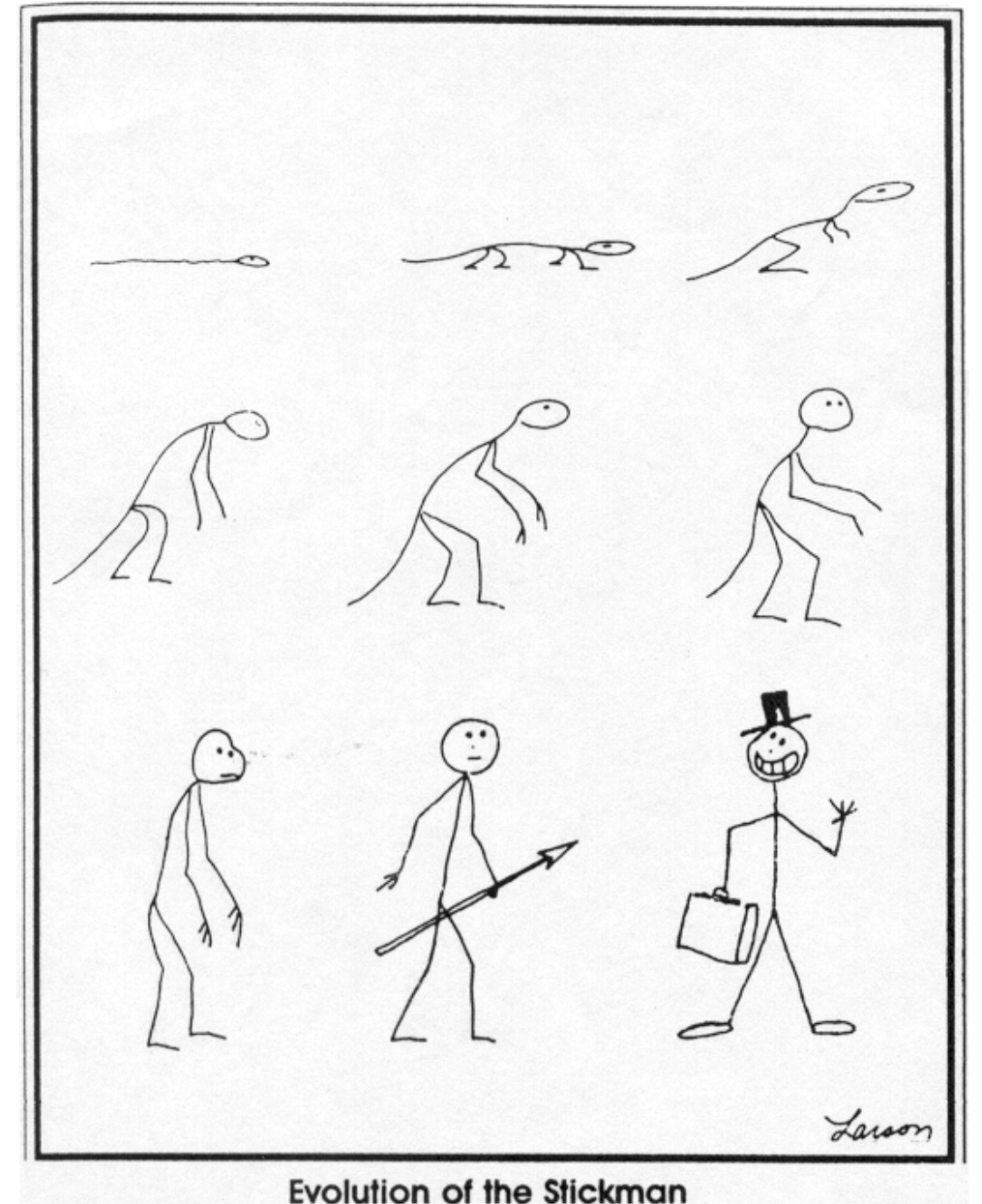
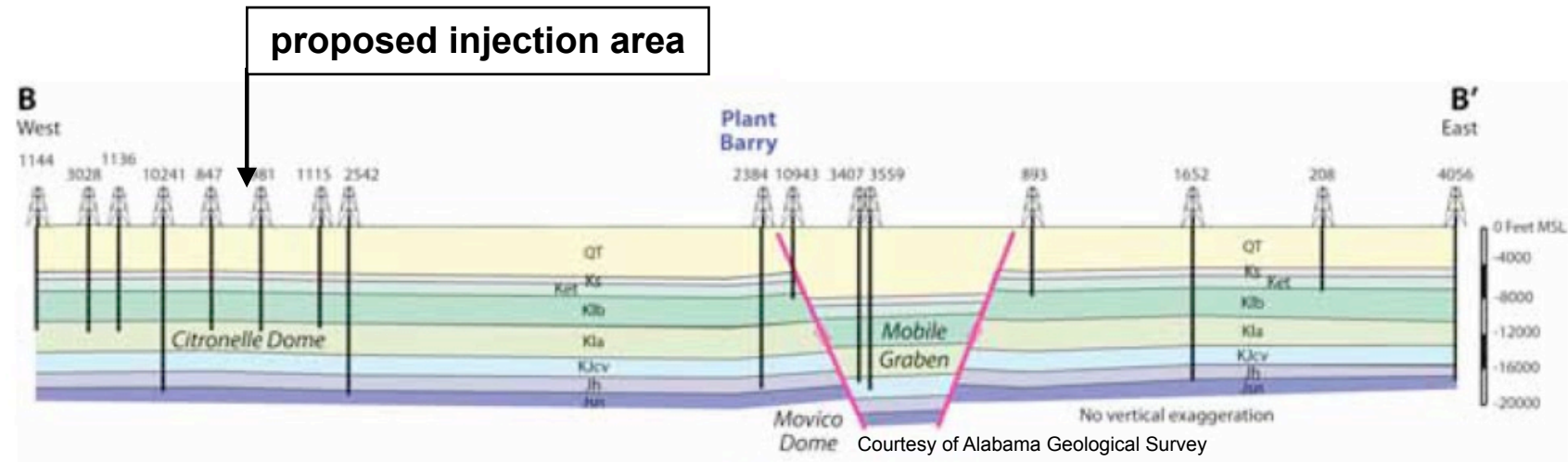
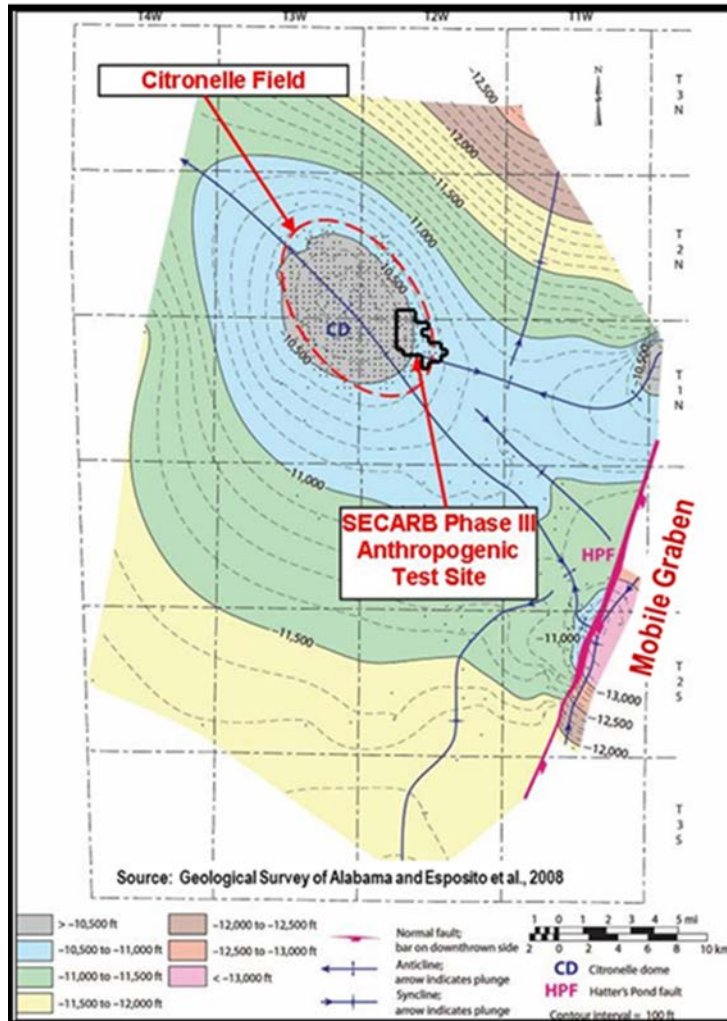




# A Reflection on Things Past (2008-2017) or A Decade of Collaboration and Evolution



# Storage Location Evolved



Regional structure showing Mobile Graben potentially up dip from Plant Barry prompted a move to Citronelle Dome to the west on Denbury Resources property where four-way closure on the structure would guarantee the CO<sub>2</sub> remained trapped

# Capture Evolved: Demonstrated Post-Combustion Capture of Over 250,000 Mt and Injection of Over 104,000 Mt of Captured CO<sub>2</sub>

**2010**



**2011**

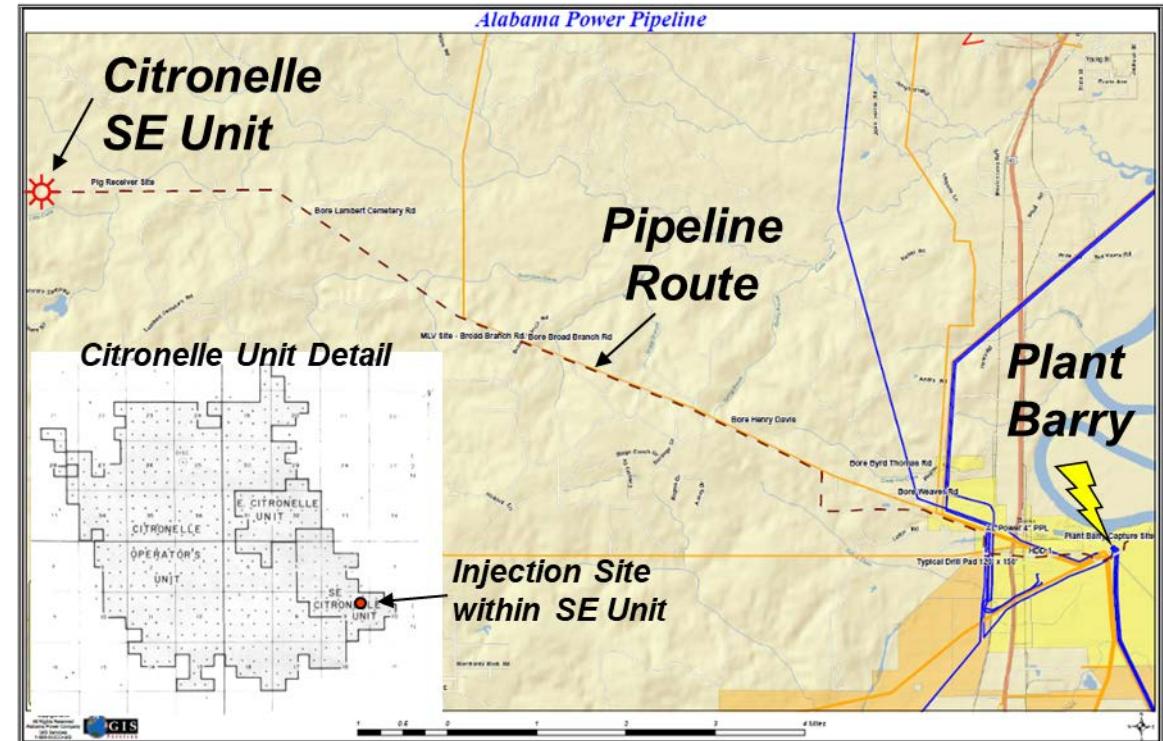


Photos Courtesy of Southern Company

**Largest integrated post-combustion CCS project in the world on a coal-fired power station using advanced amines when injection started in August 2012**

# Transportation Evolved from On-Site to 12 Mile Off-Site Pipeline

- 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<sub>2</sub> at 115°F, 1,500 psig (< 20 ppm H<sub>2</sub>S)
- Right-of-way habitat (pine forest in the Mobile River watershed; some wetlands)



# Monitoring Techniques Evolved with the Deployment of the Modular Borehole Monitoring (MBM) System

- Multi-sensor, monitoring platform
  - 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<sub>2</sub> leak detection
  - 2 7/8” production tubing open for well logging



Geophone pod and clamping assembly

# Technology Evolved with the Deployment of Fiber Optics for Distributed Acoustic Sensing (DAS) for CO<sub>2</sub> Plume Imaging and Leak Detection

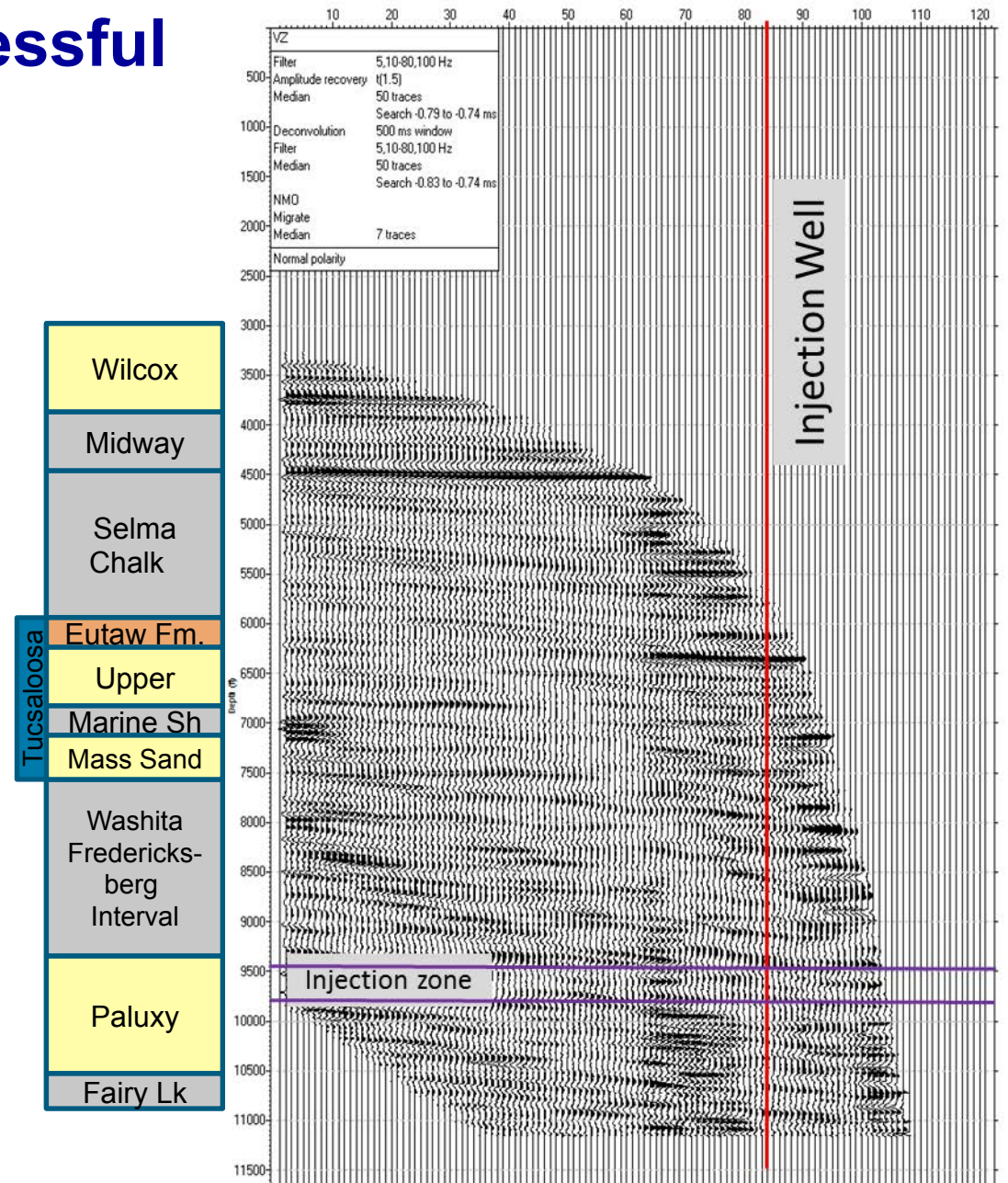
- Light emitted into a fiber is reflected throughout the fiber's length by Rayleigh scattering
- Acoustic wave exerts tiny pressure/strain changes on the fiber, resulting in changes to the backscattered light
- DAS measures these changes by generating a repeated light pulse every 100  $\mu$ s and continuously processing the returned optical signal, thus interrogating each meter of fiber
- The system records the full acoustic signal, including amplitude and phase



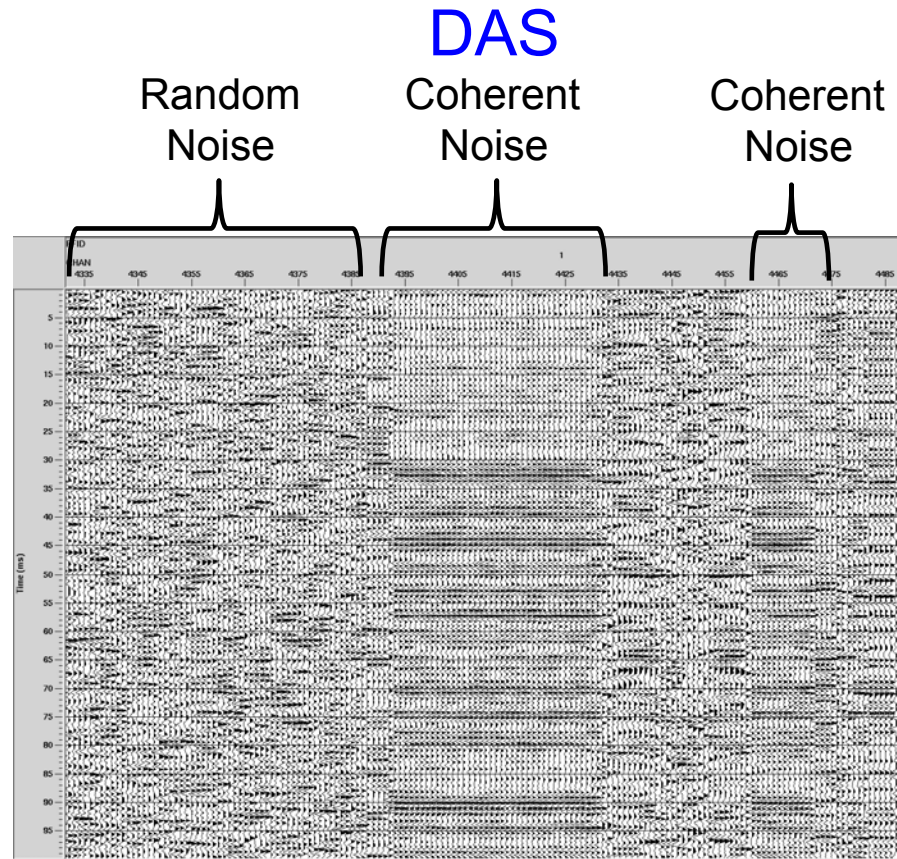
**A 10 km single mode fiber becomes a high density acoustic array with 10,000 linear sensors with 1 m spatial resolution!**

# Applications Evolved—Some Successful Like the DAS-VSP Survey Results

- Migrated image →
  - Observed strong reflectors
  - Good tie to formation logs (e.g., Selma Chalk)
- No “bright” spot observed where CO<sub>2</sub> was injected
- Image has sufficient quality to conduct time-lapse analysis using results from the second (final) survey

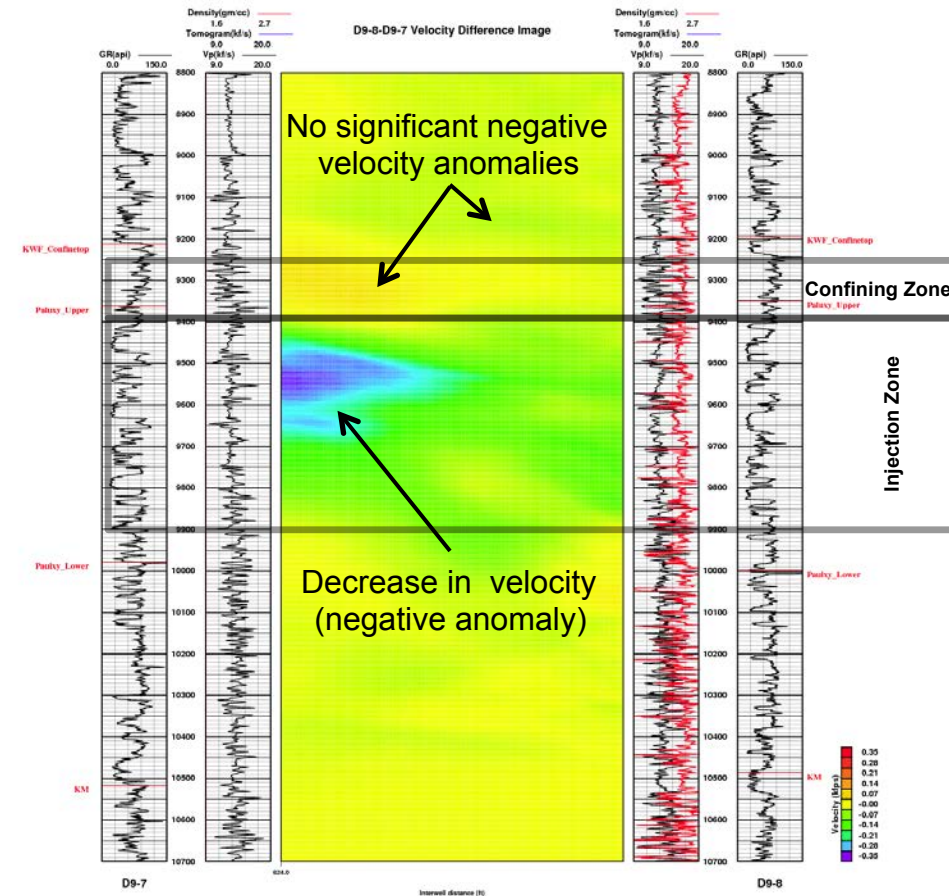


# Some Were Unsuccessful—Crosswell DAS Survey Results Showed Random Noise



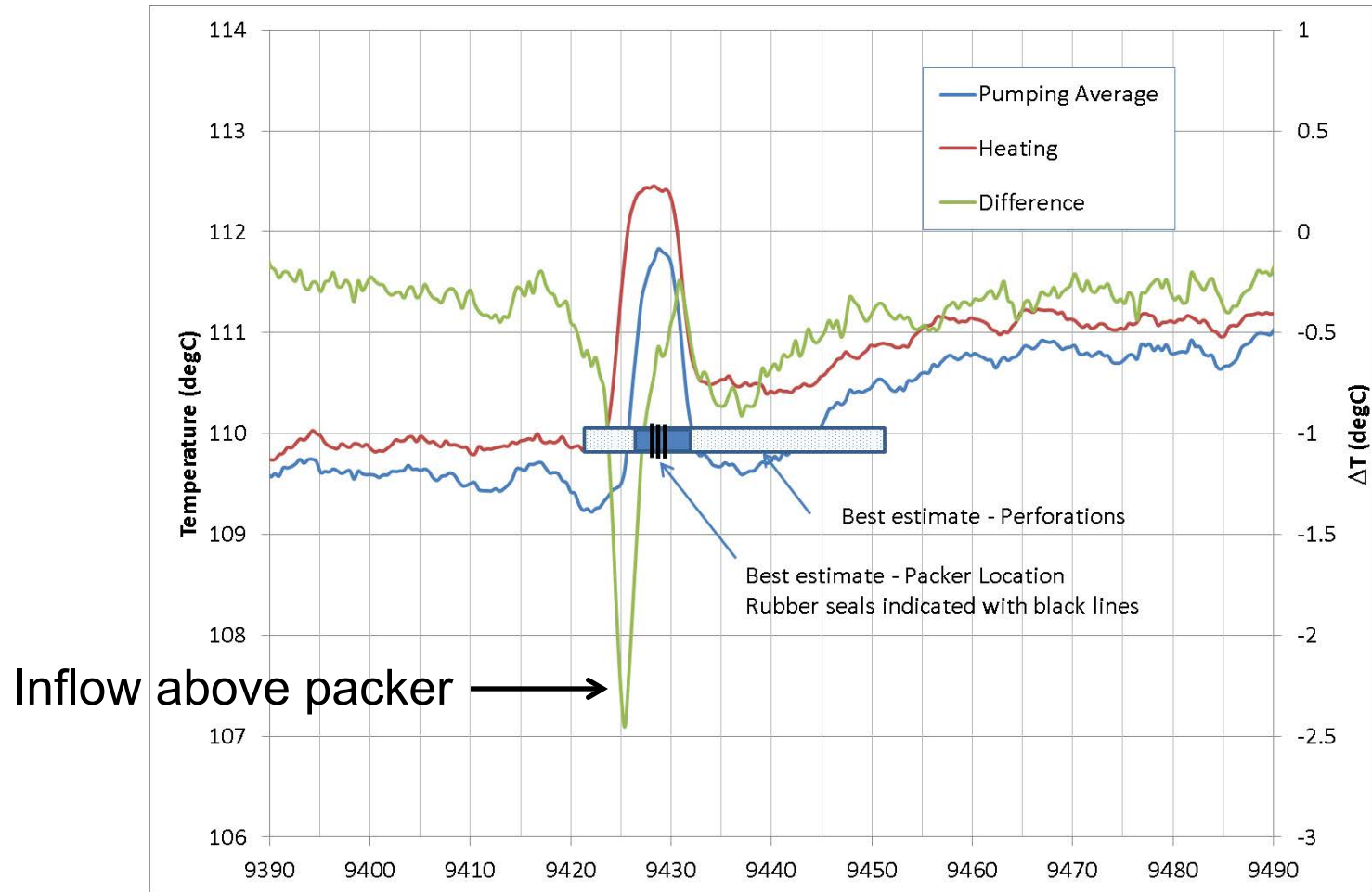
DAS Data at 9,340 ft – Only See Random Noise, Except Some Coherent Noise Not related to sweep

## Conventional



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

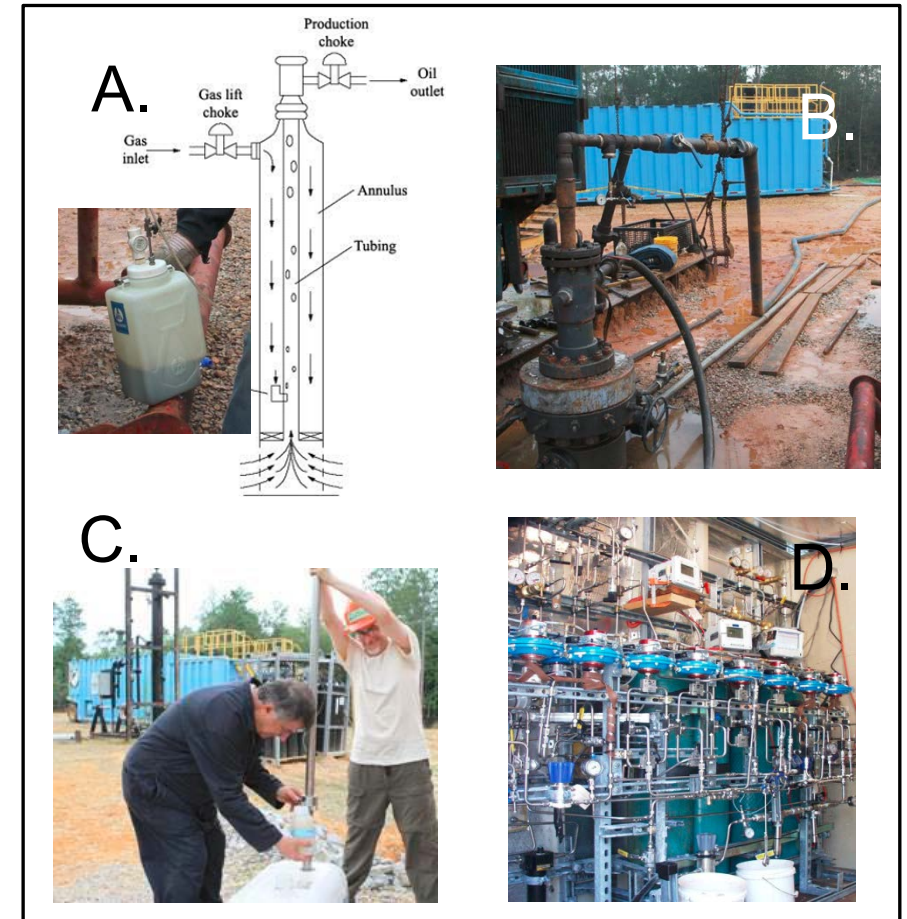
# Successful—Failure: FO-Based Distributed Temperature Sensing (DTS) Allowed Us to Diagnose a Completion Problem with Our Observation Well



# Scientific Knowledge Expanded and Evolved

## 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

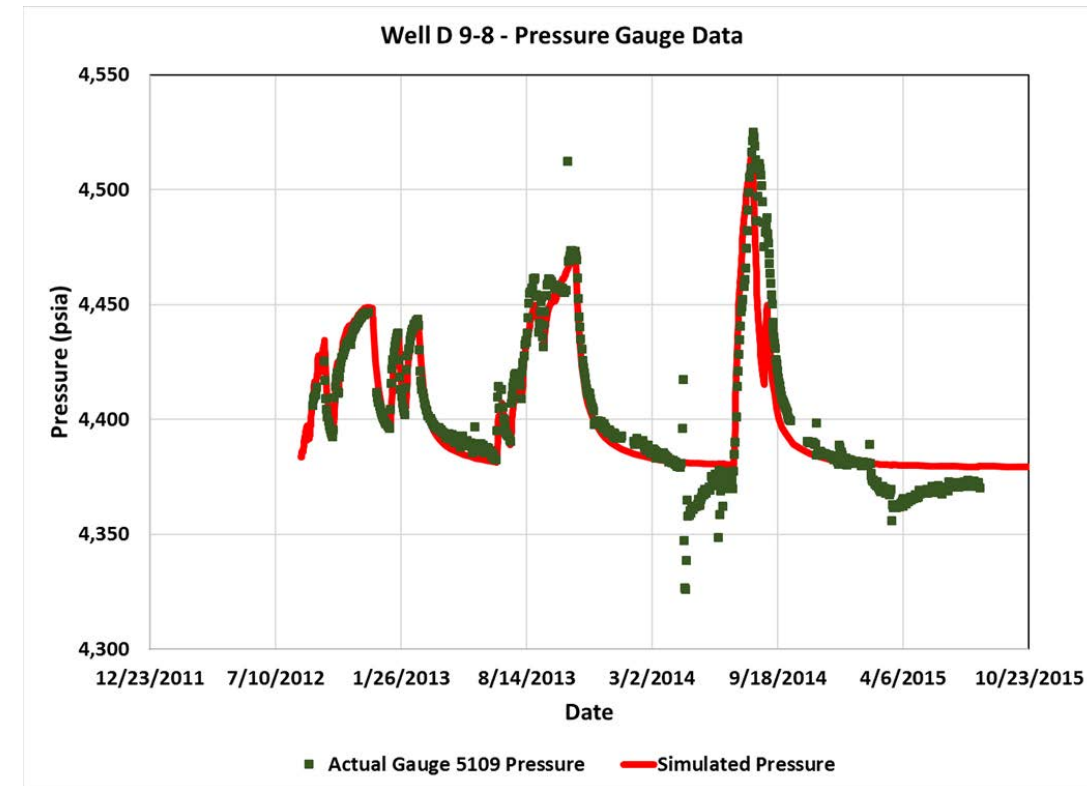


USGS collecting in-zone groundwater samples using:  
A. gas-lift; B. electric submersible pump; C. Kuster sampler;  
and D. u-tube sampler

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

# All Good Things Come to an End—Project Closeout

- Regulator approved the closure request in late August 2017
- Project closeout is underway
  - D9-8#2 observation well was plugged and abandoned in early 2017
  - Injection well plugged and abandoned in November 2017
  - Far offset observation wells were plugged in December 2017/January 2018
  - Monitoring will wrap up in 2018
  - Final reporting completed in 2019



Reservoir pressure has returned to pre-injection levels

# All Good Things Come to an End, but CO<sub>2</sub> Storage is Forever



Installation of Injection Well D9-7 #2



Abandoned Well Pad Prior to Drilling D9-7 #2

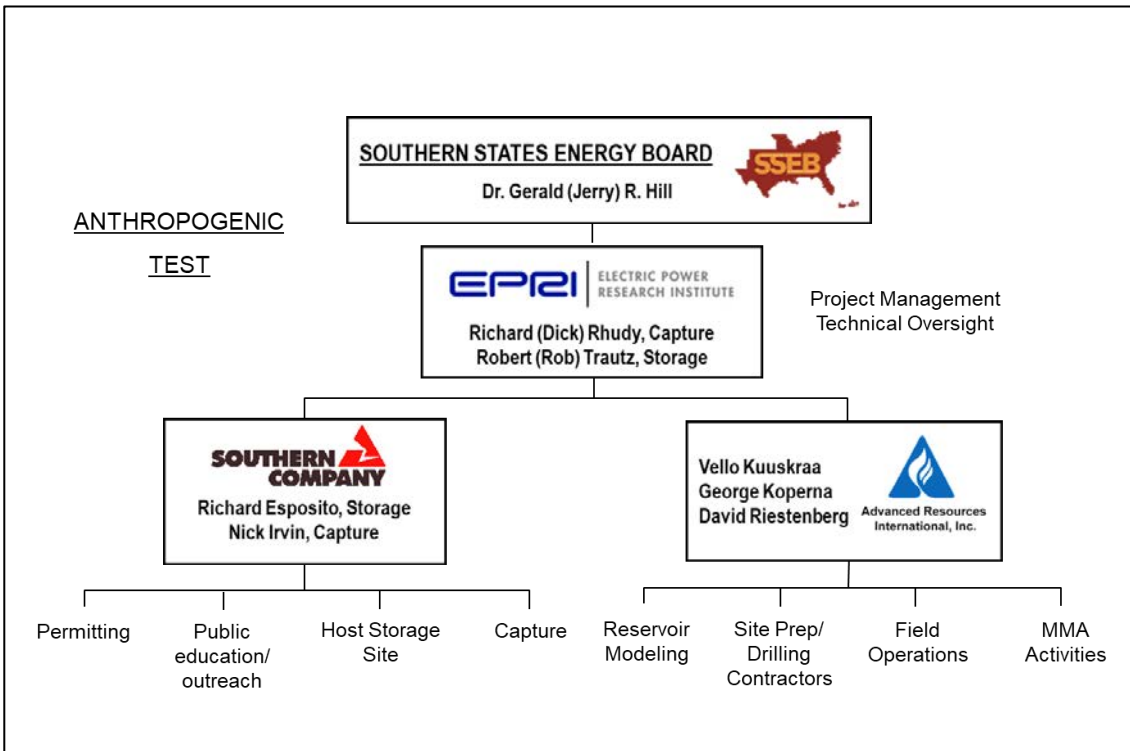
# Project Accomplishment: DOE / Southern Company / EPRI Demonstration Helped Facilitate Full-Scale Commercialization

- NRG Energy (Houston, TX) adopted the MHI KS-1 technology after visiting the Plant Barry Demonstration
- Plant scale-up at Petra Nova to 240 MW
- Post-combustion slip-stream
- Captures 5,200 tons CO<sub>2</sub>/day or 90% of CO<sub>2</sub>
- Pipeline to Hill Corps West Ranch Oil Field (70 miles)
- EOR 300 bbls/day to 15,000 bbls/day!
- 60 million bbls Recoverable Oil

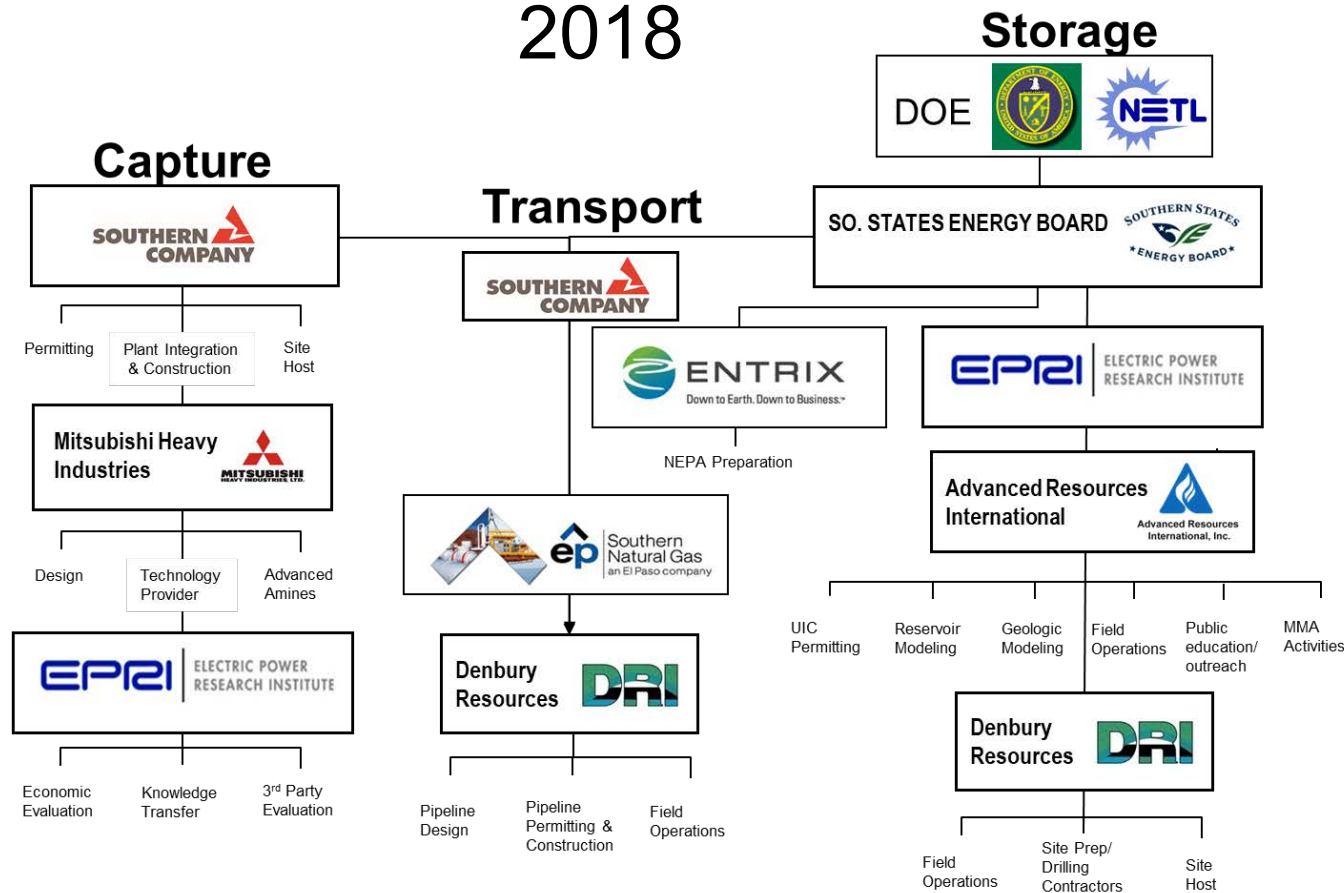


# New Partnerships and Collaborations Formed

## 2008



## 2018





# Together...Shaping the Future of Electricity