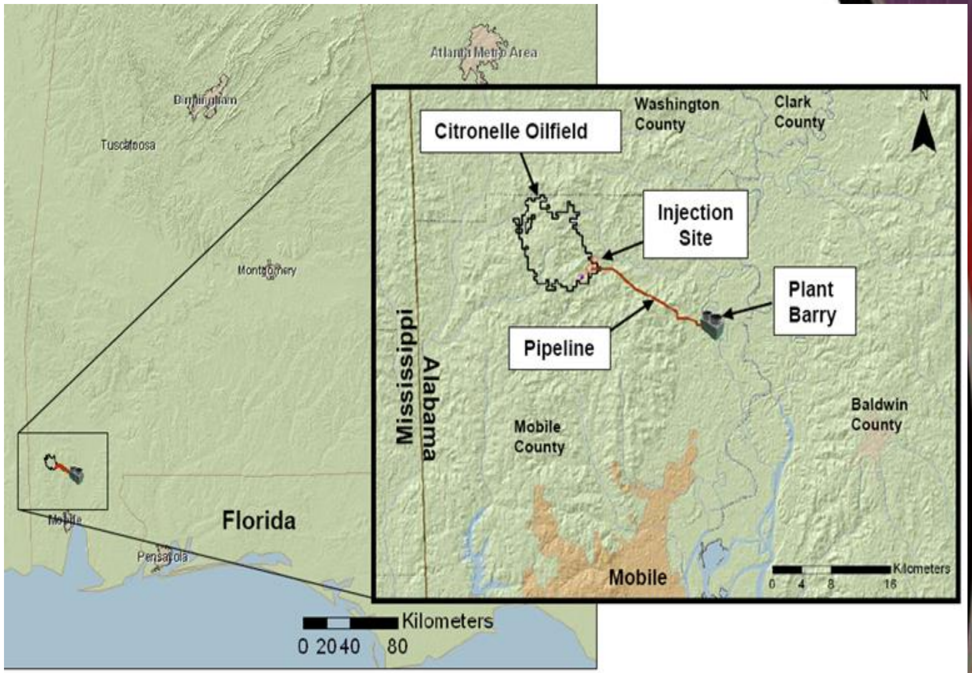


Commercial Demonstration

Plant Barry CCS Demonstration

"largest capture facility on a fossil-fueled power plant in the U.S."

- Carbon capture from Plant Barry (equivalent to 25MW of electricity).
- 12 mile CO_2 pipeline linking captured CO_2 with the injection site.
- CO_2 permitting/injection into ~9,400 ft. deep saline formation at the Citronelle Oil Field.
- Monitoring of CO_2 storage during injection and three years post-injection.



Power Plant

Capture

Transport

Storage

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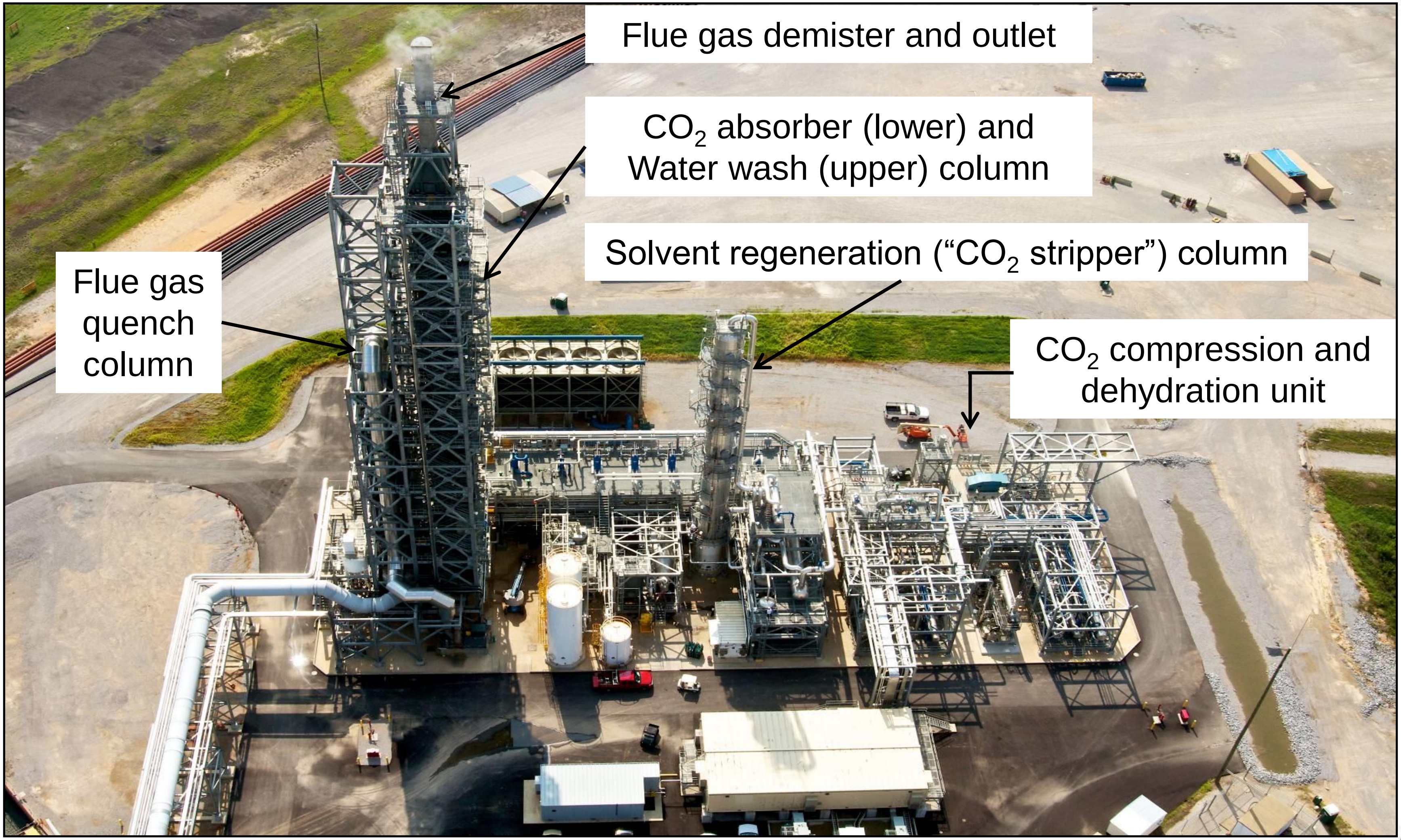
Aerial Photograph with Labels







11/04/2010

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).

CO_2 Capture 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

Items		Results*
Total Operation Time	**hrs**	**13,090**
Total Amount of Captured CO_2	**metric tons**	**240,900**
Total Amount of Injected CO_2	**metric tons**	**114,104**
CO_2 Capture Rate	**metric tons per day**	**> 500**
CO_2 Removal Efficiency	**%**	**> 90**
CO_2 Stream Purity	**%**	**99.9+/N_2**
Steam Consumption	**ton-steam/ton-CO_2**	**0.98**

*As of 12/16/2014

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Improved Technology Applications

- 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

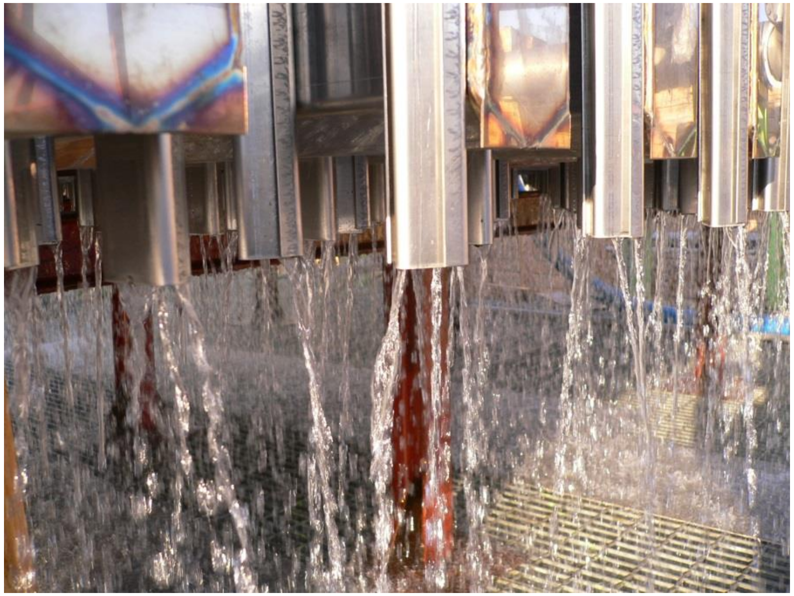

Fig. Spray Type Distributer (MHI Proprietary)

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Recent Barry 25 MW CCS Testing

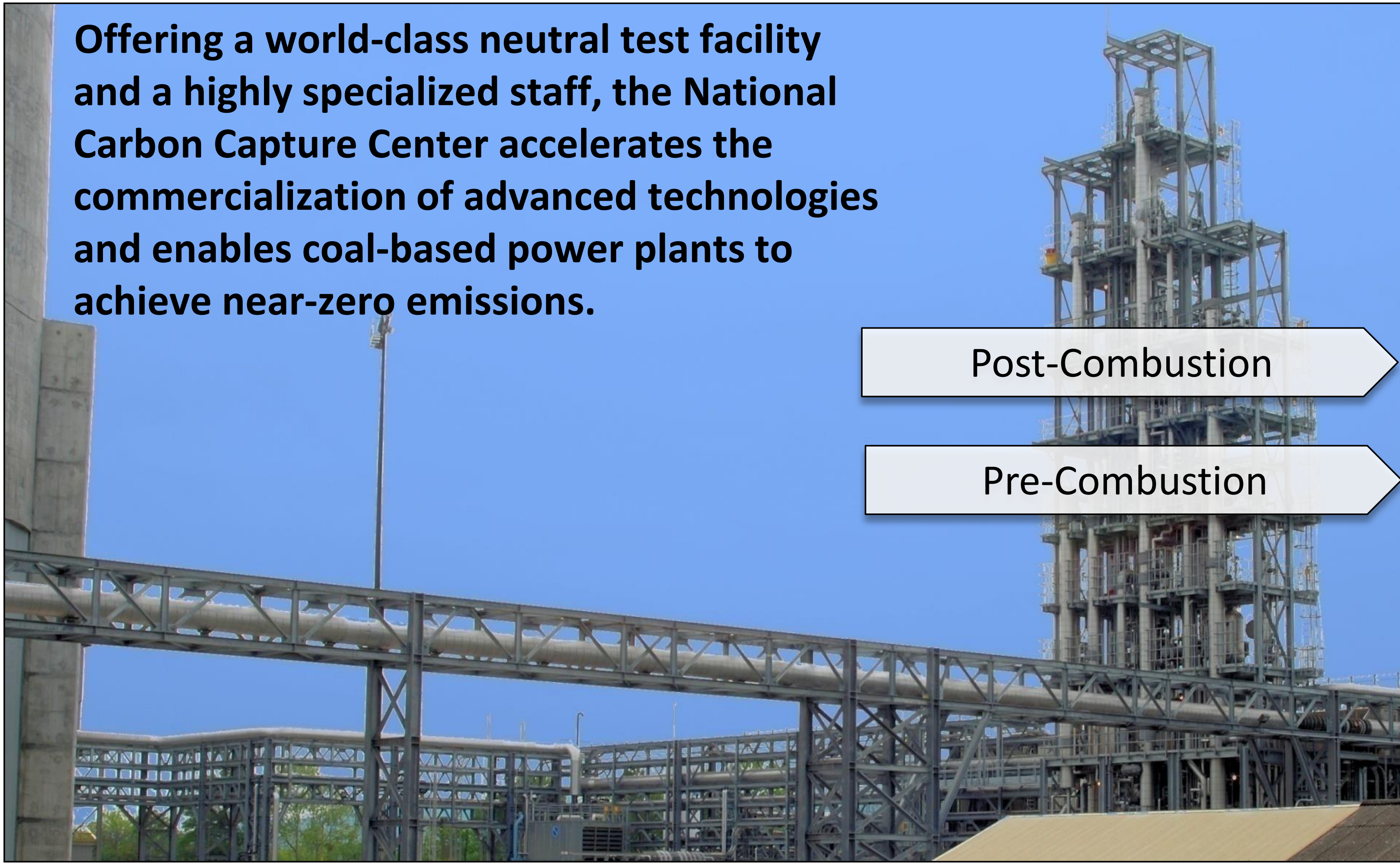
- Built-in Reboiler
  - Evaluating a new built-in reboiler design to replace the shell and tube reboiler in solvent regeneration (better heat transfer)
- Dehydration Glycol Consumption
  - Glycol consumption slightly higher than the design case (looking at different additives (O_2 scavenger)
- Caustic Scrubbing
  - Deep flue gas desulfurization was substituted with 20% caustic instead of the traditional limestone scrubbing.

SOUTHERN COMPANY

The National Carbon Capture Center

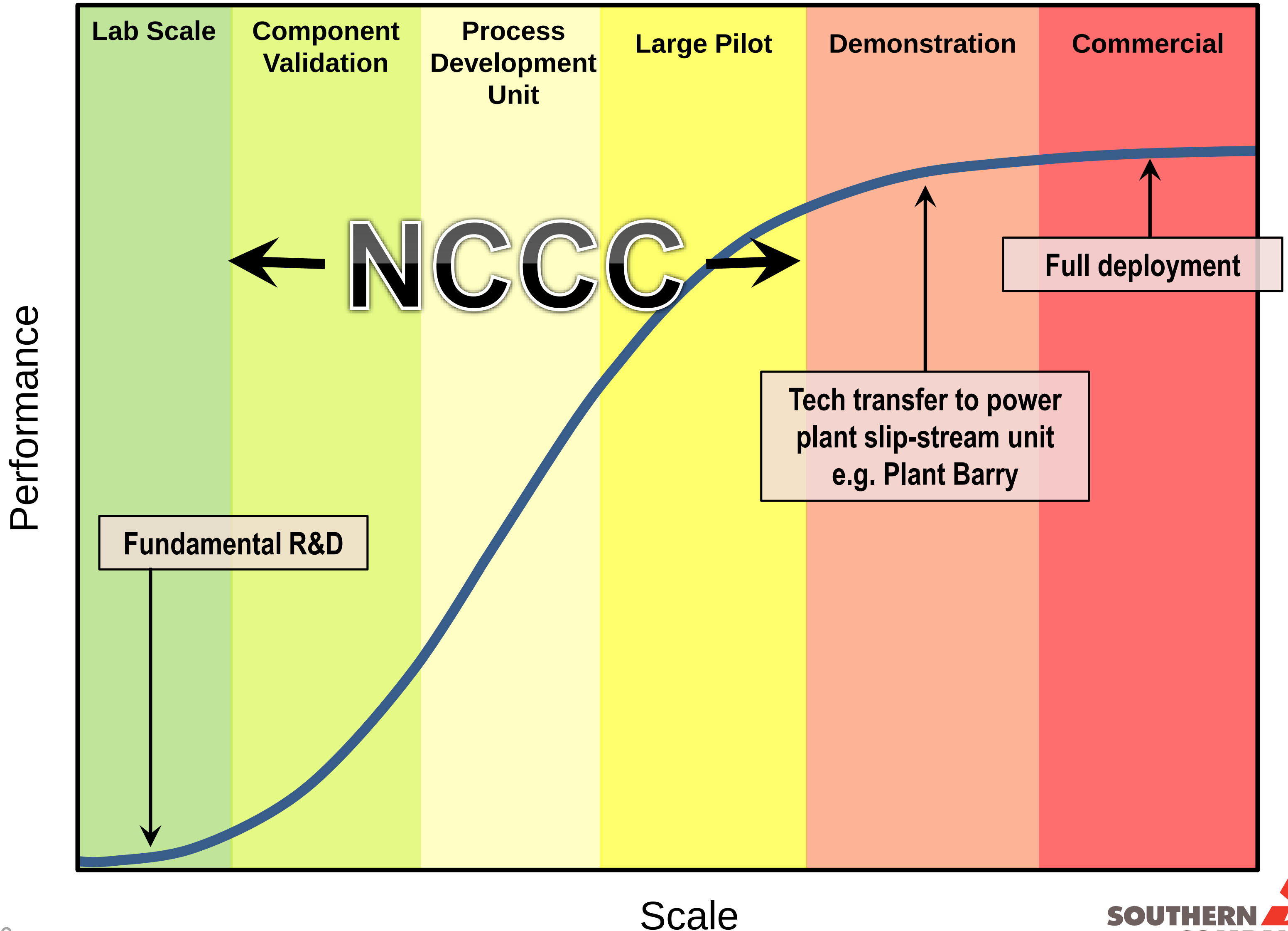
"at the Power Systems Development Facility"

Offering a world-class neutral test facility and a highly specialized staff, the National Carbon Capture Center accelerates the commercialization of advanced technologies and enables coal-based power plants to achieve near-zero emissions.



Luminant · Peabody · NRG · AEP American Electric Power · ACI Arch Coal, Inc. · RioTinto · EPRI Electric Power Research Institute · Southern Company

R&D Role of the NCCC/PC4



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Kemper Energy Facility

582-MW TRIG™ IGCC with 65% CO_2 Capture

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Kemper County IGCC

TRIG™
TRANSPORT INTEGRATED GASIFICATION

- First of a kind gasification technology developed by SO and KBR with U.S. DOE support
- Carbon footprint equivalent to a combined cycle natural gas unit
  - 65% CO_2 capture for enhanced oil recovery
  - CO_2 sold to oil companies for EOR
- Affordable, abundant, low-rank coal resource
  - Mine mouth lignite coal
- Technology platform for the future of coal

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Geologic Characterization

"to advance site certification for commercial storage"

Alabama Power William Crawford
Gorgas Stratigraphic Test Well

Mississippi Power Victor J. Daniel
CO_2 Pilot Injection Study

Alabama Power James M. Barry
CO_2 Injection Demonstration

Georgia Power Plant Bowen
Deep Site Geology Investigation

Other supported/collaborative efforts

- **Outreach & Education:**
  - DOE Research Experience in Carbon Sequestration (RECS)
  - DOE CCS Training & Education/SECARB Ed
- **Standards:**
  - CSA US-Canada Standards for Geologic Storage of CO_2
  - ANSI ISO TC-265 international standards for carbon capture and geologic storage
- **Infrastructure Assessment:**
  - CCS Technology and Pipeline Infrastructure Study (LANL)
  - Florida Panhandle Pipeline Infrastructure Model (University of North Florida)
- **University Collaborations:**
  - Carbon Sequestration Simulation Center (University of Alabama at Birmingham)
  - Geologic Cap Rock Integrity Lab (University of Alabama at Birmingham)
  - Geological assessment of the South Rift Basin (University of South Carolina)
  - Membership in MIT Carbon Sequestration Initiative and GCCSI
- **Risk Management:**
  - Well bore leakage mitigation study for biomineralization remediation of legacy well bores (Montana State University)
  - Valuation of human health and environmental damages from CCS operations (Industrial Economics Incorporated)

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Concluding thoughts on CCS

- The Barry project represents a significant understanding and improvements in post combustion CCS and is a stepping stone to commercial deployment
- CCS will be a niche market with Southern Company in the Southeast
- Early project development benefits from long-term CO_2 off-take agreements for EOR to support financial investment
- Pipeline infrastructure for EOR and saline storage could be a limiting factor with existing generating units
- Environmental risks are not as large as we one thought
- Low natural gas prices will continue to limit commercial CCS deployment

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Southern Company

R&D for the Future of Clean Energy

Thank You!

SECARB 10th Annual Stakeholders' Briefing

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SECARB Phase III Citronelle Project (Anthropogenic Test) in Alabama

Dave Riestenberg, PM, ARI

Rob Trautz, SR. TECH MGR., EPRI

George Koperna, VP, ARI

Steve Carpenter, VP, ARI

10th Annual SSEB Stakeholders Meeting

12 March 2015

Acknowledgement

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SECARB
Southeast Regional Carbon Sequestration Partnership

SOUTHERN COMPANY
Energy to Serve Your World℠

SOUTHERN STATES ENERGY BOARD

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Denbury

Topics of Discussion

1. *BRIEF* Introduction
2. Monitoring & Modeling Lines of Evidence
3. AoR & Modeling Update
4. Lessons Learned
5. Questions, Answers, Discussion

Project Objectives

1. Support the United States' largest prototype coal-fired 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.

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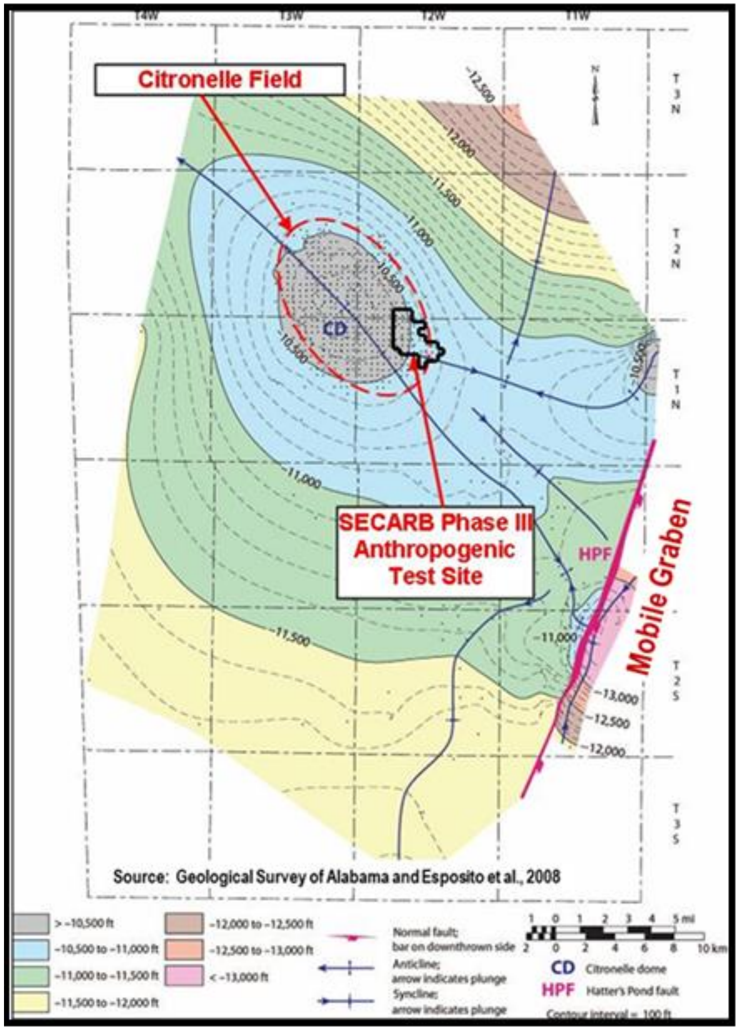
Storage Site: The Citronelle Oilfield



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	Saline Reservoir
	Paleocene		Bashi Marl	
			Salt Mountain LS	
		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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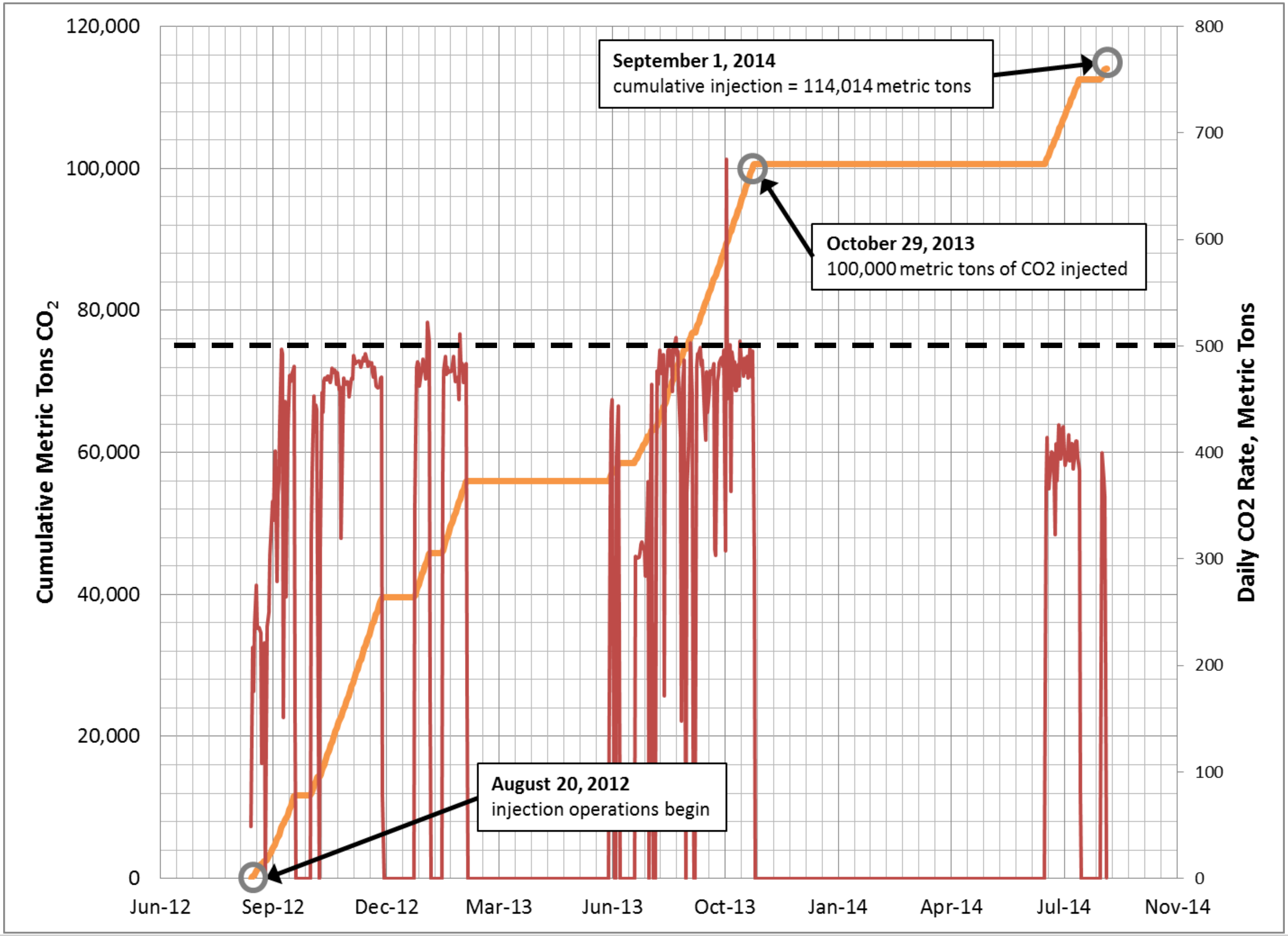
UIC Class V Permit

- **Class V Experimental Injection Well permit**
  - Short duration of injection (3 years) and modest volumes of CO_2
  - Characterization and modeling of “stacked” CO_2 storage
  - CO_2 injection under “real world” operating conditions
  - Demonstration of experimental monitoring tools and methods
- **Many Class VI (CO_2 sequestration well) standards were applied**
  - *Injection Area of Review (AOR) determined by modeling and monitoring results (updated annually)*
  - *Deep, shallow and surface CO_2 monitoring*
  - Injection stream monitoring
  - *Site closure based on USDW non-endangerment demonstration and CO_2 containment (5-yr renewal)*
    - *Based on monitoring and modeling results*

Storage Project Status

- ADEM granted permission to inject on August 8, 2012
  - Injection commenced on August 20, 2012
- Through September 1, 2014, approximately 114 thousand metric tons of CO_2 were injected
- A crosswell seismic survey acquired in June, 2014 captured a time-lapse image of the CO_2 plume
- Other testing and monitoring activities indicate containment
- The project entered the *Post-Injection Site Care Period* in September, 2014
- Site closure based on CO_2 containment and USDW non-endangerment

CO_2 Injection History



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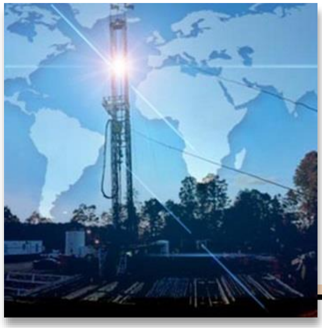
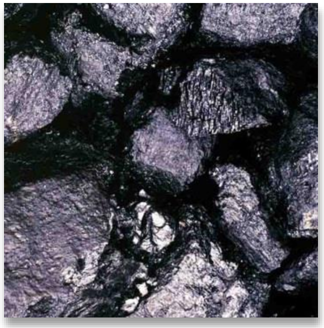




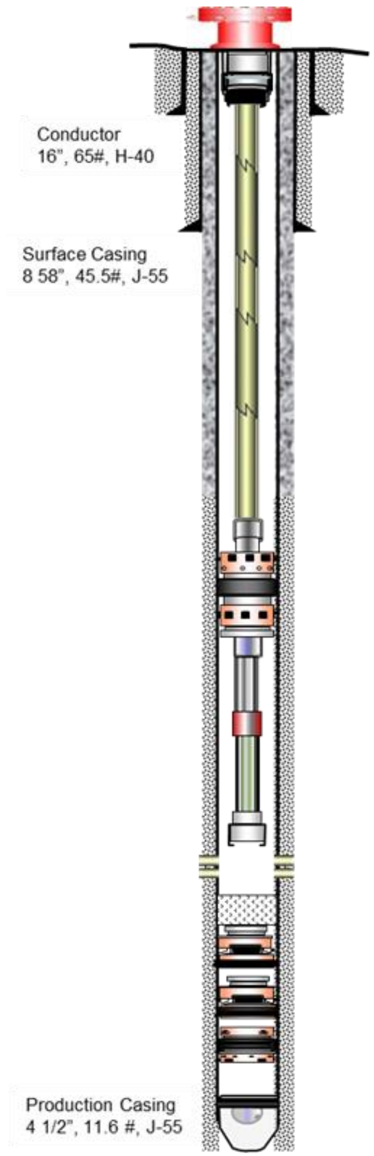
1. Monitoring & Modeling Lines of Evidence

Anthro Test MVA Program Drivers

- Multiple lines of evidence to confirm CO_2 containment
  - Soil CO_2 flux and tracer monitoring
  - Crosswell seismic and VSP
  - Pulsed neutron capture logging (in- and above-zone saturation)
  - USDW monitoring
- Assure non-endangerment of USDWs
  - Monitoring geochemistry of shallow aquifers
- Test experimental methodologies
- Inform the reservoir simulation
  - Above tools plus downhole pressure

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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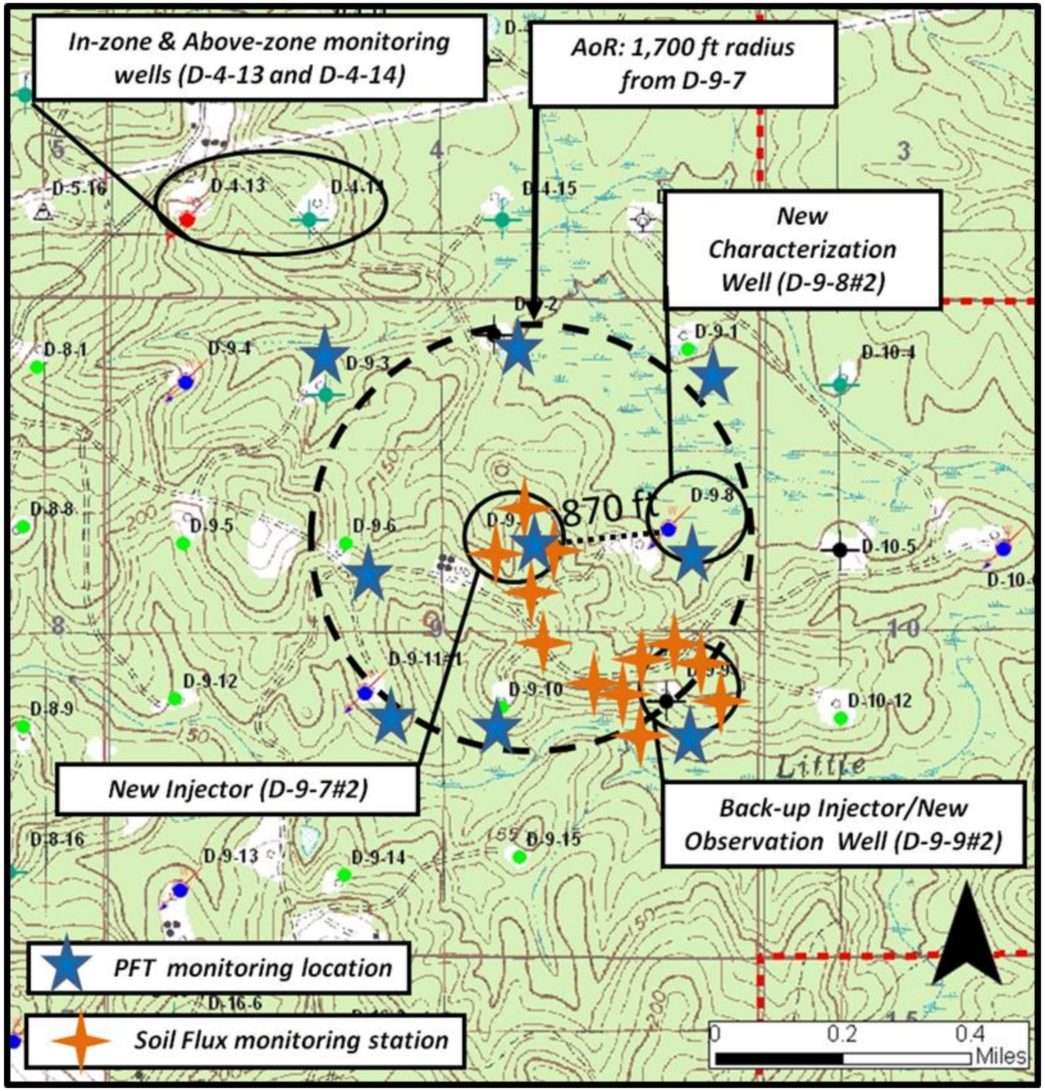
Anthro Test MVA Program



- One new injector (D-9-7 #2)
- Two new deep observation wells (D-9-8 #2 & D-9-9 #2)
- Two in-zone & above zone monitoring wells (Citronelle wells D-4-13 & D-4-14)
- One PNC logging well (D-9-11)
- 12 soil flux monitoring locations
- PFT monitoring on nine well pads
- Crosswell and VSP between D-97#2 and D-9-8#2

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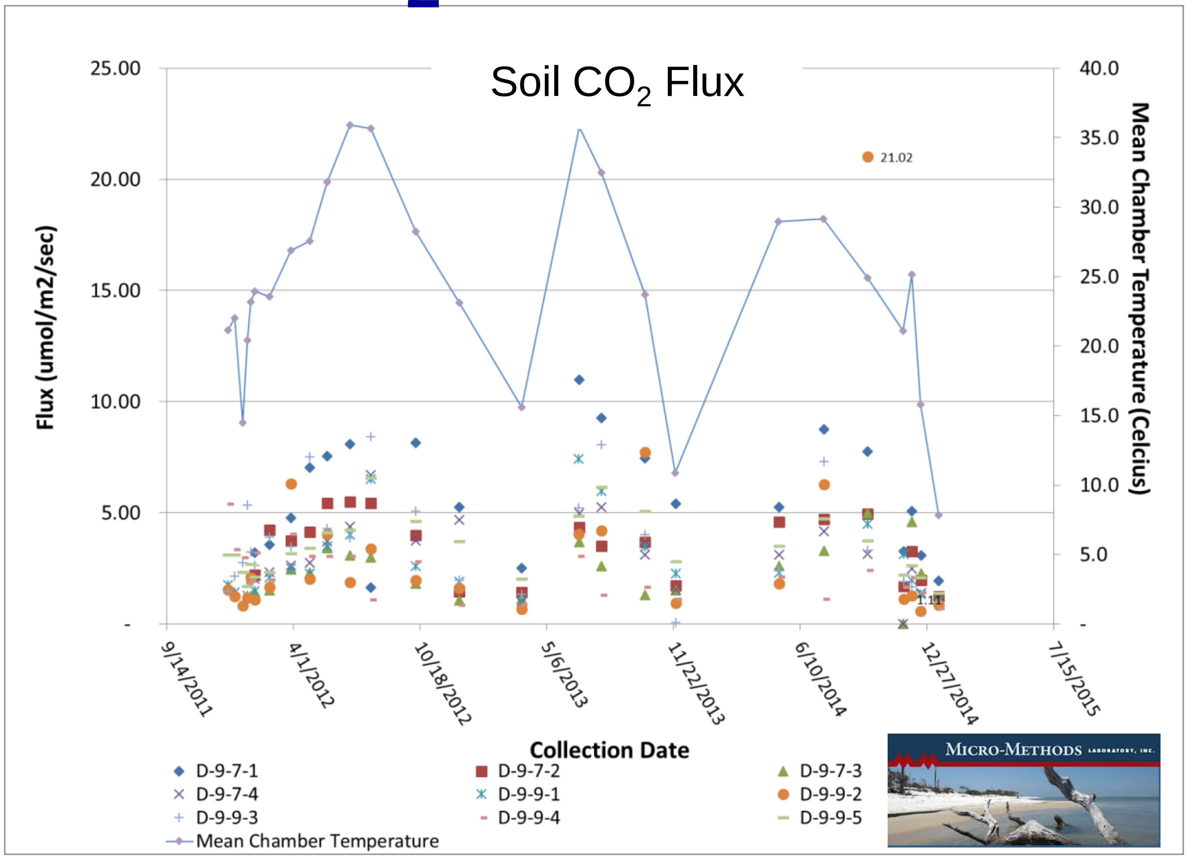
CO_2 Containment-
Soil CO_2 Flux and Tracer Monitoring



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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Deep Monitoring – Time-Lapse Crosswell Seismic

Schlumberger Carbon Services

- 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

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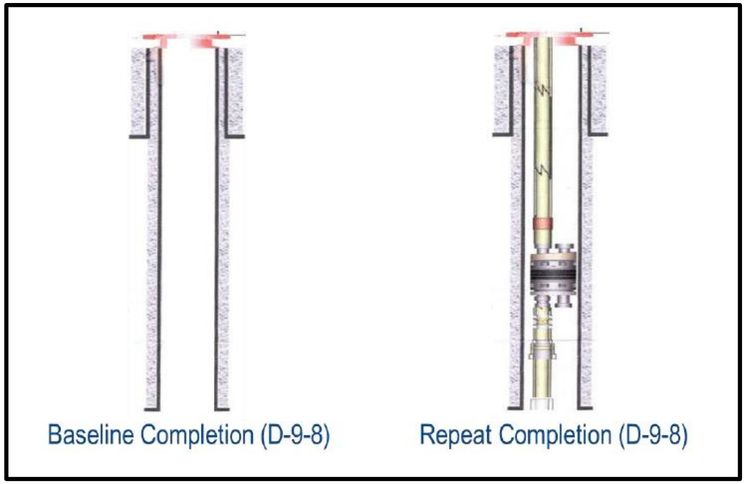
Crosswell Survey Configuration and Parameters

- 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
- 840' 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 baseline conditions

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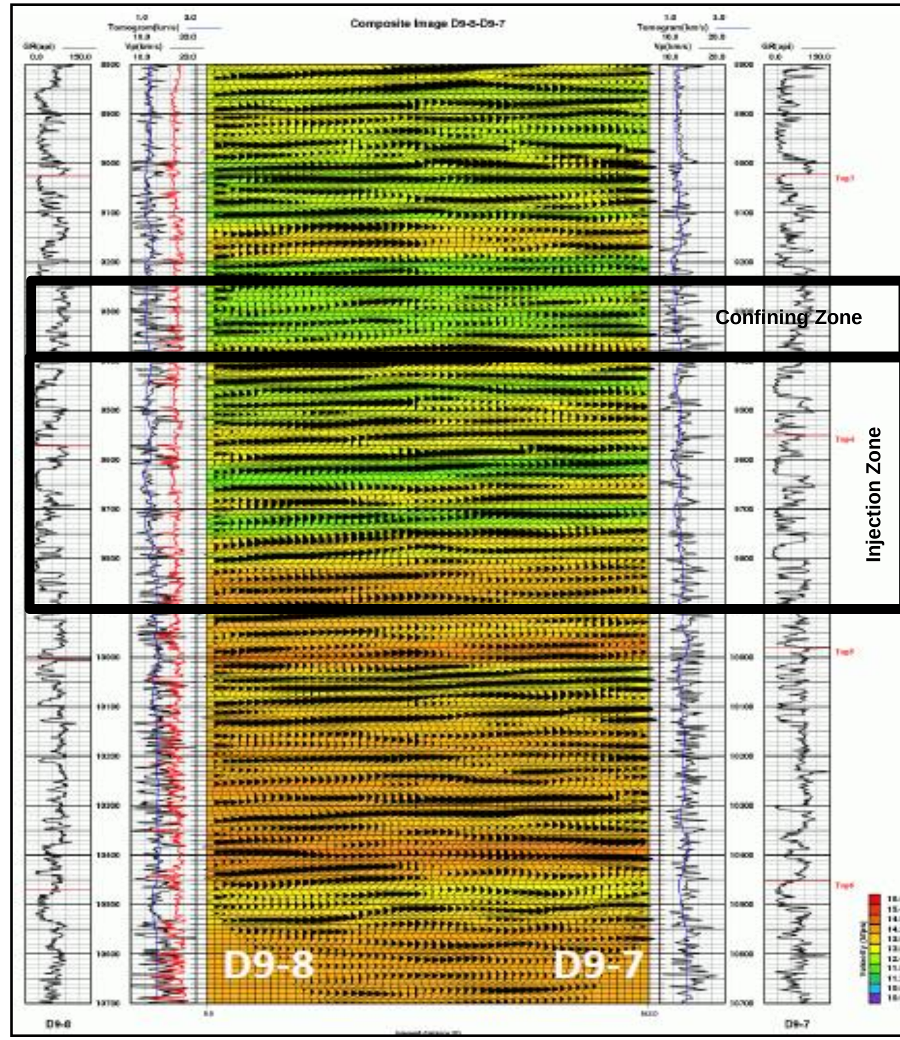
Baseline Survey Results

- Velocity tomography and reflection imaging (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)

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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

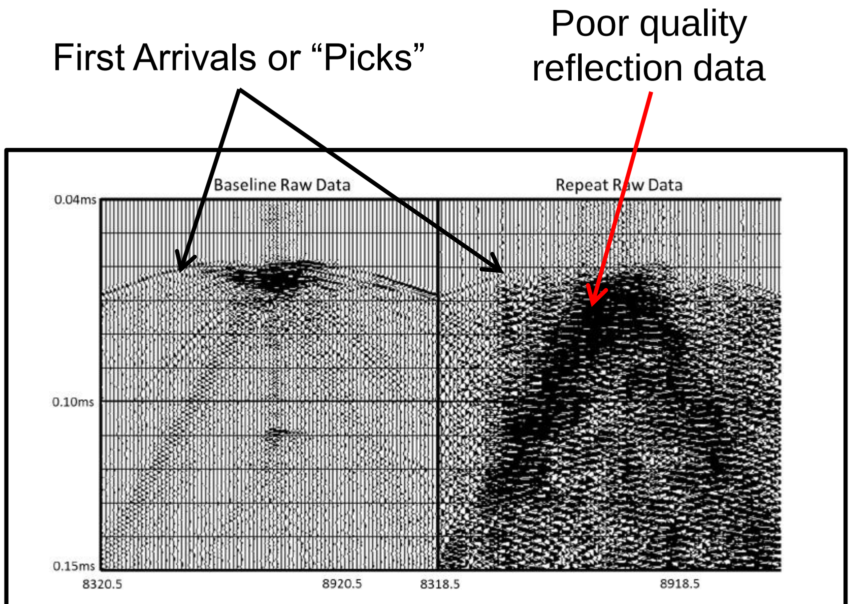

Figure I-3. Profile D-9-8 – D-9-7 baseline and monitor raw data comparison.

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

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Comparison of Crosswell Reflectors

Baseline Tomogram

Strong, continuous reflectors

Repeat Tomogram

Weak and/or discontinuous reflectors

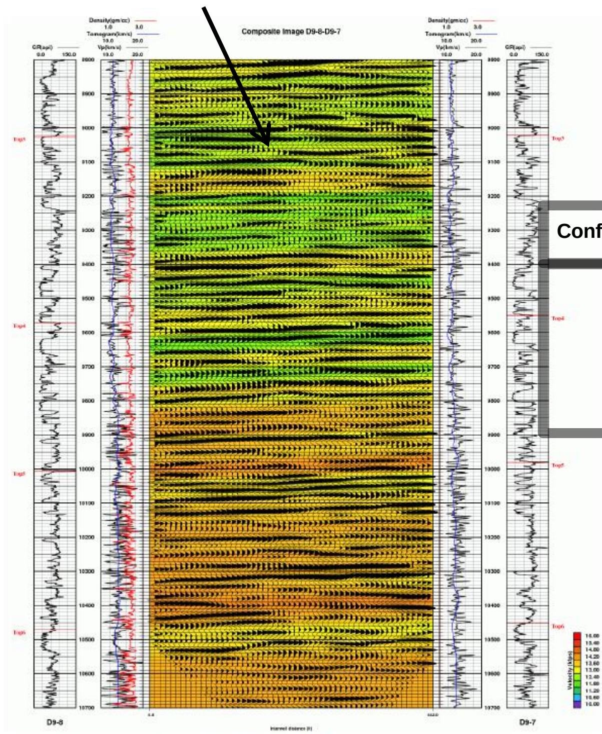

Figure I-4. Profile D-9-8 – D-9-7 baseline composite image

Confining Zone

Injection Zone

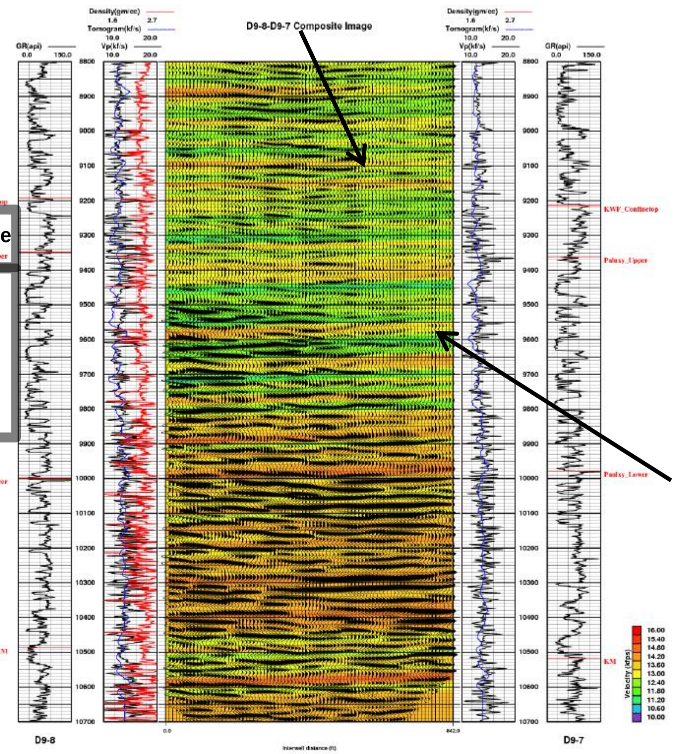

Figure I-5. Profile D-9-8 – D-9-7 monitor composite image

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

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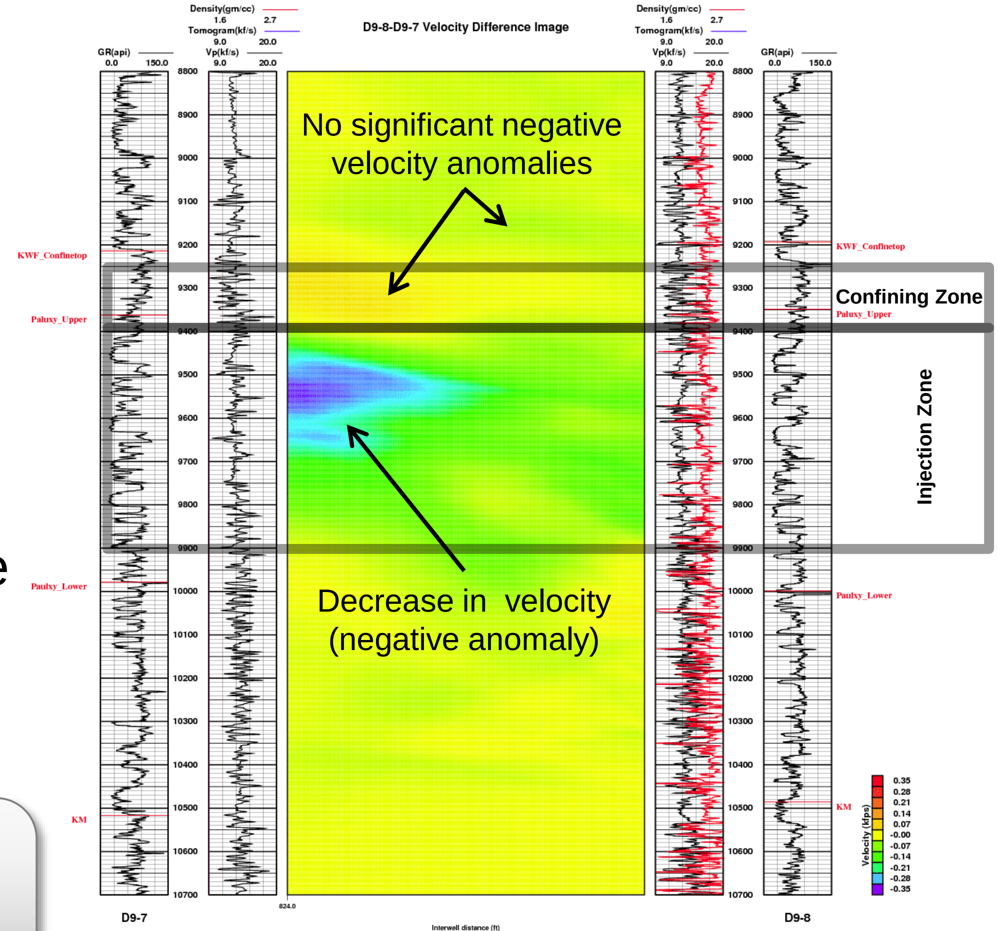
Time-Lapse Differencing Using the Baseline and Repeat Velocity Tomograms

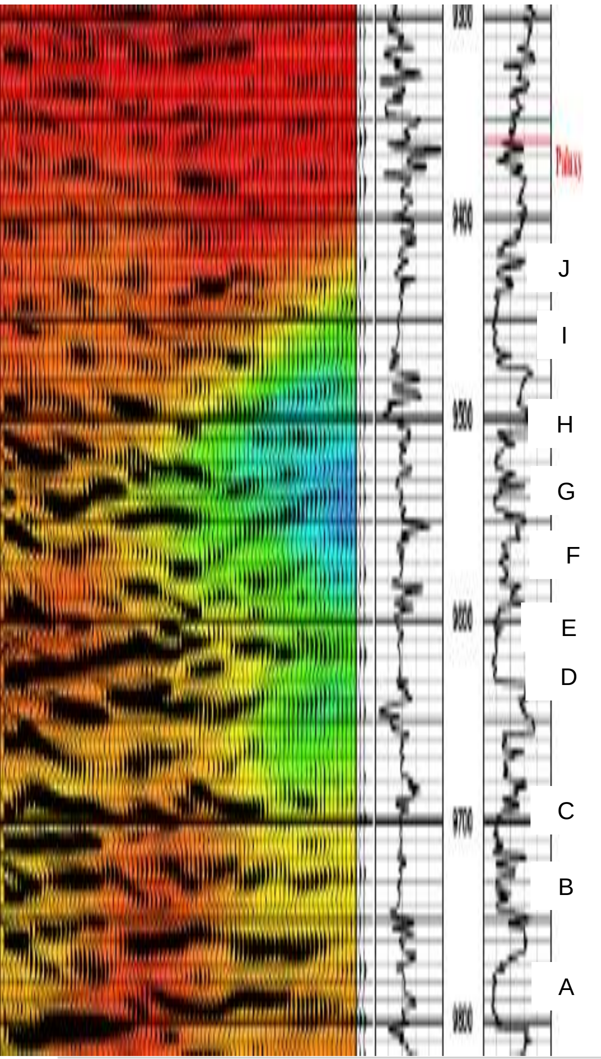
- First arrivals from repeat survey were of sufficient quality to produce a velocity difference image (right) showing regions where seismic velocity has changed over time
- Time-lapse difference image indicates a decrease in seismic velocity in the upper injection zone of up to 3%, suggesting an increase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

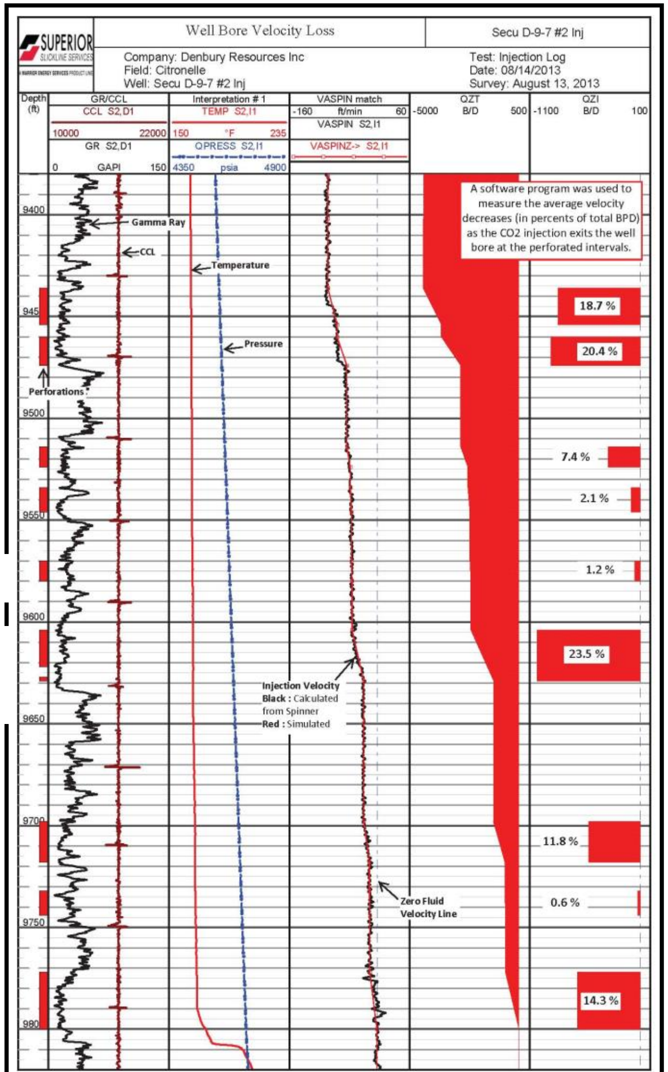
More importantly, no negative velocity anomalies are observed in or above the confining unit…implying no detectable leakage out of inj. zone



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 CO2 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

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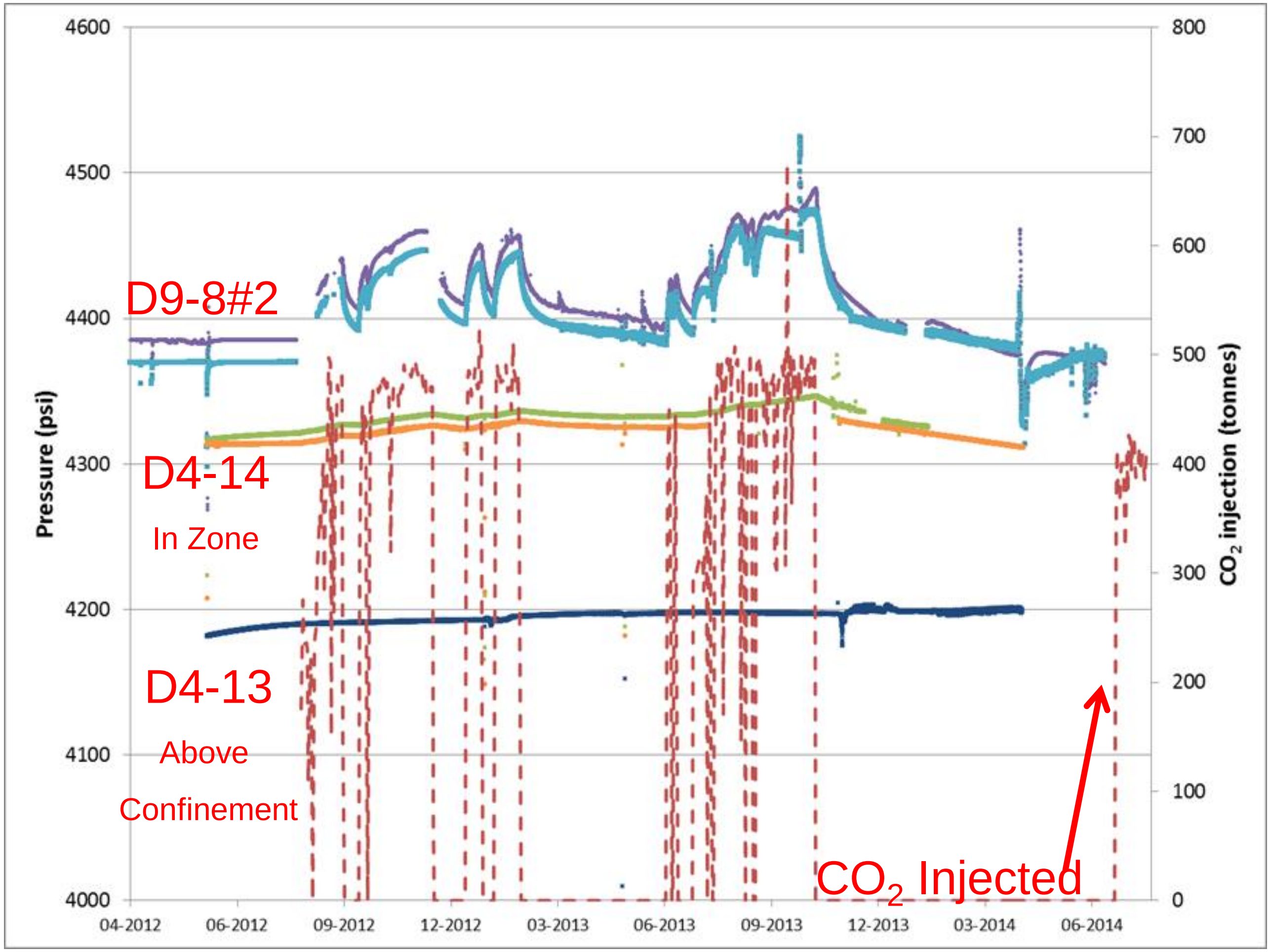
Deep MVA – Pressure Response



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

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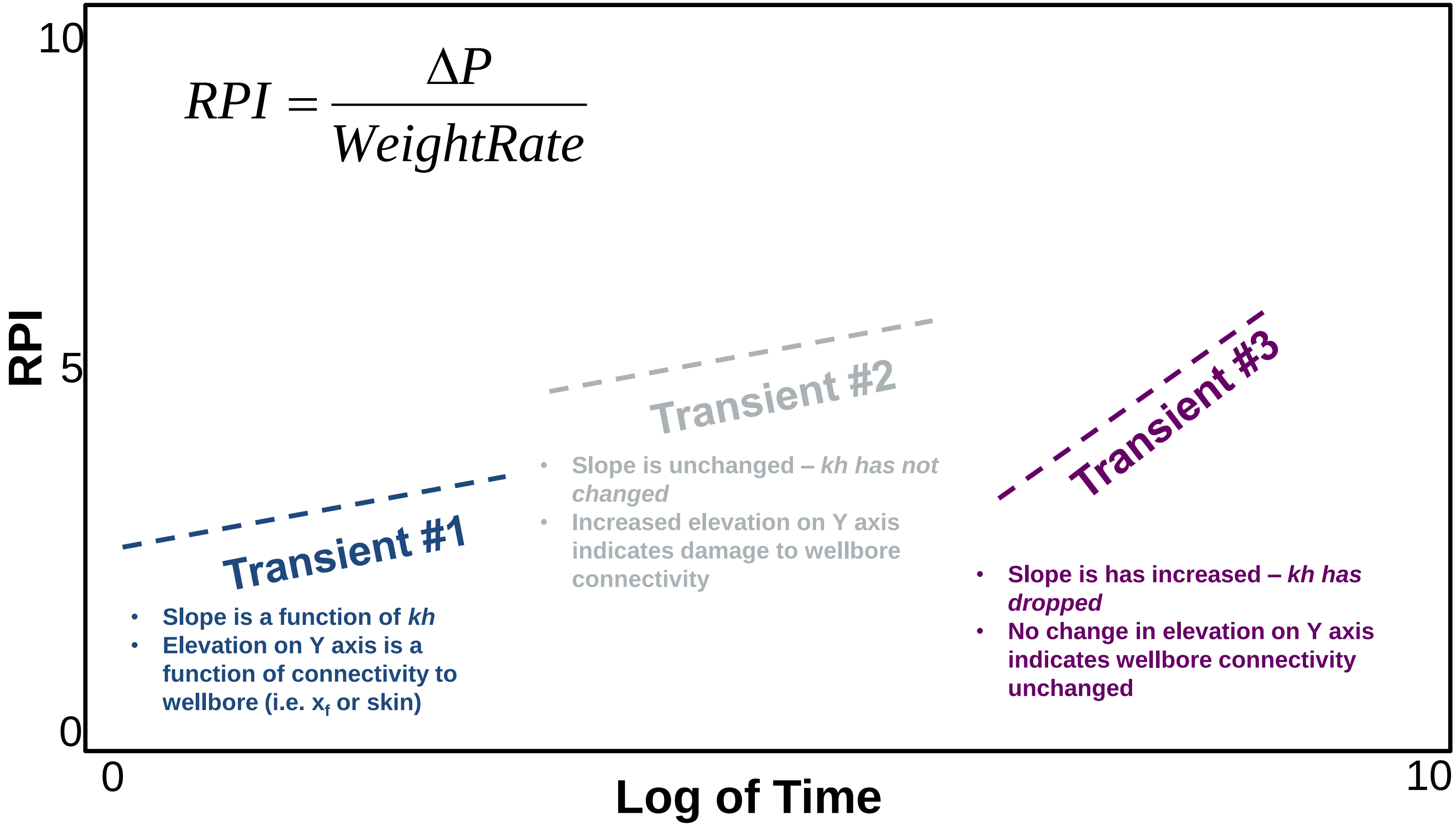
CO_2 Injection "Production Analysis"

In the plot below, the slope of each line is related to the transmissibility (kH) of the reservoir and the y-intercept is related to the wellbore-reservoir connectivity



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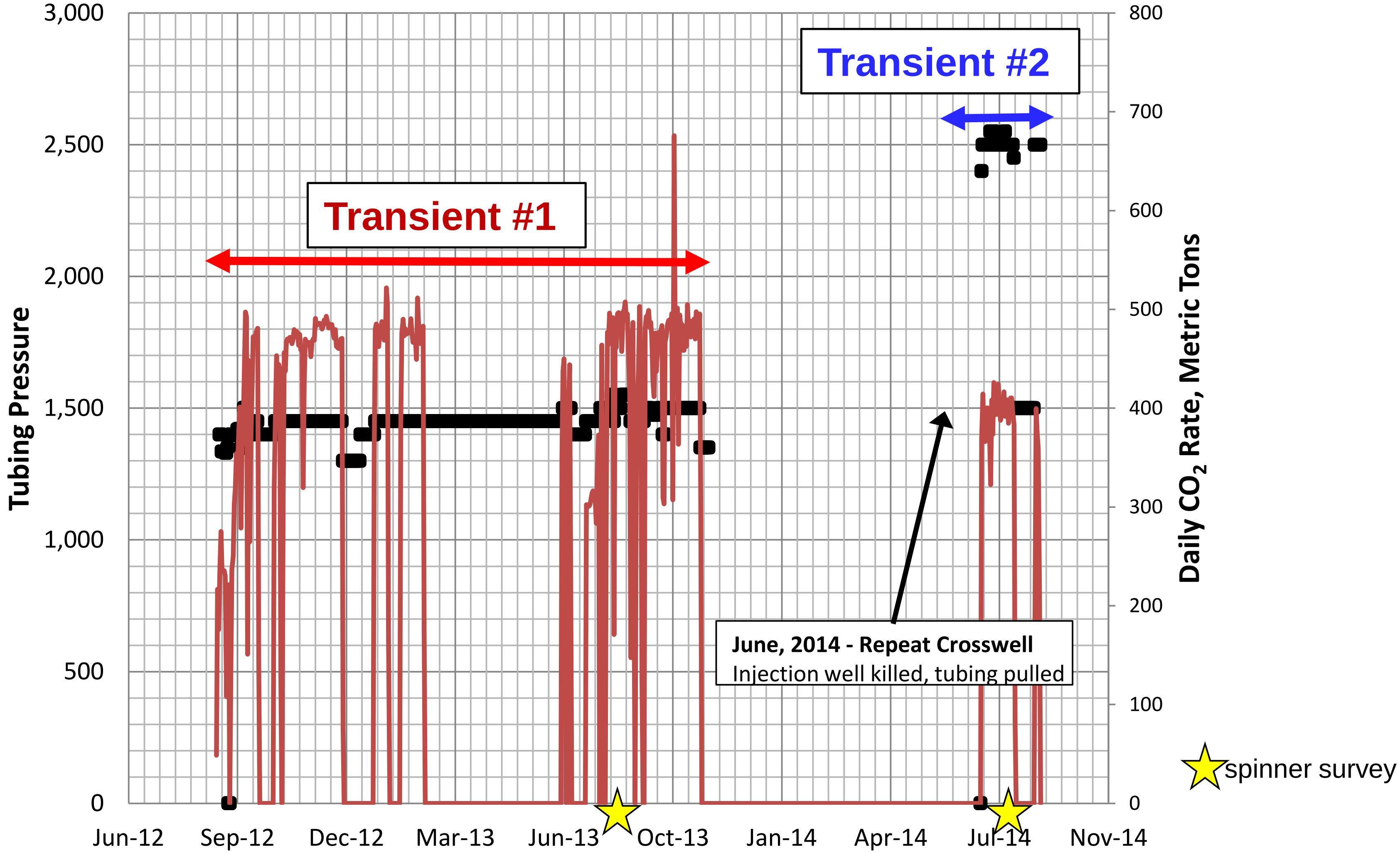
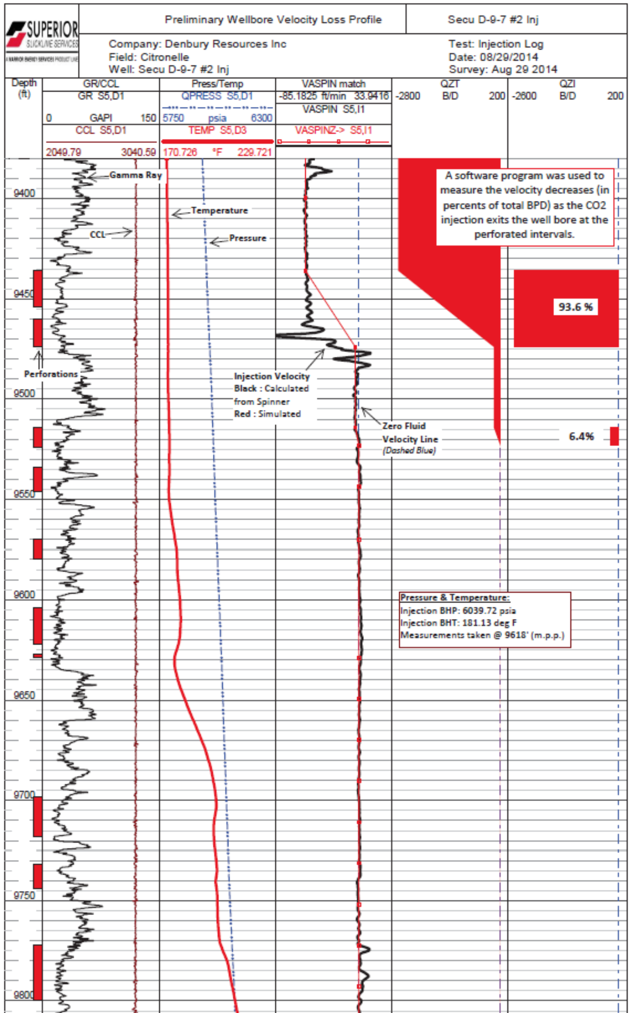
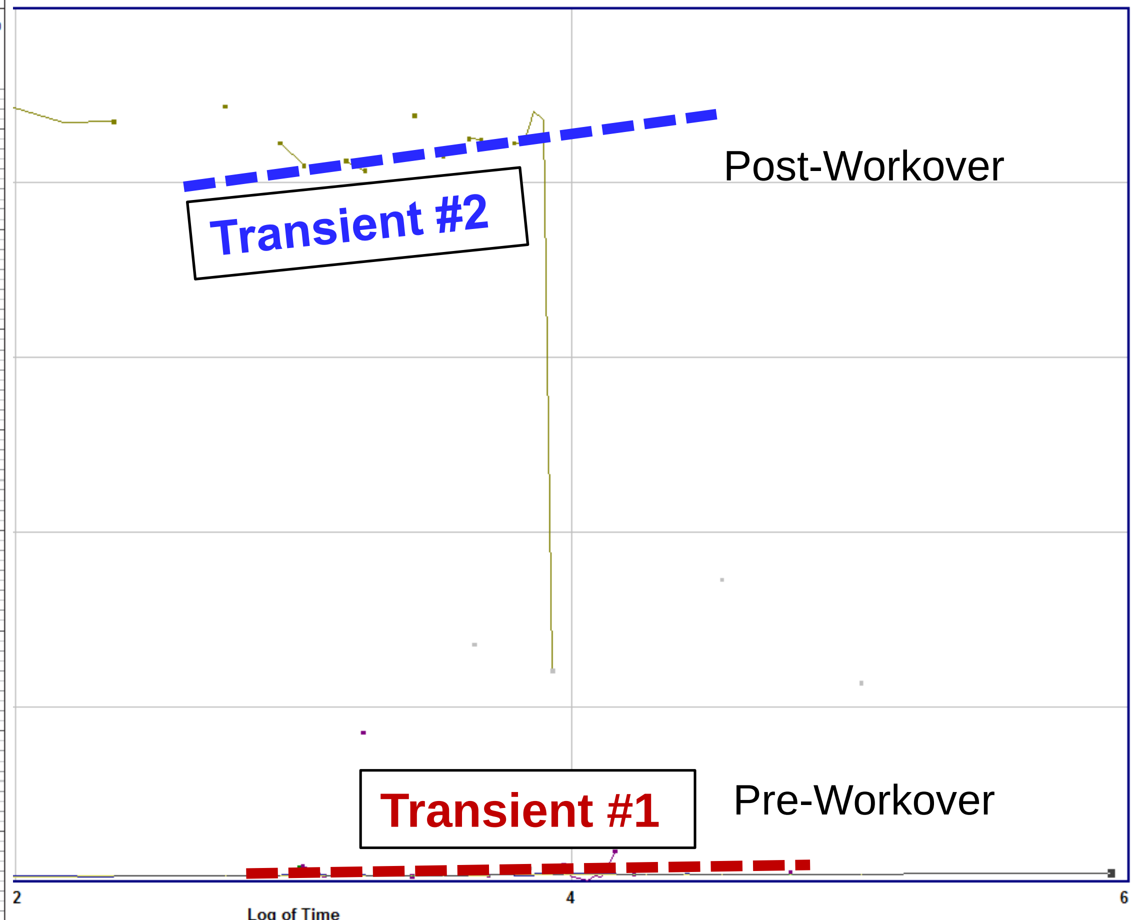
D-9-7#2 Injection Pressure History



Notable Increase in injection tubing pressure after crosswell seismic workover

CO_2 Injection "Production Analysis"





Decrease in "connectivity" and transmissibility (kH) after D-9-7#2 workover

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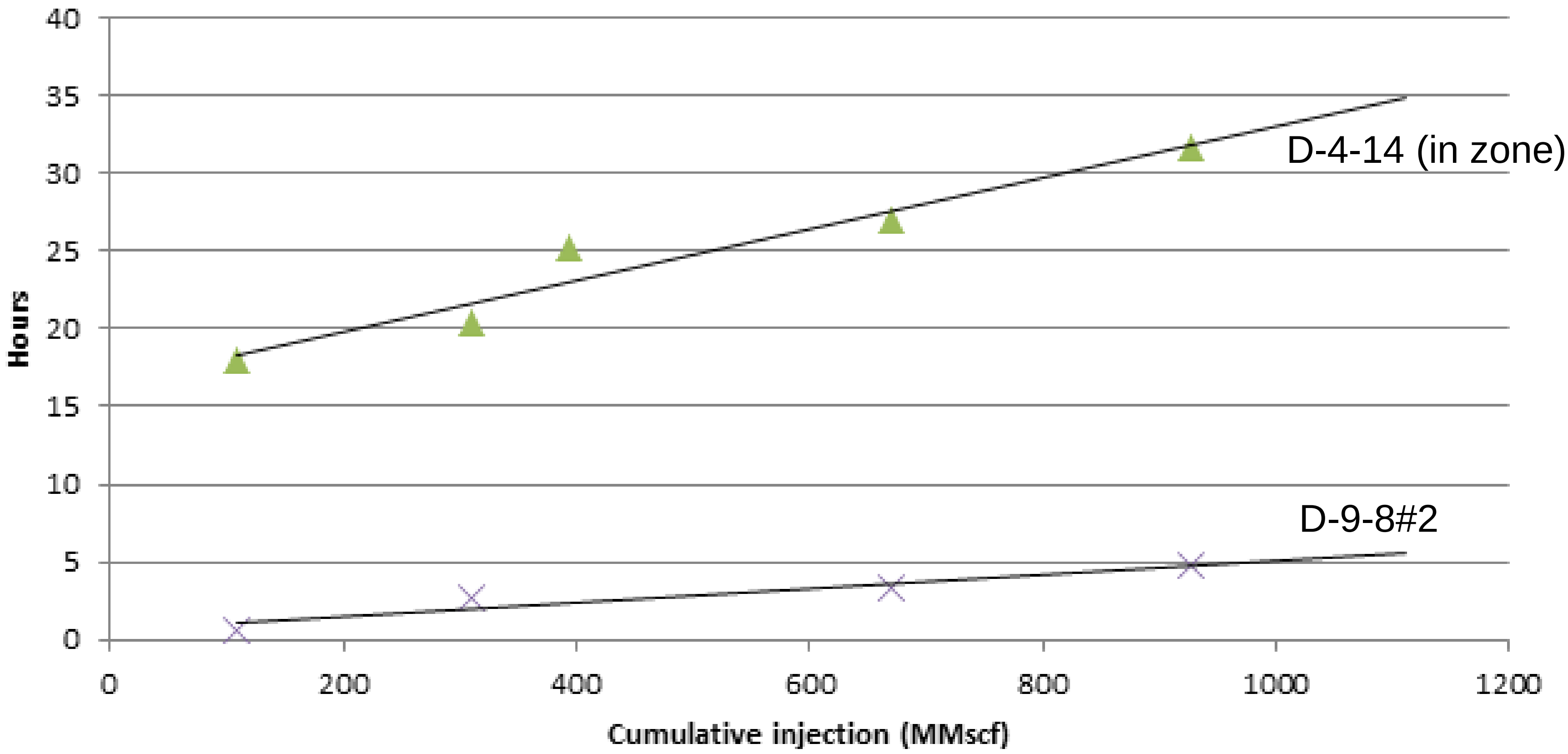
Deep MVA – Pressure Response Time

- The system, as expected, is getting more compressible with continued injection. As a result, the pressure transient travel time between the injection and observation wells continues to grow.



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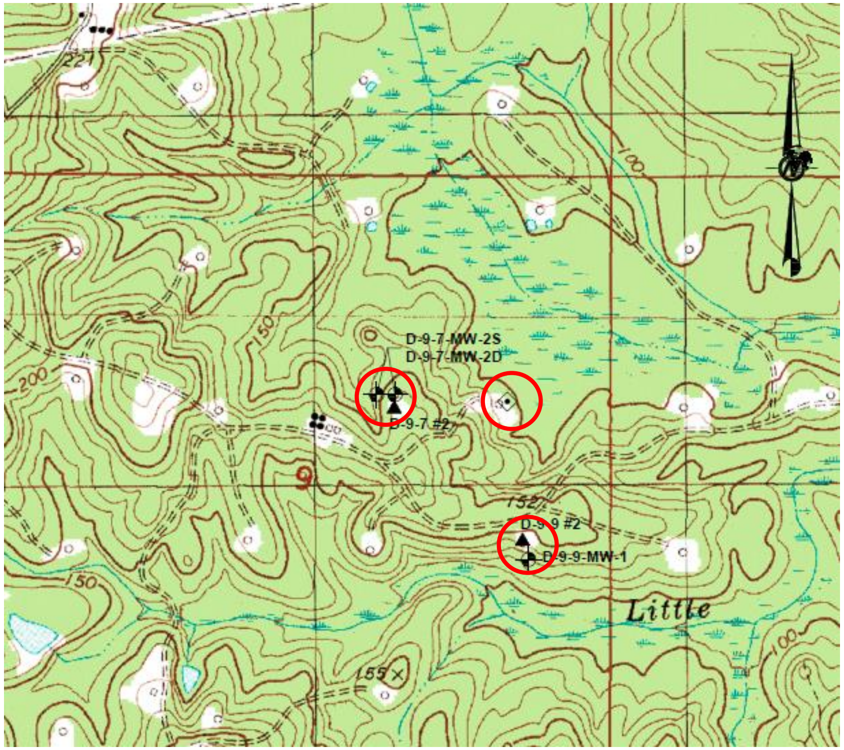
Citronelle Groundwater Sampling Program

- Three dedicated groundwater sampling wells and one water well

Well	Depth (ft)	Elev. (ft)
D9-9 MW-1	169.6	-20.23
D9-7 MW-2S	170.8	-5.24
D9-7 MW-2D	501.0	-335.6
D9-8 WW	143	--

- Three background sampling events prior to CO_2 injection
- Nine quarterly sampling events since injection started
- 17 metals, alkalinity, TDS, TIC, pH…etc.

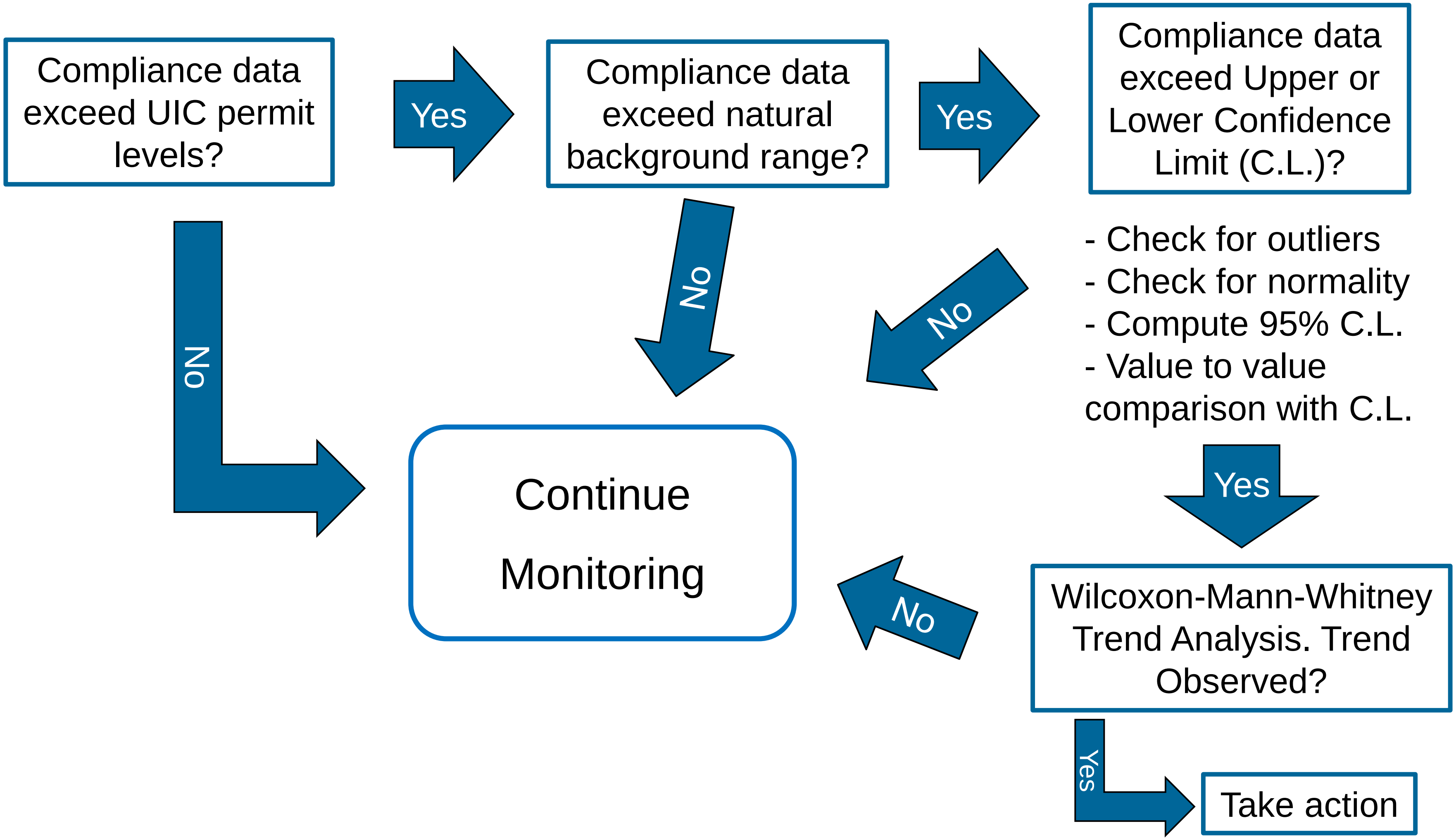


Groundwater sampling locations (circled)

Metals, pH, inorganic carbon, etc …Occur Naturally in Groundwater Complicating Regulatory Interpretation

Analyte	Unit	UIC Permit Level	Backgrd MW-1	Backgrd MW-2S	Backgrd MW-2D	Backgrd WW
Metals, Total						
Aluminum	ug/l	200	<100–340	<100	<100-4600	<100–500
Antimony	ug/l	6	<5	<5	<5	<5
Arsenic	ug/l	10	<5	<5	<5	<5
Barium	ug/l	2000	32–66	38–41	<10–29	40–50
Berylium	ug/l	4	<3	<3	<3	<3
Cadmium	ug/l	5	<5	<5	<5	<5
Chromium	ug/l	100	<5	<5	<5–13	<5
Copper	ug/l	1,300	<10	<10	<10	<10–150
Iron	ug/l	300	430–1000	300–550	<100–3200	720–1600
Lead	ug/l	15	<5	<5	<5–5.5	<5–35
Manganese	ug/l	50	90–99	51–56	<10–18	64–73
Mercury	ug/l	2	<0.2	<0.2	<0.2	<0.2
Nickel	ug/l	100	<5	<5	<5–5.1	<5
Selenium	ug/l	50	<10	<10	<10	<10
Silver	ug/l	100	<5	<5	<5	<5
Thallium	ug/l	2	<1–<10	<1	<1	<1
Zinc	ug/l	5000	<20–25	<20	<20–69	<20–21
General Chemistry						
Alkalinity, Bicarbonate as CaCO3	mg/l	Monitor	55–59	51–53	78–110	46–49
Alkalinity, Total	mg/l	--	55–59	51–53	85–120	47–49
Total Dissolved Solids	mg/l	500	76–160	72–90	470–560	74–82
Total Inorganic Carbon	mg/l	Monitor	8.6–34	12–31	2.4–14	9.3–31
Field Parameters						
pH	Std units	6.5-8.5	7.04–7.38	6.80–7.14	8.71–9.02	6.26–7.66

Citronelle Compliance Monitoring Program is Based on U.S. Environmental Protection Agency RCRA Guidelines

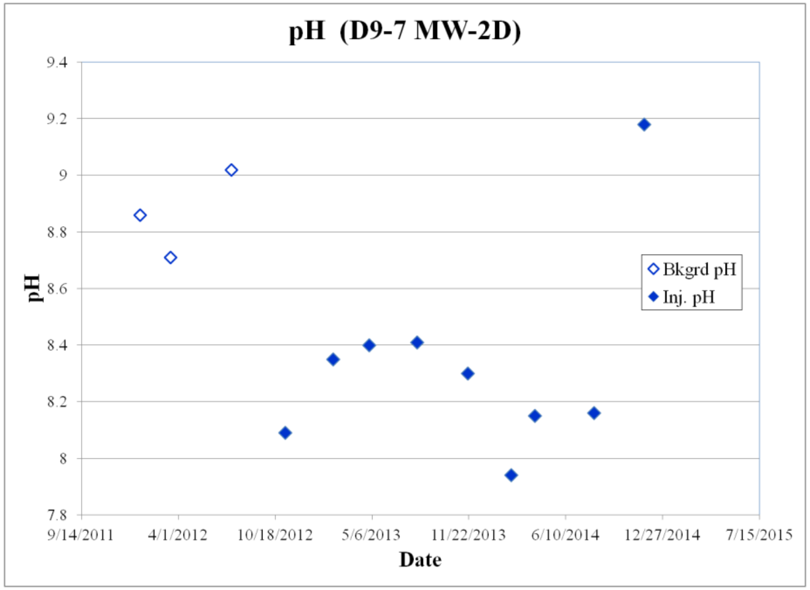


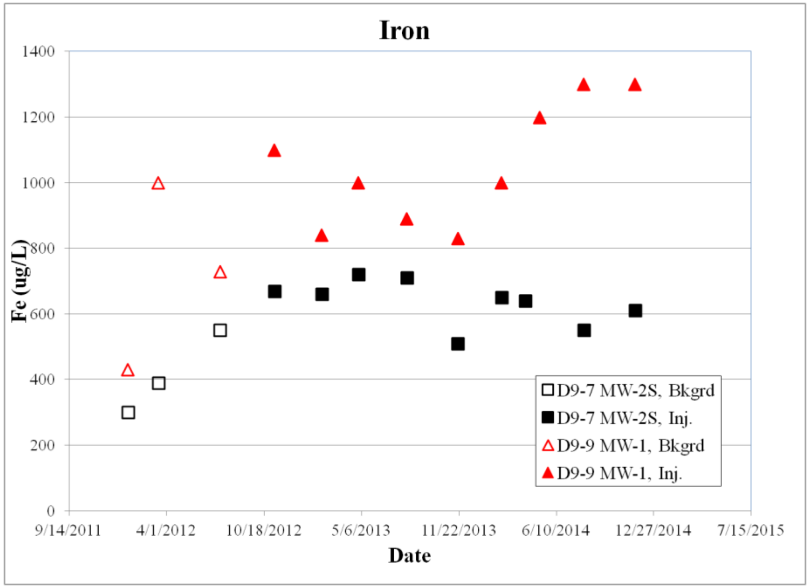
Summary of Intra-Well Statistics

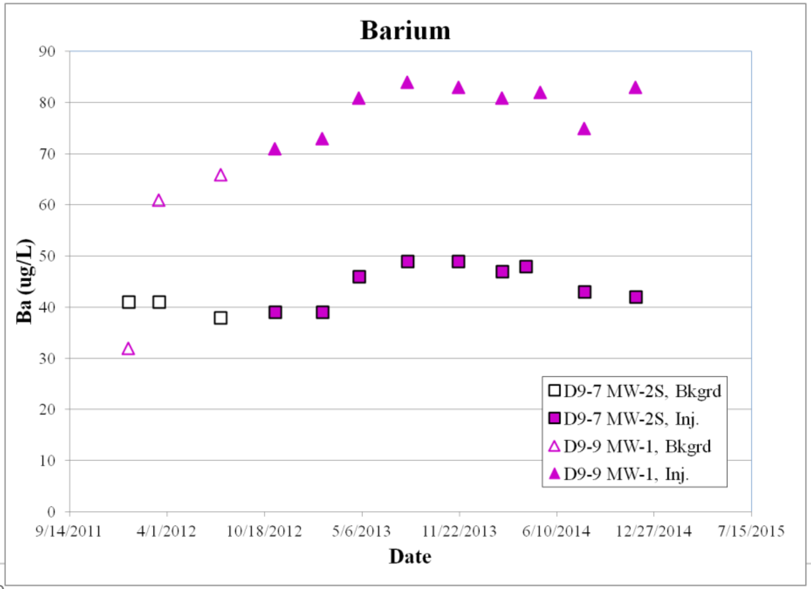
- Intra-well statistical analyses indicates several significant trends for the N=3 through 12 sampling events
  - pH decrease at D-9-7 MW-2D
  - Ba, Fe, Mn and sulfate increase at D-9-7 MW-2S
  - Ba, Fe and Mn increase at D-9-9 MW-1

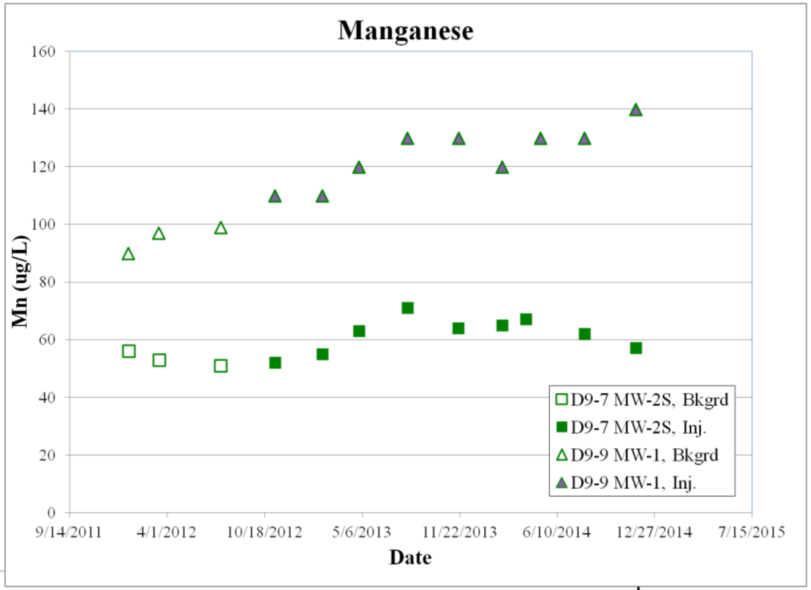
The statistical analysis would imply that the groundwater quality is changing at Citronelle, but is CO_2 the cause?

Time Series Trends (N=1 through 12 Sampling Events)









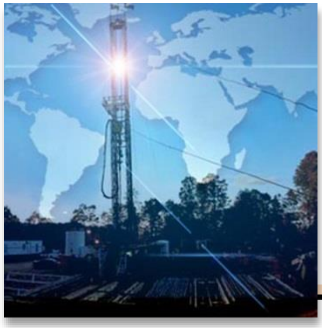
Multiple Lines of Evidence are Needed to Prevent False-Negatives and Positives

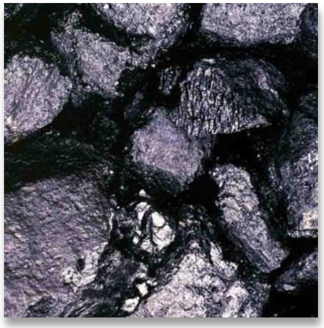
Statistically Determined Potential Lines of Evidence for Carbon Dioxide Influence

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	Ba, Fe, Mn
D-9-9 MW-1	No	No	No	Ba, Fe, Mn
Water Supply Well	No	No	No	No

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

1. Multiple lines of evidence for the potential influence of carbon dioxide at individual monitoring wells have not been identified to date at Citronelle
2. Groundwater systems are inherently complex requiring thoughtful design of the background sampling and compliance monitoring programs





2. AoR & Modeling Update

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Introduction

CMG's GEM software was used to model the injection into the upper Paluxy Sandstone and forecast the subsurface movement and pressure profile of the CO_2 in order to meet our Class V UIC AoR guidelines. Modeling was done in a three-step process. These steps were:

- History matching the injection through 31 AUG 2013.
- Forecasting continued injection through the end of the proposed injection period to account for anticipated interruptions (reserve shut-down from 01 NOV 2013 – 31 APR 2014).
- Then, the plume was allowed to relax to understand pressure equilibration and plume stabilization.

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Injection Profile Match

- Field gathered injection profile surveys were used to understand how the CO_2 entered the Paluxy reservoir sand bodies (8 sands, 10 sets of perforations).

Sand Unit	Sand Unit Properties (ft) Bottom	Top	Thickness	Nov 2012 Flow %	Aug 2013 Flow %	Oct 2013 Flow %	Simulation
J	9,454	9,436	18	14.8	18.7	16.7	26.1
I	9,474	9,460	14	8.2	20.4	19.6	
H	9,524	9,514	10	2.8	7.4	7.7	3.4
G	9,546	9,534	12	2.7	2.1	0.9	4.3
F	9,580	9,570	10	0.0	1.2	1.2	0.9
E	9,622	9,604	18	26.8	23.5	30.8	25.8
D	9,629	9,627	2	0.0	0.0	0.0	
C	9,718	9,698	20	16.5	11.8	10.3	11.1
B	9,744	9,732	12	4.9	0.6	0.4	4.2
A	9,800	9,772	28	23.3	14.3	12.4	24.2

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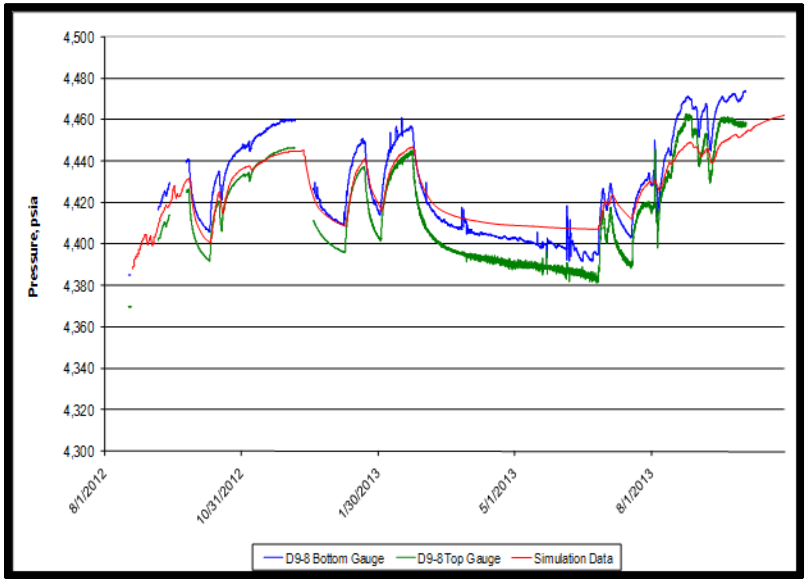
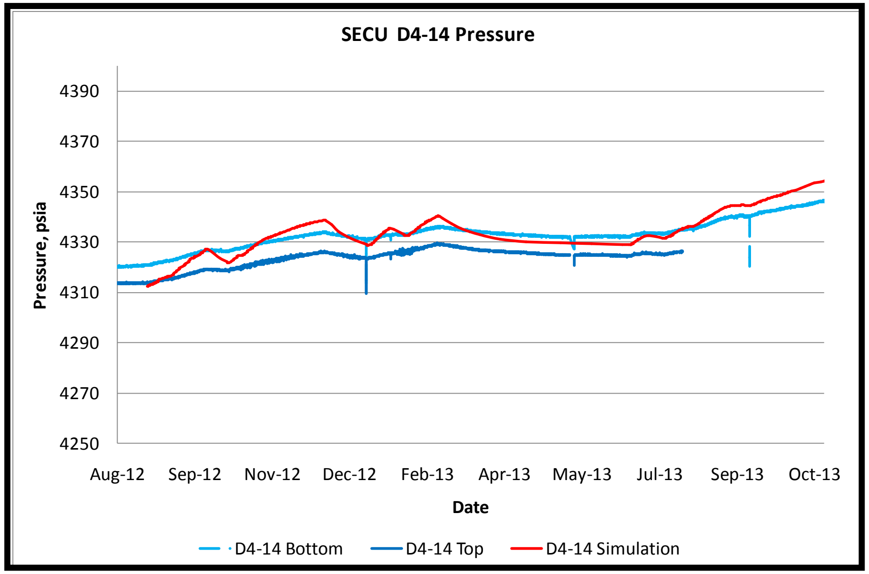
Offset Pressure Profile Match

- Pressure data was used to calibrate modeled upper Paluxy sand layer (perf sets 1 and 2) pressure responses at 870 ft (265m) at D 9-8 #2 and more than 3,000 ft (914m) at the D 4-14. Note: the late time erratic pressure data in the D 9-8 #2.

Upper Paluxy Pressure Match at the D 9-8 #2



Upper Paluxy Pressure Match at the D 4-14



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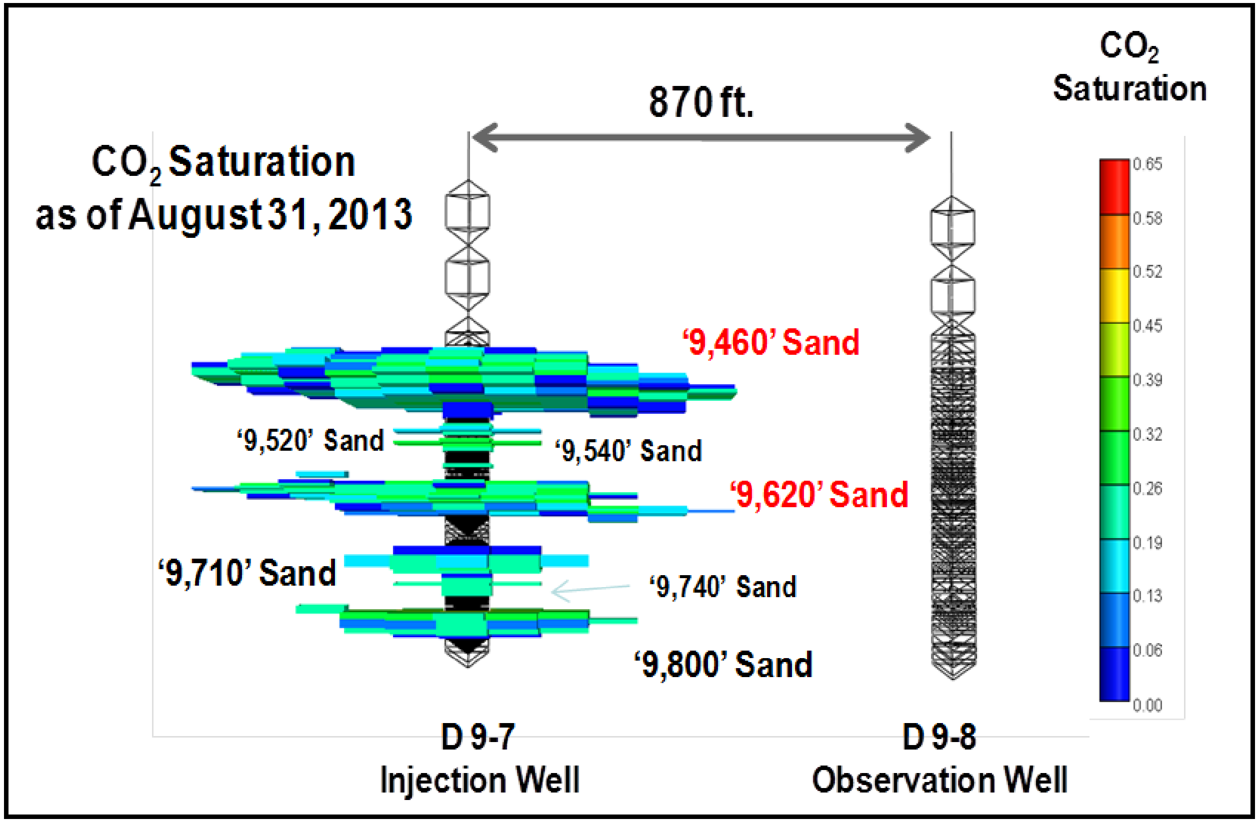
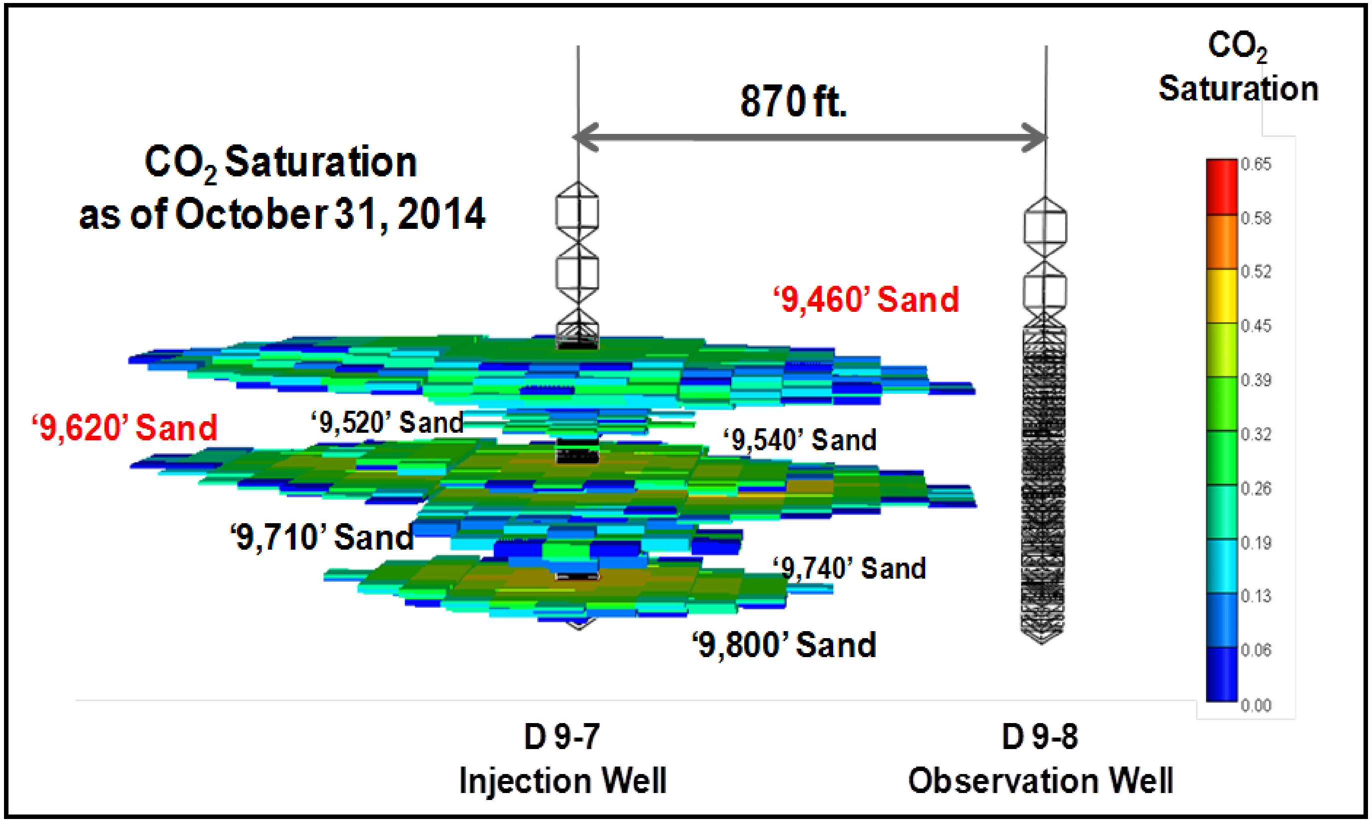
Predicted Radial CO_2 Plume Extent on August 31, 2013 of 440 ft (134 m)

- As expected, the two most porous and permeable sands accepted the bulk of the CO_2.



Predicted Radial CO_2 Plume Extent on October 31, 2014 of 720 ft (219 m)

- Continuing the injection (135,000 tonnes more), the plume continues to spread across the 9460 and 9620 sands.



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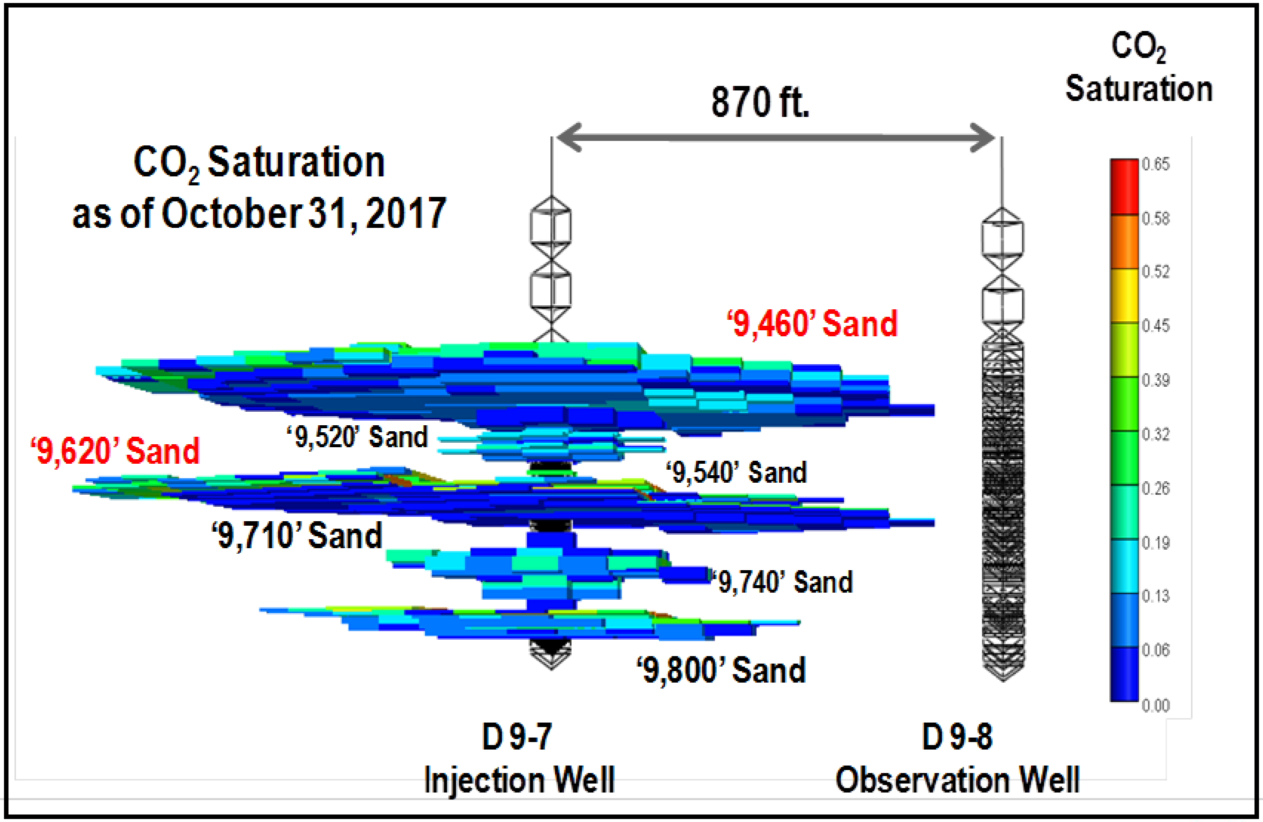
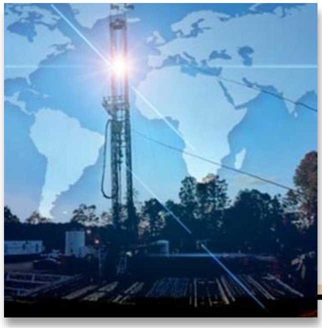
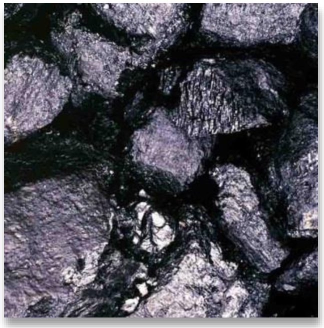
Predicted Radial CO_2 Plume Extent on October 31, 2017 of 720 ft (219 m)

- Despite the high permeability of the formation and a gentle dip, there is not a substantial change in the plume extent in the three years following the cessation of injection. In fact, the plume extent has equilibrated.







3. Lessons Learned

Lessons Learned

- Time and cost reductions realized, but not yet commercial
- Data, data, & more data
- MVA systems can impact injection and vice versa
- We have good reservoir capacity and injectivity
  - apparent injection damage after workover

Lessons Learned

- Data resolution may be challenging in deep settings
- Every potential storage project is different & MVA should be site specific in design
- When deploying non-commercial MVA protocols, redundancy with more commercial tools is necessary to ensure the data quality
- Build from the lessons learned at existing projects

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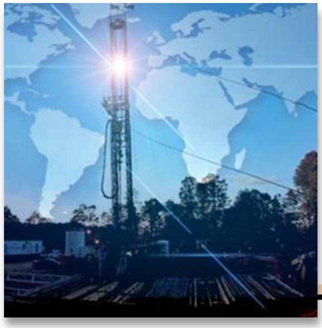
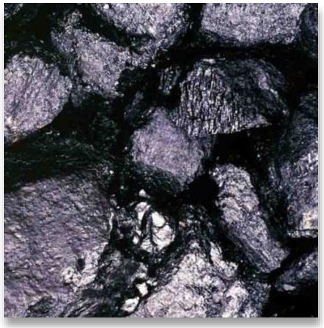


4. Questions, Answers, Discussion



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Together…Shaping the Future of Electricity

EXTRAS

USDW Protection - Groundwater Geochemistry

3 - Background Monitoring Events:

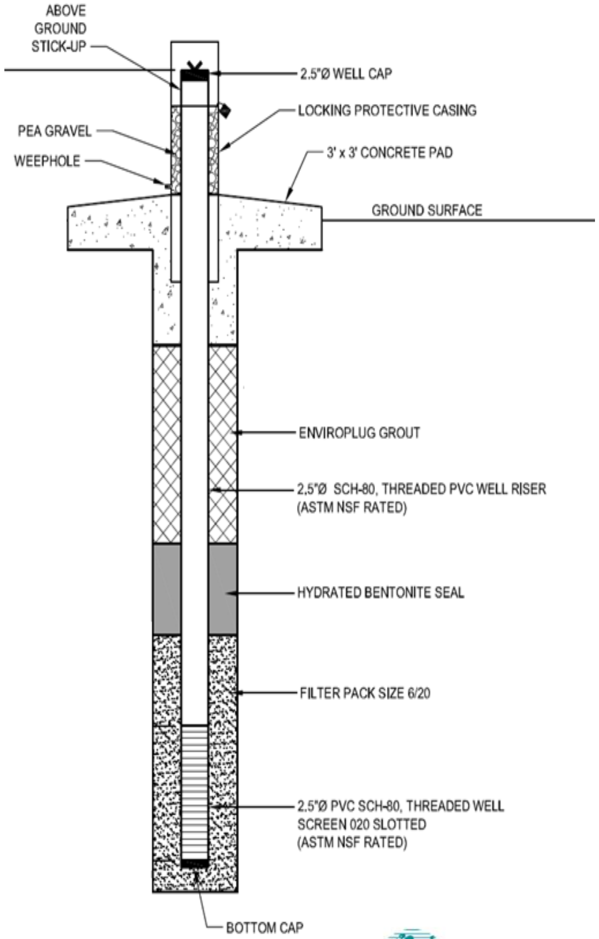
- January 2012 (N=1) through July 2012 (N=3)

10 - Injection Period Monitoring Events:

- November 2012 (N=4) through February 2015 (N=13)
- Background anomalies of Mn, Fe, and Cl above UIC permit discharge limits.
- To evaluate the potential exceedance of regulatory standard (*e.g.*, UIC permit discharge limit), the EPA GW Unified Guidance recommends statistical comparisons (*"value to value"* comparison to standard and evaluation of changes between baseline and monitoring)
- Quarterly testing to continue throughout the PISC

USDW Monitoring Well Network

Monitoring Well	Screened USDW	Well Depth (ft. BTOC)	Well TOC Elevation (ft. AMSL)
D-9-7 MW-2S	Miocene-Pliocene Aquifer	170.8	165.56
D-9-7 MW-2D	Miocene-Pliocene Aquifer	501	165.4
D-9-9 MW-1	Miocene-Pliocene Aquifer	169.6	149.37
Water Supply Well Near D-9-8	Miocene-Pliocene Aquifer/Watercourse Aquifer	~143	Not Surveyed



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Comparison of Baseline Values to Permit

D-9-7 MW2D		
Analyte	**UIC Permit Discharge Limits (µg/l)**	**Range of Valid Background Concentrations (µg/l)**
Aluminum	200	<100 - 4600
Antimony	6	<5
Arsenic	10	<5
Barium	2,000	<10 - 29
Beryllium	4	<3
Cadmium	5	<5
Chromium	100	<5 - 13
Copper	1,300	<10
Iron	300	<100 - 3200
Lead	15	<5 - 5.5
Manganese	50	<10 - 18
Mercury	2	<0.2
Nickel	100	<5 - 5.1
Selenium	50	<10
Silver	100	<5
Thallium	2	<1
Zinc	5,000	<20 - 69

Range of values because of the small background data set (N=3).

Selected naturally occurring background concentrations which exceed UIC Permit discharge.

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Statistically Determined Potential Lines of Evidence for CO_2 Influence*

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	Ba, Fe, Mn
D-9-9 MW-1	No	No	No	Ba, Fe, Mn
Water Supply Well	No	No	No	No

Notes: Purple Shading = A potential line of evidence for carbon dioxide influence
Blue Shading = A potential line of evidence for carbon dioxide influence is not present

Multiple lines of evidence for the potential influence of CO_2 at individual monitoring wells have NOT been identified

*e.g. Wilkin and Digiulio (2010)