Fourth Annual Conference on Carbon Capture & Sequestration

Developing Potential Paths Forward Based on the Knowledge, Science and Experience to Date

Update on the Frio Brine Pilot

Susan D. Hovorka

May 2-5, 2005, Hilton Alexandria Mark Center, Alexandria Virginia

Update on the Frio Brine Pilot: Eight months after injection

Susan D. Hovorka
Bureau of Economic Geology
Jackson School Of Geosciences
The University of Texas at Austin

Dan Collins
Field Service Provider
Sandia Technologies, LLC

Sally Benson and Larry Myer
GeoSeq Project
Lawrence Berkeley National Lab

Charles Byrer and Karen Cohen
DOE NETL Project Managers

Frio Brine Pilot Research Team

- Bureau of Economic Geology, Jackson School, The University of Texas at Austin: Susan Hovorka, Mark Holtz, Shinichi Sakurai, Seay Nance, Joseph Yeh, Paul Knox, Khaled Faoud, Jeff Paine
- Lawrence Berkeley National Lab, (Geo-Seq): Larry Myer, Tom Daley, Barry Freifeld, Rob Trautz, Christine Doughty, Sally Benson, Karsten Pruess, Curt Oldenburg, Jennifer Lewicki, Ernie Majer, Mike Hoversten, Mac Kennedy, Paul Cook
- Schlumberger: T. S. Ramakrishna, Nadja Mueller, Austin Boyd, Mike Wilt
- Oak Ridge National Lab: Dave Cole, Tommy Phelps, David Riestberg
- Lawrence Livermore National Lab: Kevin Knauss, Jim Johnson
- Alberta Research Council: Bill Gunter, John Robinson, Bernice Kadatz
- Texas American Resources: Don Charbula, David Hargiss
- Sandia Technologies: Dan Collins, “Spud” Miller, David Freeman; Phil Papadeas
- BP: Charles Christopher, Mike Chambers
- SEQUIRE – National Energy Technology Lab: Curt White, Rod Diehl, Grant Bromhall, Brian Stratizar, Art Wells
- Paulsson Geophysical – Bjorn Paulsson
- University of West Virginia: Henry Rausch
- USGS: Yousif Kharaka, Bill Evans, Evangelos Kakauros, Jim Thorsen
- Praxair: Joe Shine, Dan Dalton
- Australian CO2CRC (CSIRO): Kevin Dodds, Don Sherlock
- Core Labs: Paul Martin and others

Additional participation welcome

Frio Experiment: Monitoring CO_2 Storage in Brine-Bearing Formations

Project Goal: Early success in a high-permeability, high-volume sandstone representative of a broad area that is an ultimate target for large-volume sequestration.

- **Demonstrate that CO_2 can be injected into a brine formation without adverse health, safety, or environmental effects**
- **Determine the subsurface distribution of injected CO_2 using diverse monitoring technologies**
- **Demonstrate validity of conceptual and numerical models**
- **Develop experience necessary for success of large-scale CO_2 injection experiments**

Frio Experiment: Status of Results

1600 metric tons CO_2 was introduced into well-characterized relatively homogenous high permeability sandstone system characteristic of the Gulf Coast region of the US and monitored before, during, and after injection

•Vigorous public/industry outreach - favorable response

•Saturation and transport properties measured horizontally, vertically, and through time using multiple tools

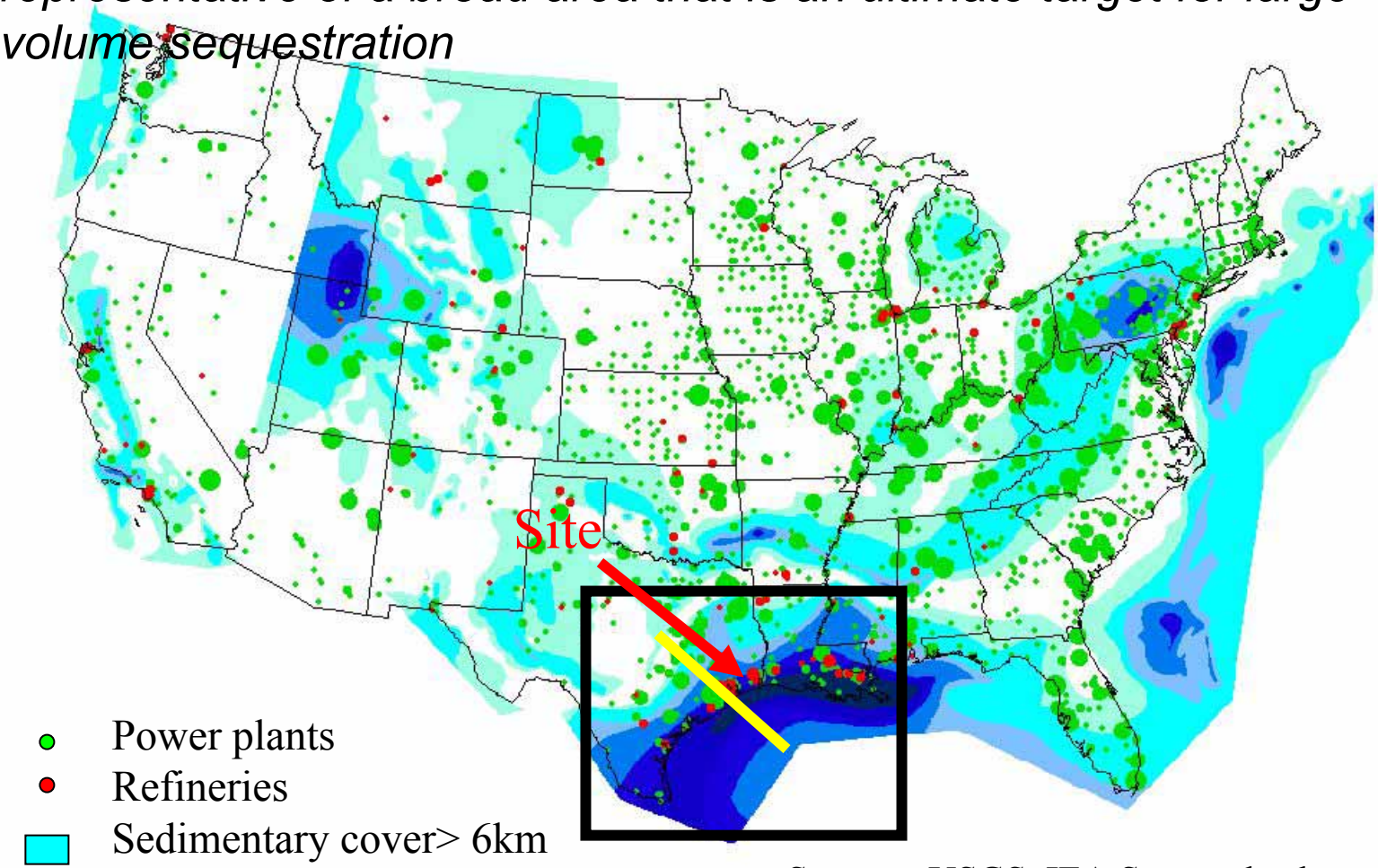
•Improved model conceptual and numerical inputs

•Make results available to field projects planned by Regional Sequestration Partnerships and to Carbon Sequestration Leadership Forum projects

•Analysis continues

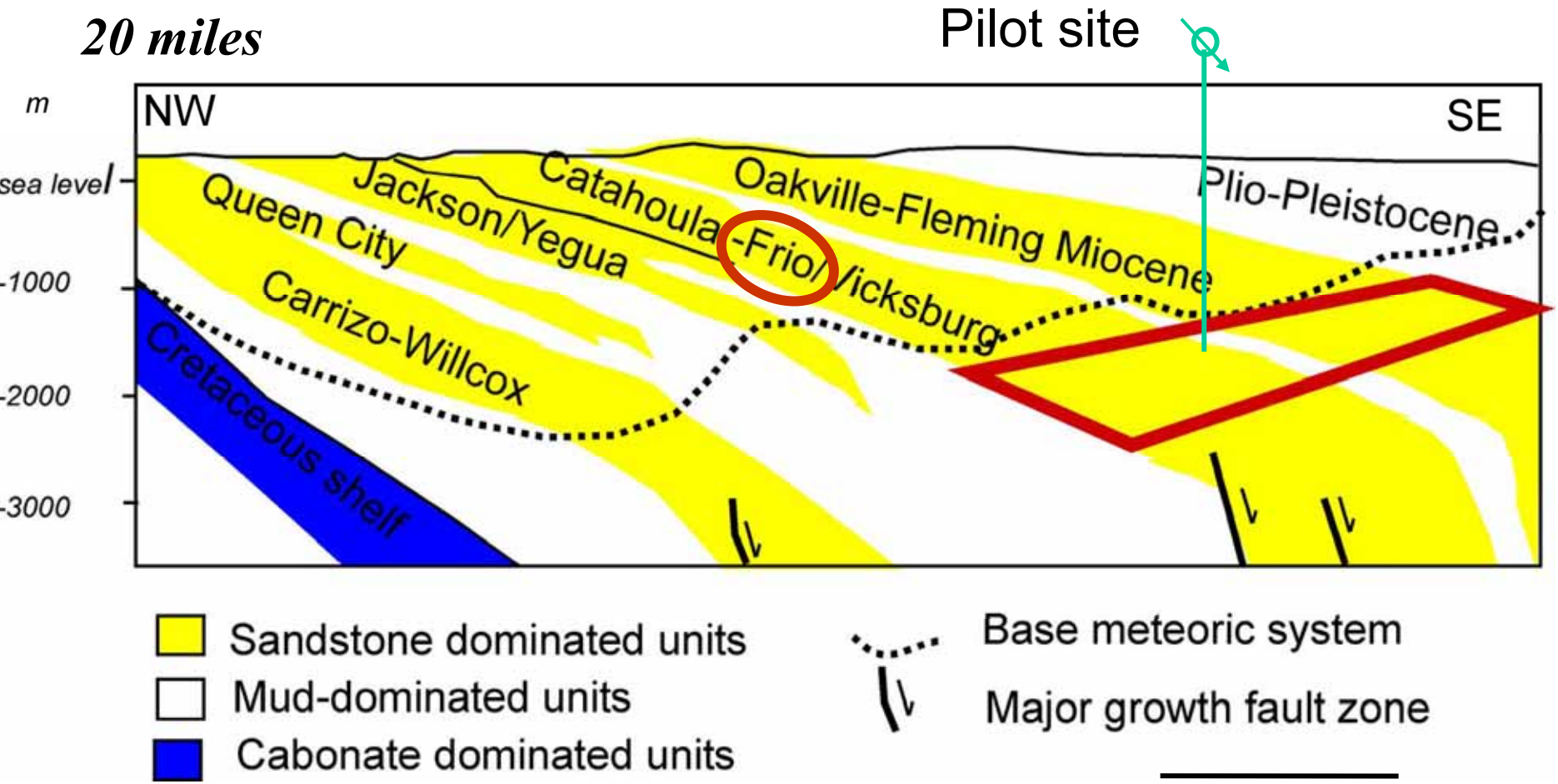
Site Search

Locating a high-permeability, high-volume sandstone representative of a broad area that is an ultimate target for large-volume sequestration



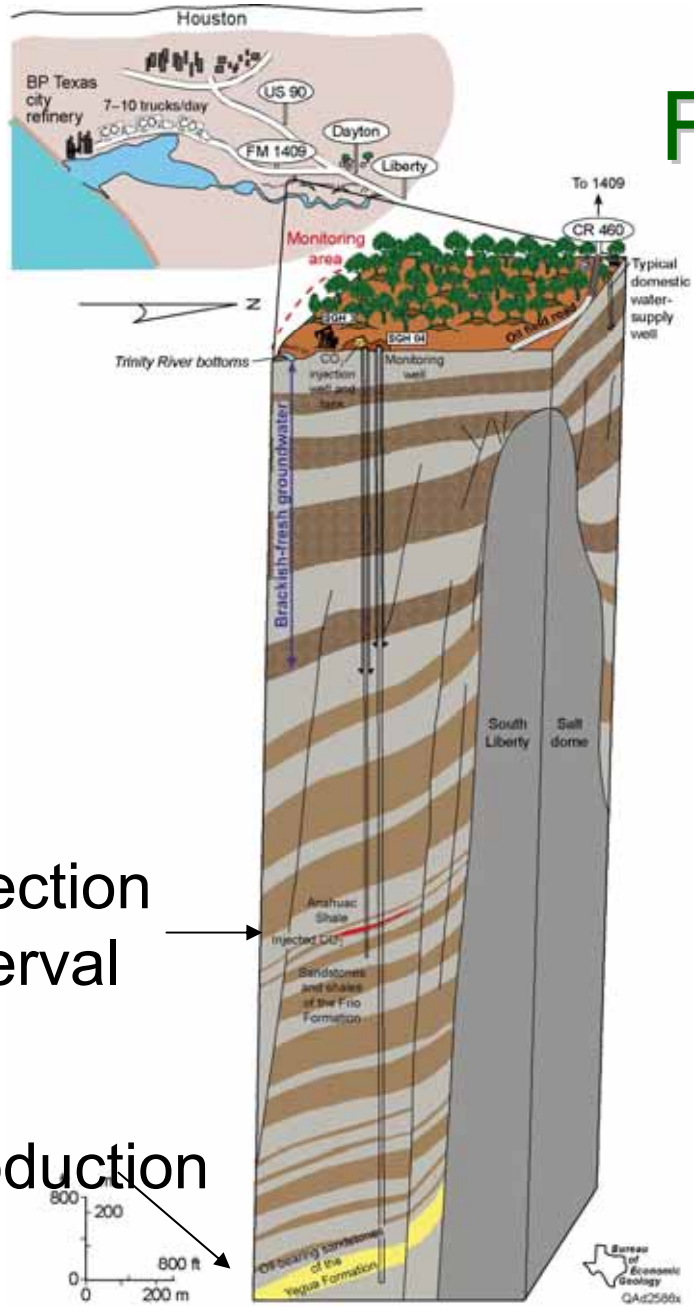
Sources: USGS, IEA Source database

Regional Geologic Setting – Cross Section



Modified from Galloway and others, 1982

Frio Brine Pilot Site



Injection interval

Oil production

- Injection interval: 24-m-thick, mineralogically complex Oligocene reworked fluvial sandstone, porosity 24%, Permeability 2.5 Darcys
- Steeply dipping 18 degrees
- 7m perforated zone
- Seals – numerous thick shales, small fault block
- Depth 1,500 m
- Brine-rock system, no hydrocarbons
- 150 bar, 53 degrees C, supercritical CO_2

Health, Safety, and Outreach Activities

Demonstrate that CO_2 can be injected into a brine formation without adverse health, safety, or environmental effects

15 news articles

Houston Express-News

Reuters, BBC

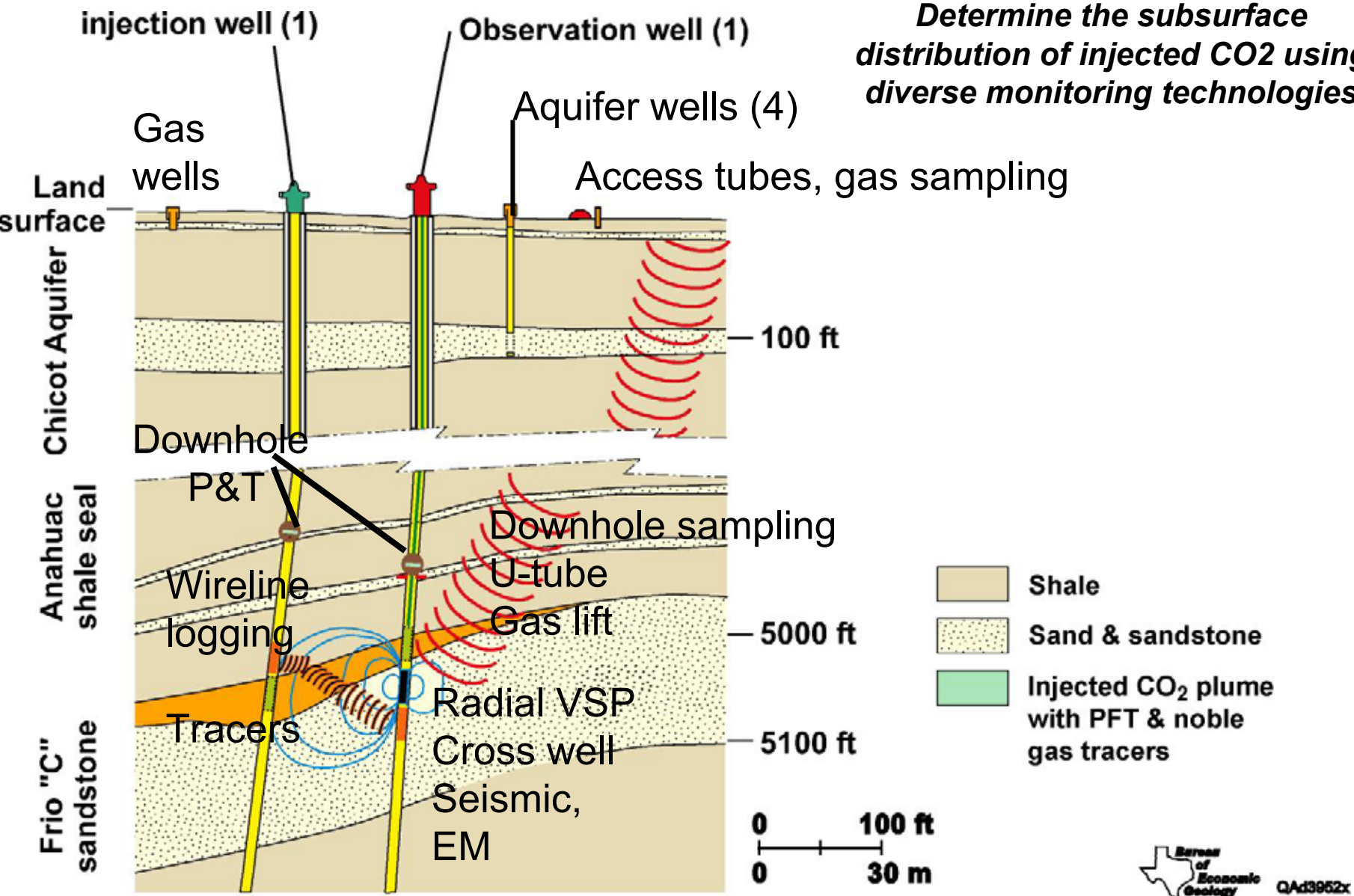
100 visitors

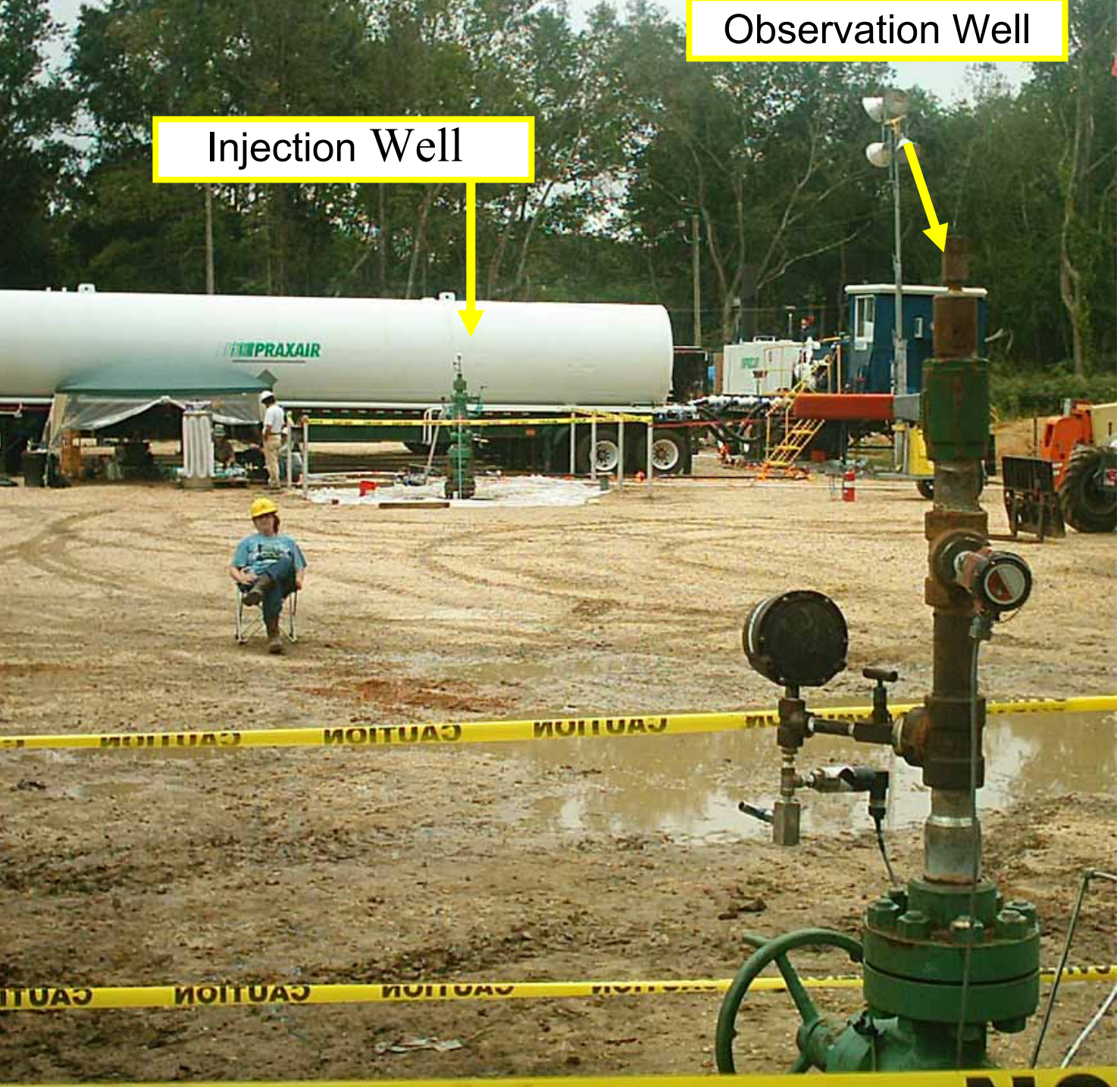
17 papers + 2 posters here

Regional Sequestration Partnerships visit the Frio Site

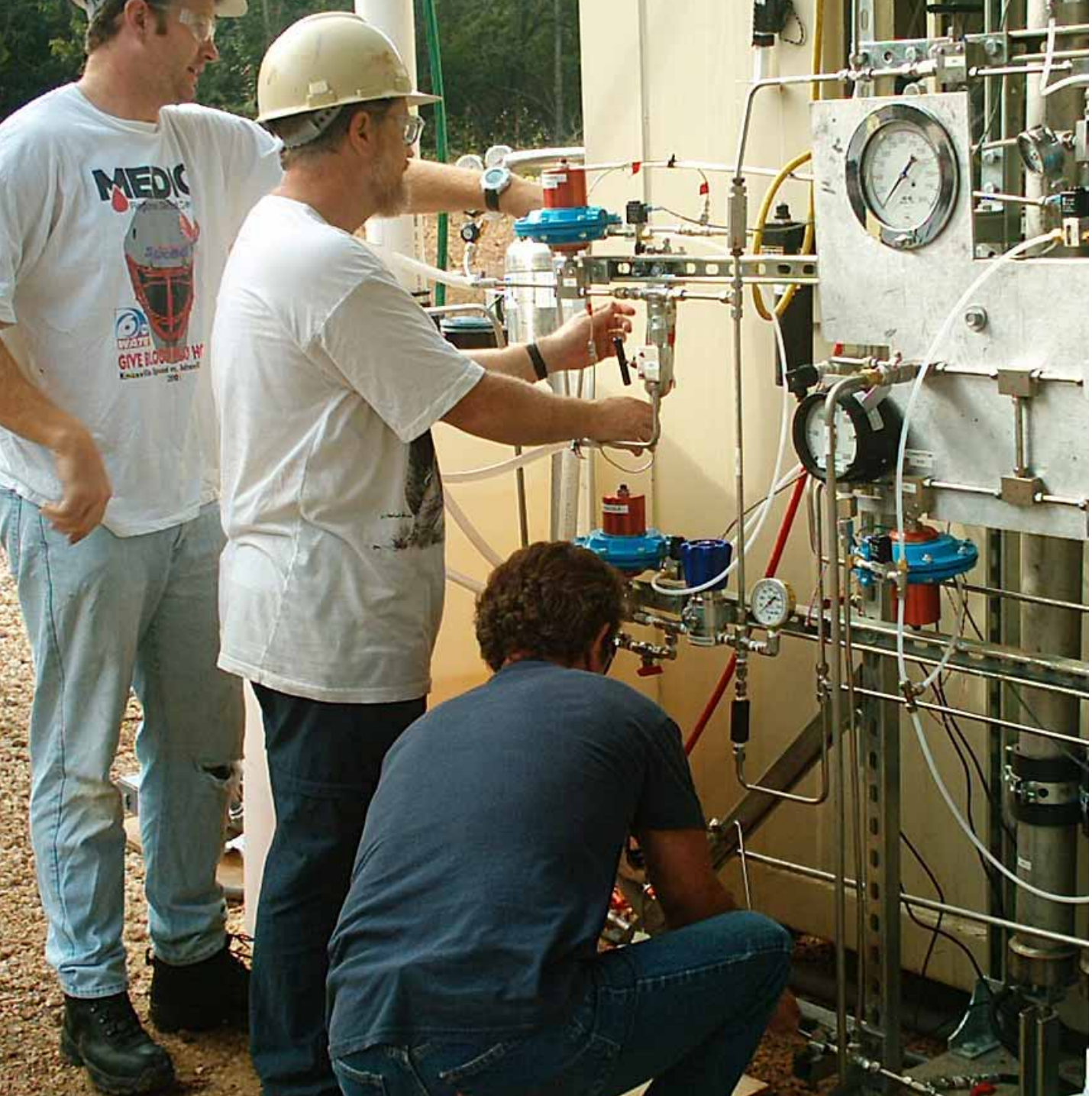
Monitoring at Frio Pilot

Determine the subsurface distribution of injected CO2 using diverse monitoring technologies





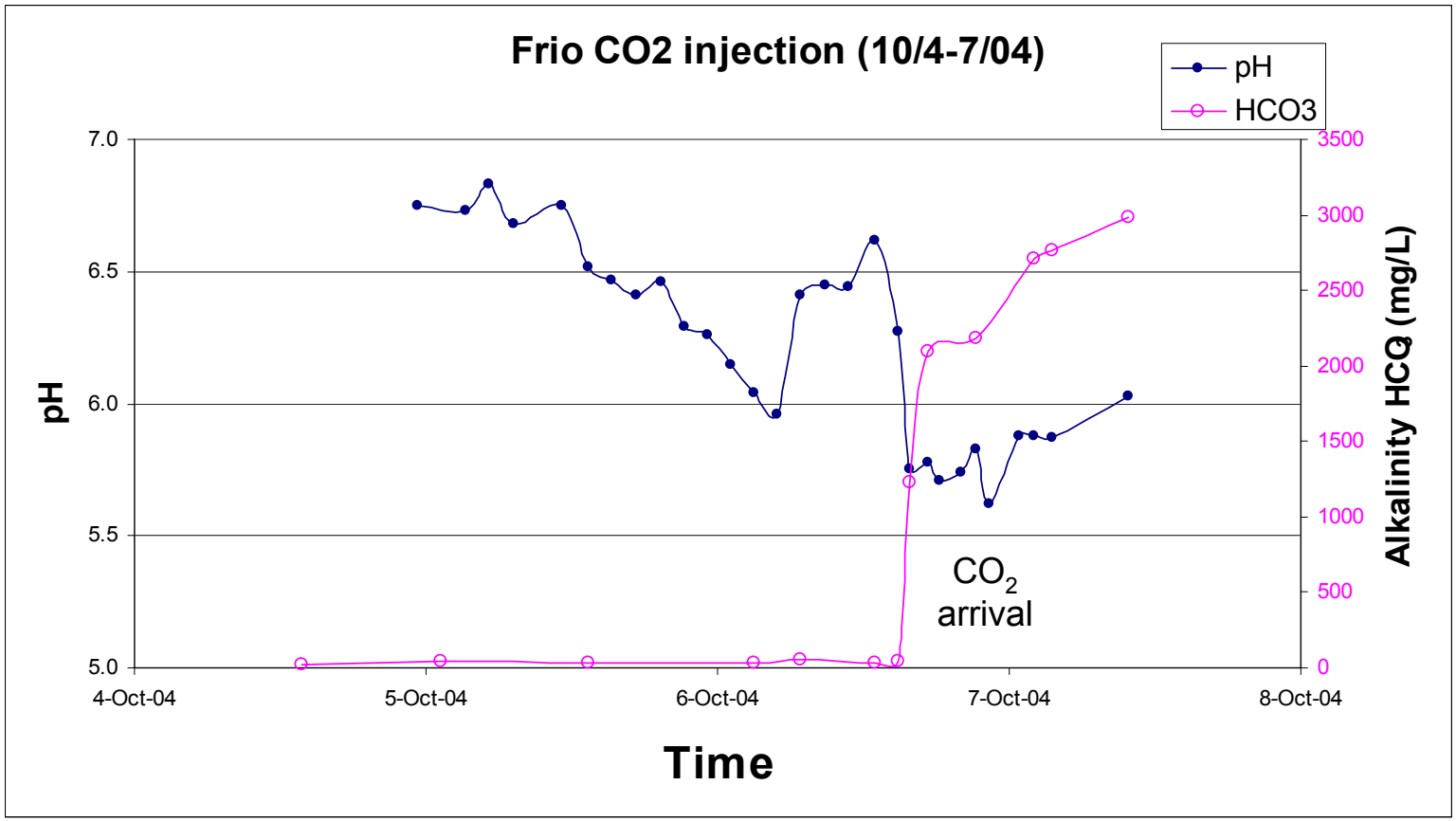
Closely spaced measurements in time and space



New tool to do the job:
LBNL U-tube

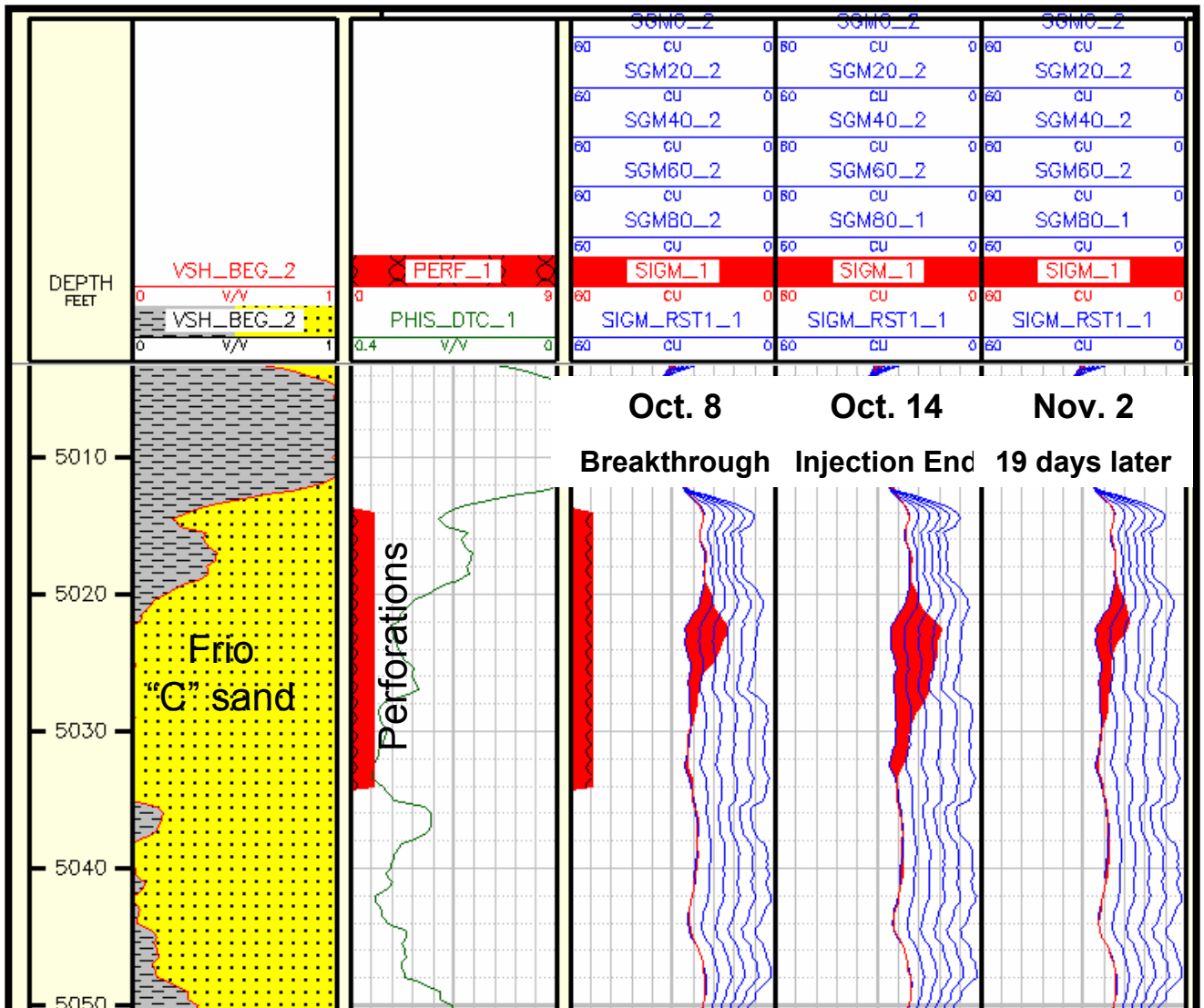
instrument to collect high frequency, high quality two-phase samples

Alkalinity and pH of Brine from Observation Well During CO_2 Injection



Y. Kharaka, USGS; H. S. Nance, BEG

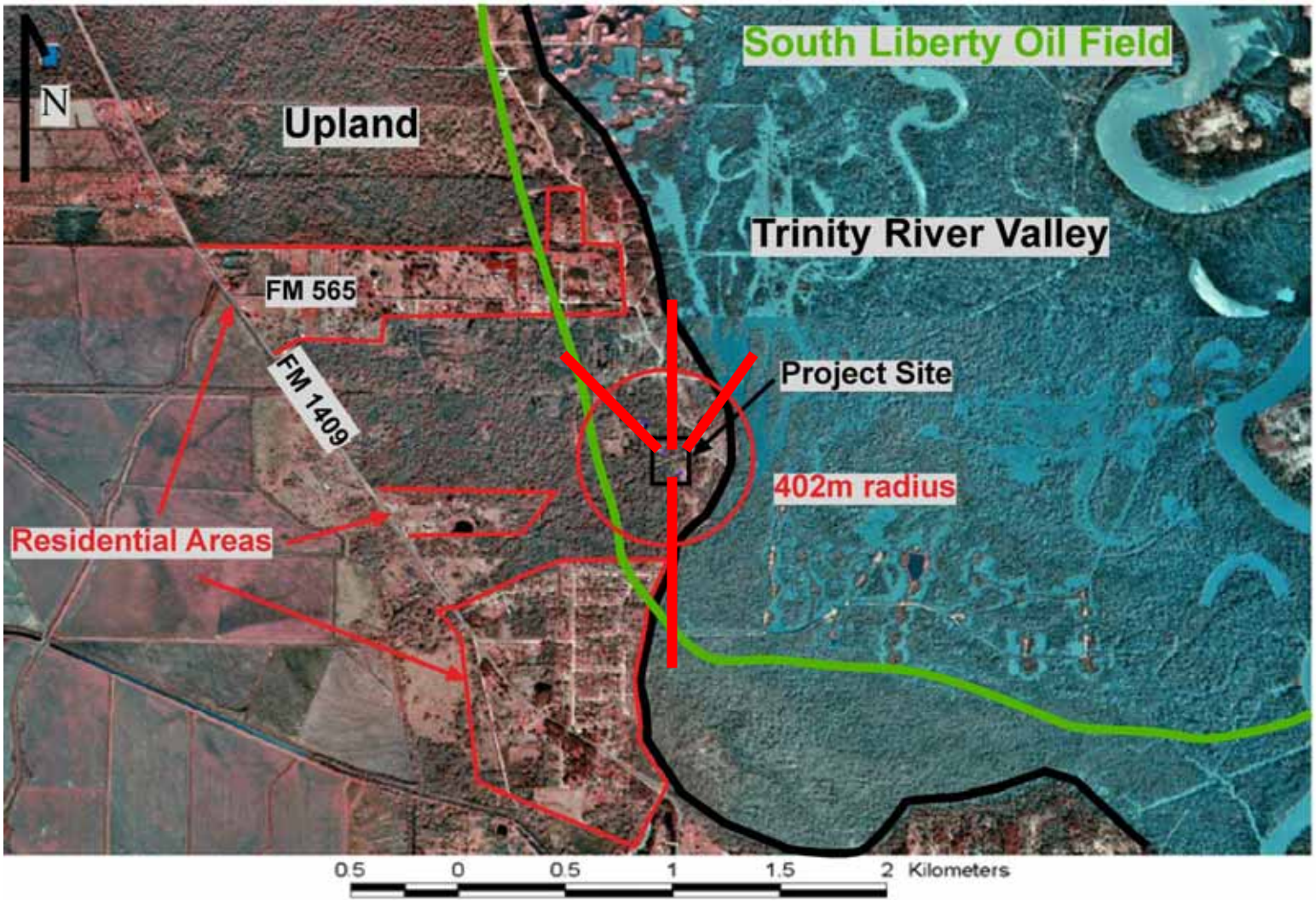
Wireline logging to measure changes in CO_2 saturation



Quantitative,
High resolution
Low cost

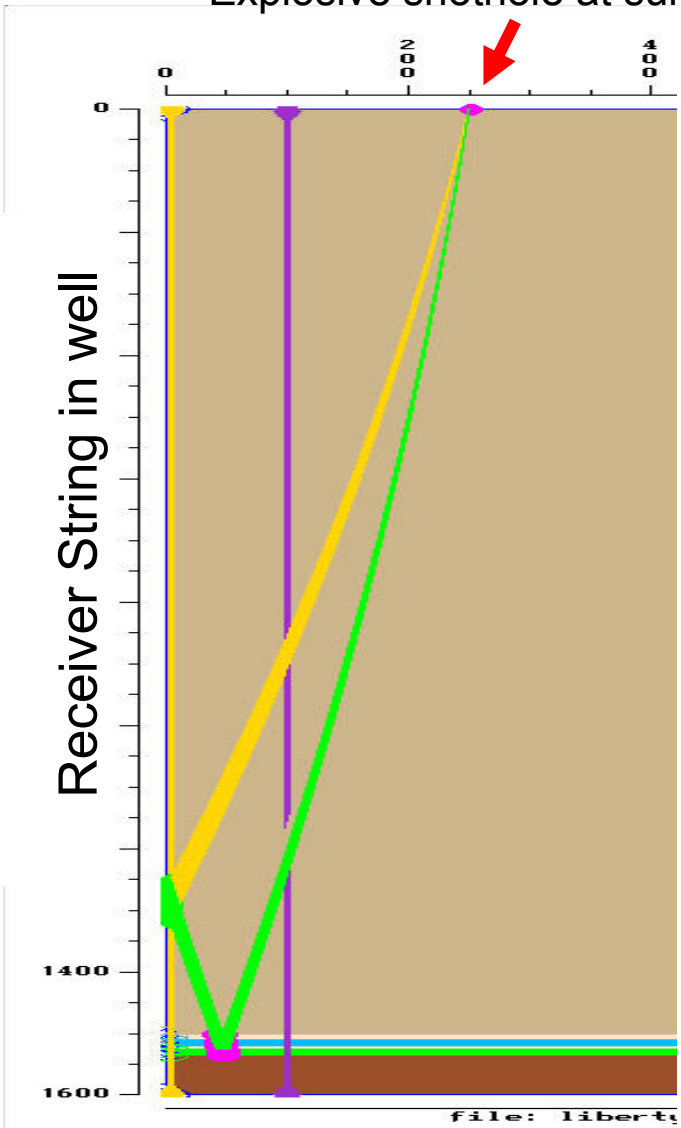
Change in sigma
Pulsed Neutron Log

Azimuthal Array of Vertical Seismic Profiles



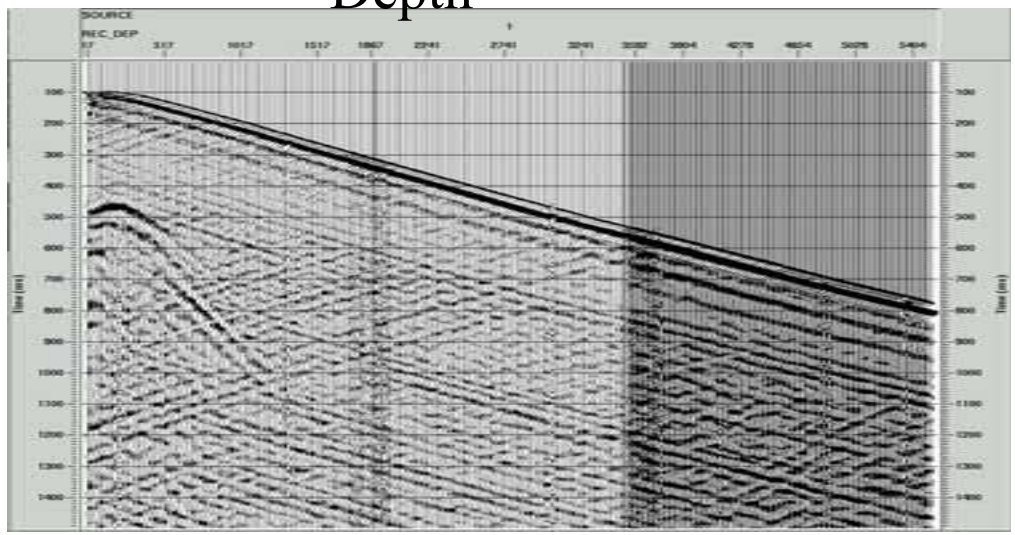
Vertical Seismic Profiling

Explosive shothole at surface



Raw Data Site 1

Depth →



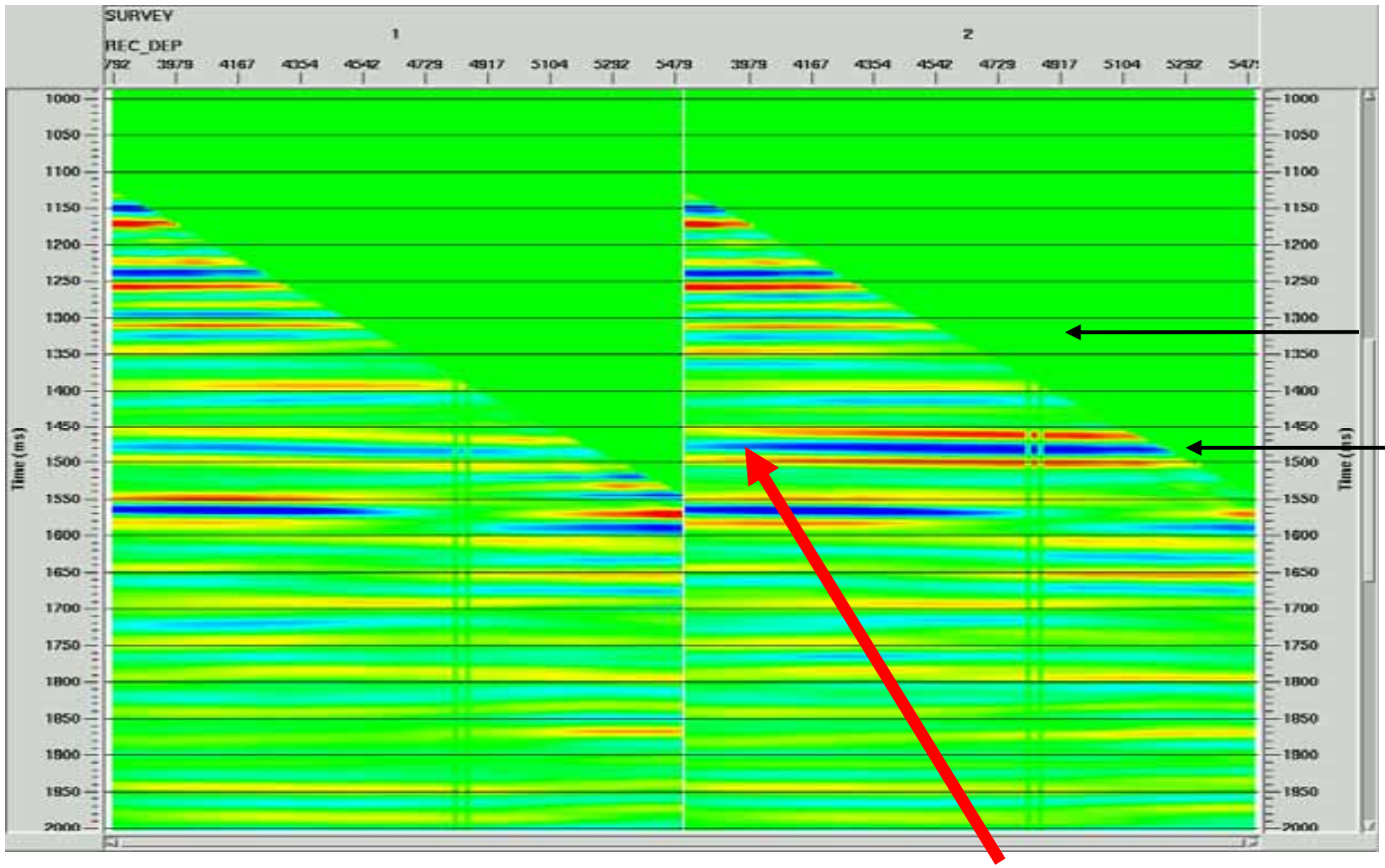
Time →

Denser spacing in reservoir interval

Tom Daley LBNL

VSP Imaged CO_2

Demonstrates the usefulness of the seismic techniques for leak detection

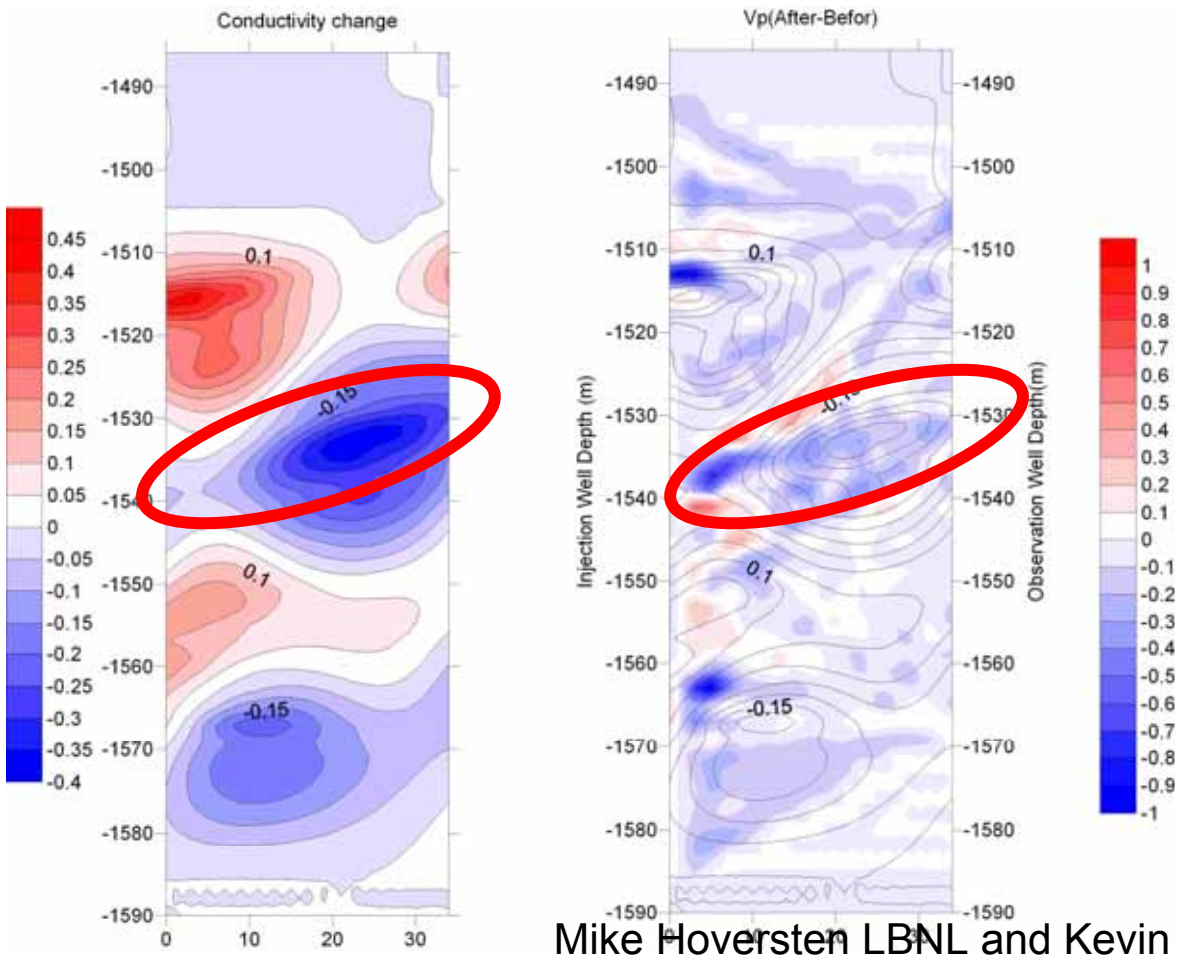


Site 1 (North, Up Dip)
Reflection Section Tom Daley

Measurement of CO_2 distribution with cross-well techniques

EM Inverted Resistivity Difference

Time Lapse Cross well Seismic With Tim-lapse EM contours

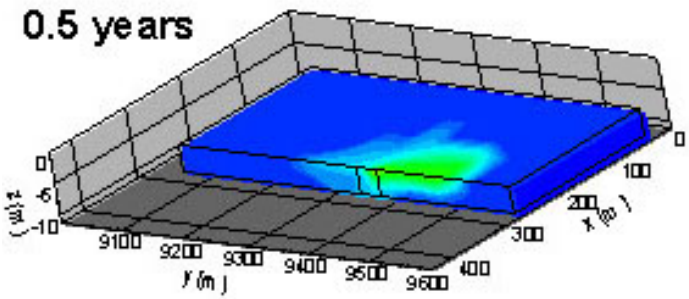


CO_2 detection

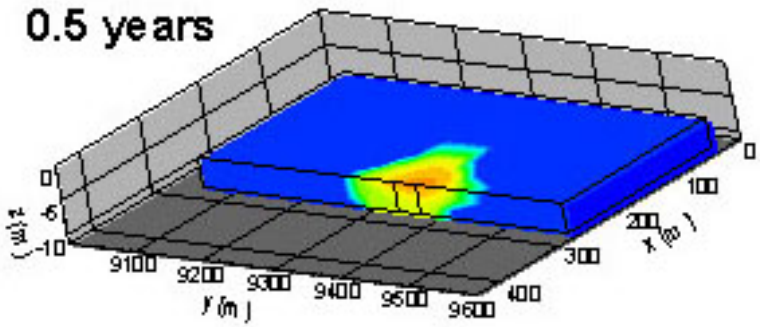
Mike Hoversten LBNL and Kevin Dodds CO2CRC

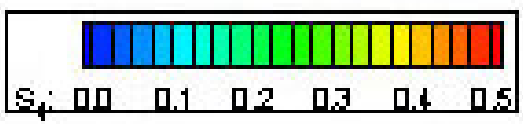
How Modeling and Monitoring Demonstrate Permanence

Residual gas saturation of 5%



Residual gas saturation of 30%

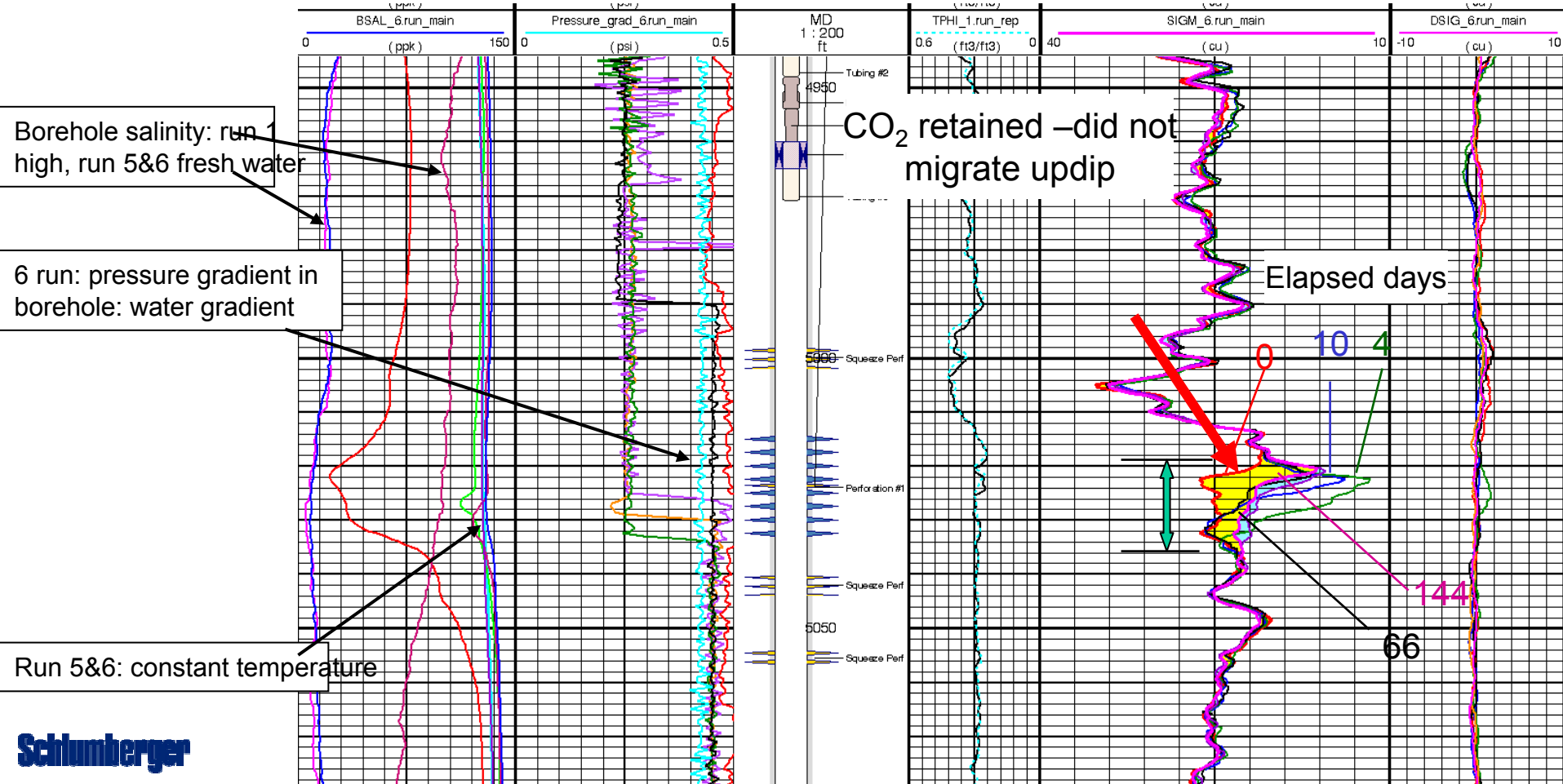




- Modeling has identified variables which appear to control CO_2 injection and post injection migration.
- Measurements made over a short time frame and small distance confirm the correct value for these variables
- Better conceptualized and calibrated models will now be used to develop larger scale longer time frame injections

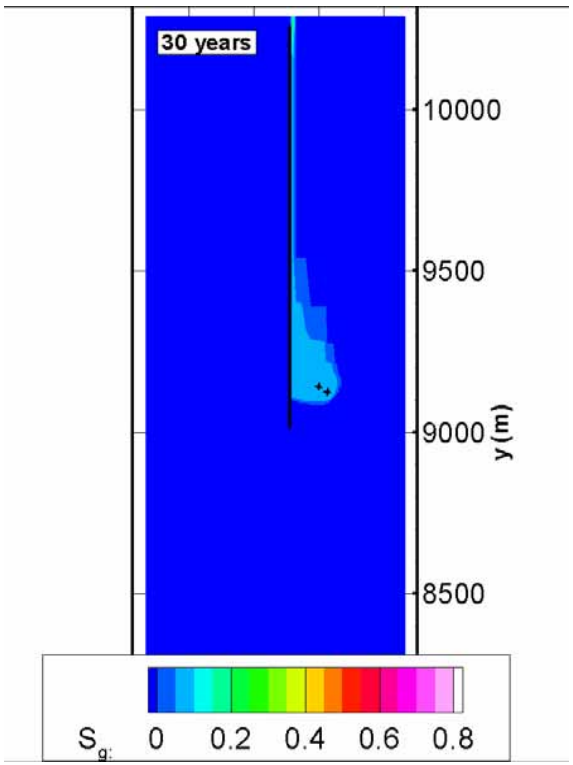
TOUGH2 simulations
C. Doughty LBNL

Preliminary Saturation Log Interpretation 6-months post injection- Saturation remains high

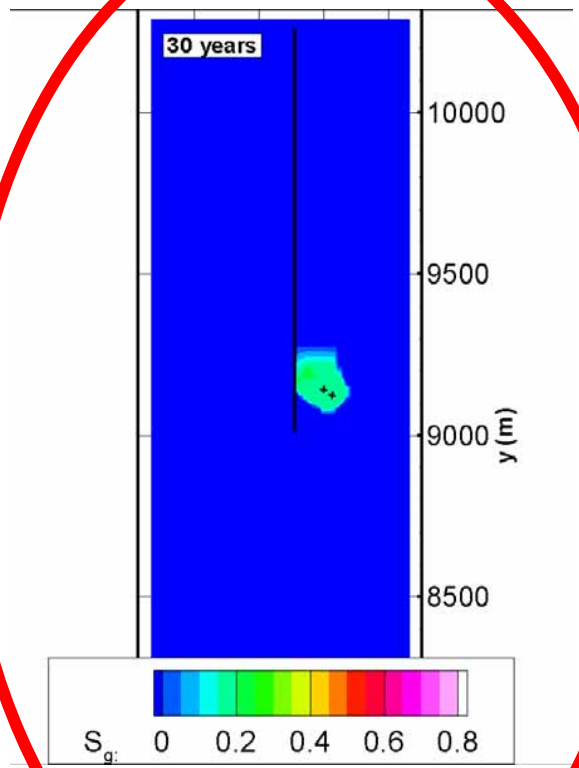


Schlumberger

Modeled Long-term Fate
30 years based on observed post-injection saturation

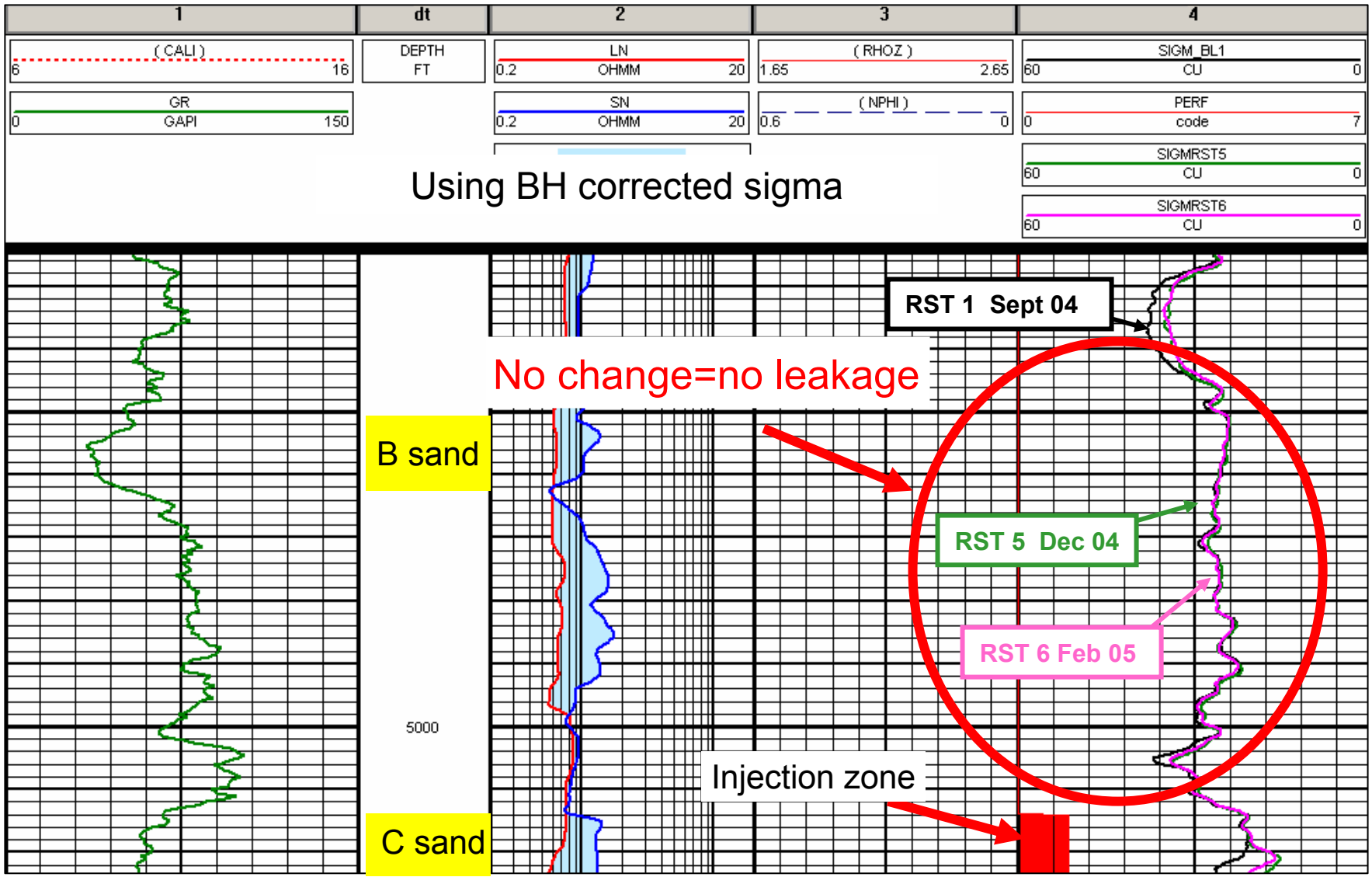


Minimal Phase trapping



Predicted significant phase trapping

Evidence of upward leakage?
From saturation logs: No

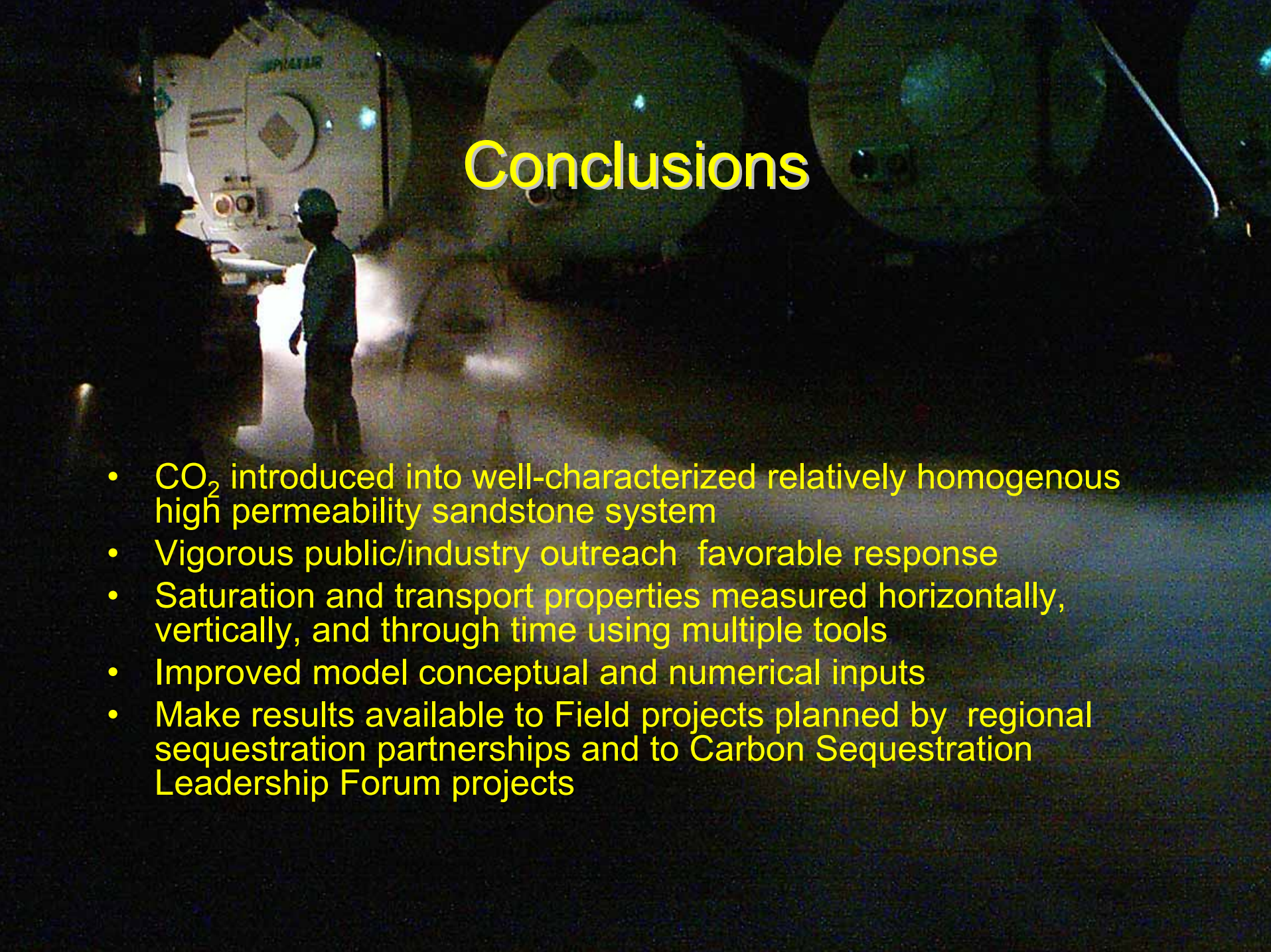


Surface Monitoring continues: results pending

Gas well sampling

Water well sampling

Soil gas sampling



Conclusions

- CO_2 introduced into well-characterized relatively homogenous high permeability sandstone system
- Vigorous public/industry outreach favorable response
- Saturation and transport properties measured horizontally, vertically, and through time using multiple tools
- Improved model conceptual and numerical inputs
- Make results available to Field projects planned by regional sequestration partnerships and to Carbon Sequestration Leadership Forum projects

More work needed: experiments not done at Frio

Experiment	why not done?
• Large volume of CO_2	Risk, $
• Interaction with faults premature	Risk, complex,
• 4-D survey	Problematic, $
• Observation well array in zone	$
• Tilt	Problematic, $
• Microseismic array	Problematic,$
• WAG	Interference
• EOR	interference
• EGR	interference
• Streaming potential	$
• Ecosystem impact survey	Problematic, $
• Massive pre-project PR	Problematic
• Legal/regulatory system test case	Problematic

Experiment	why not done?
• During experiment pressure monitoring in overlying brine aquifers, fresh aquifers	Interference
• Ecosystem CO2 flux towers	Problematic, $
• Surface CO2 monitoring lasers	Problematic, $
• Airborne/ satellite monitoring	Problematic
• Dealing with dissolved methane	no plan
• Exhaustive logging	Problematic, $
• Other edgy down hole monitoring	
• (e.g. non-conductive wells)	$
• Long-term monitoring	problematic, $
• Pipeline issues	premature
• Complex gas injection	interference
• Inject low, recover high	$
• Well integrity, special cement	premature
• Long-term geochemistry	$

Problematic = estimated to be unlikely to collect useful measurements at Frio scale, duration, site specific conditions

Interference = interferes with success of another experiment

$ = cost prohibitive in total project context. Might be used in a larger budget project