THE UNIVERSITY OF TEXAS AT AUSTIN

WHAT STARTS HERE CHANGES THE WORLD

SECARB Early Test Retrospective

Susan Hovorka, Ramón Treviño, Tip Meckel,
Jacob Anderson, Seyyed Hosseini, Jiemin Lu, JP Nicot,
Katherine Romanak, Changbing Yang, Vanessa Nuñez-Lopez

Bureau of Economic Geology

TEXAS Geosciences
The University of Texas at Austin
Jackson School of Geosciences

GCCC
GULF COAST CARBON CENTER

Early Test Research team

NETL

SECARB
Southeast Regional Carbon Sequestration Partnership

SOUTHERN STATES ENERGY BOARD

SECARB Anthropogenic Test At Plant Barry/Citronelle

Bureau of Economic Geology
Gulf Coast Carbon Center

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Bureau of Economic Geology
Jackson School of Geosciences
The University of Texas at Austin

Core Lab
UT DoG
Anchor QEA

Environmental Information Volumes
Walden Consulting

Vendors
e.g. equipment

Denbury Resources
Field owner and injection system design, management, 4-D survey, HS&E

Vendors
e.g. local landman

Sandia Technologies
Monitoring Systems Design, Installation, HS&E

50 Vendors
e.g. Schlumberger

MSU UMiss
Hydro & hydrochem

Federal collaborators Via FWP

- LBNL
  Well-based geophysics, U-tube and lab design and fabrication
- LLNL
  ERT
- USGS
  Geochemistry

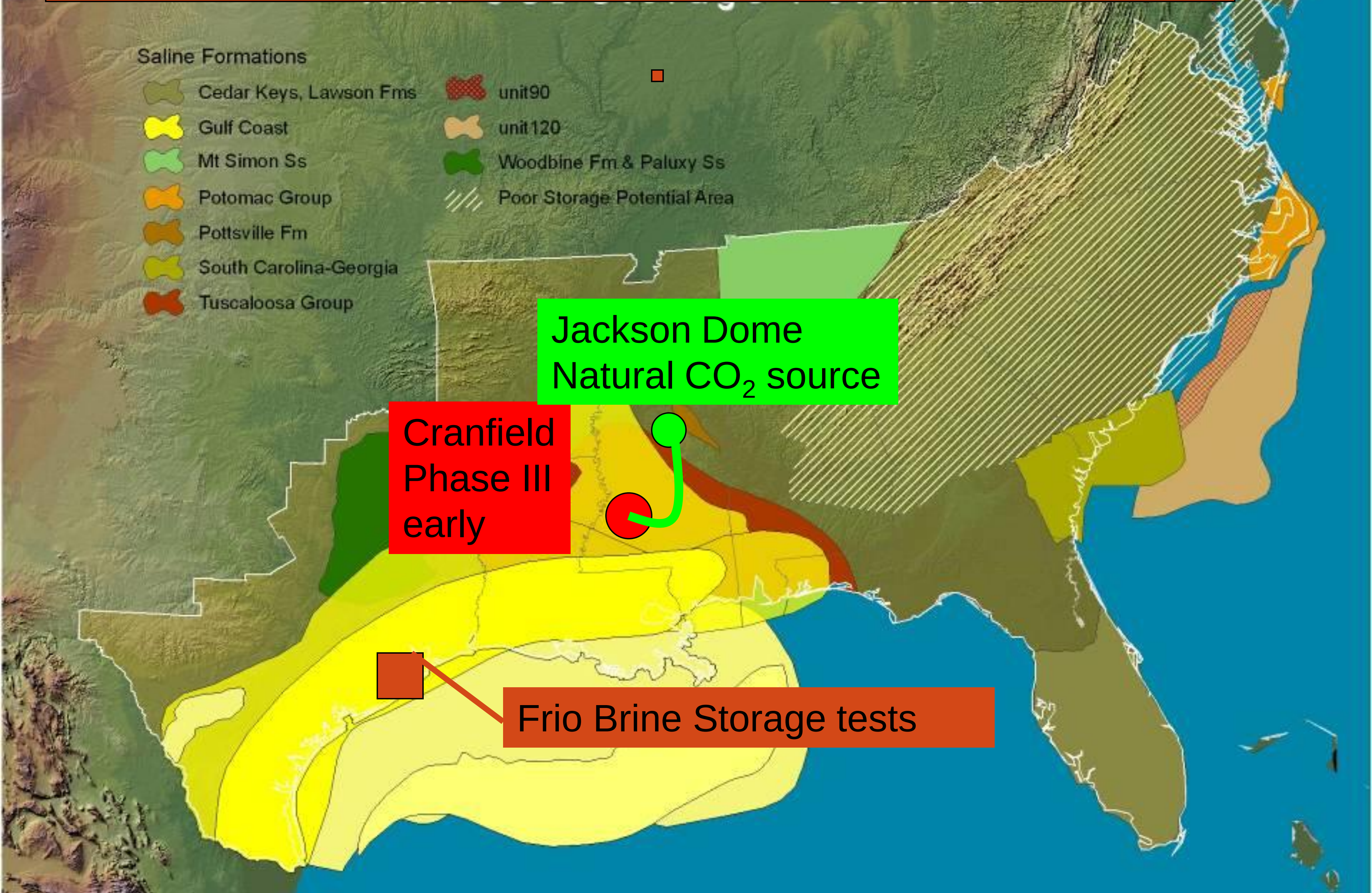
Curtin University, Perth

Separately funded

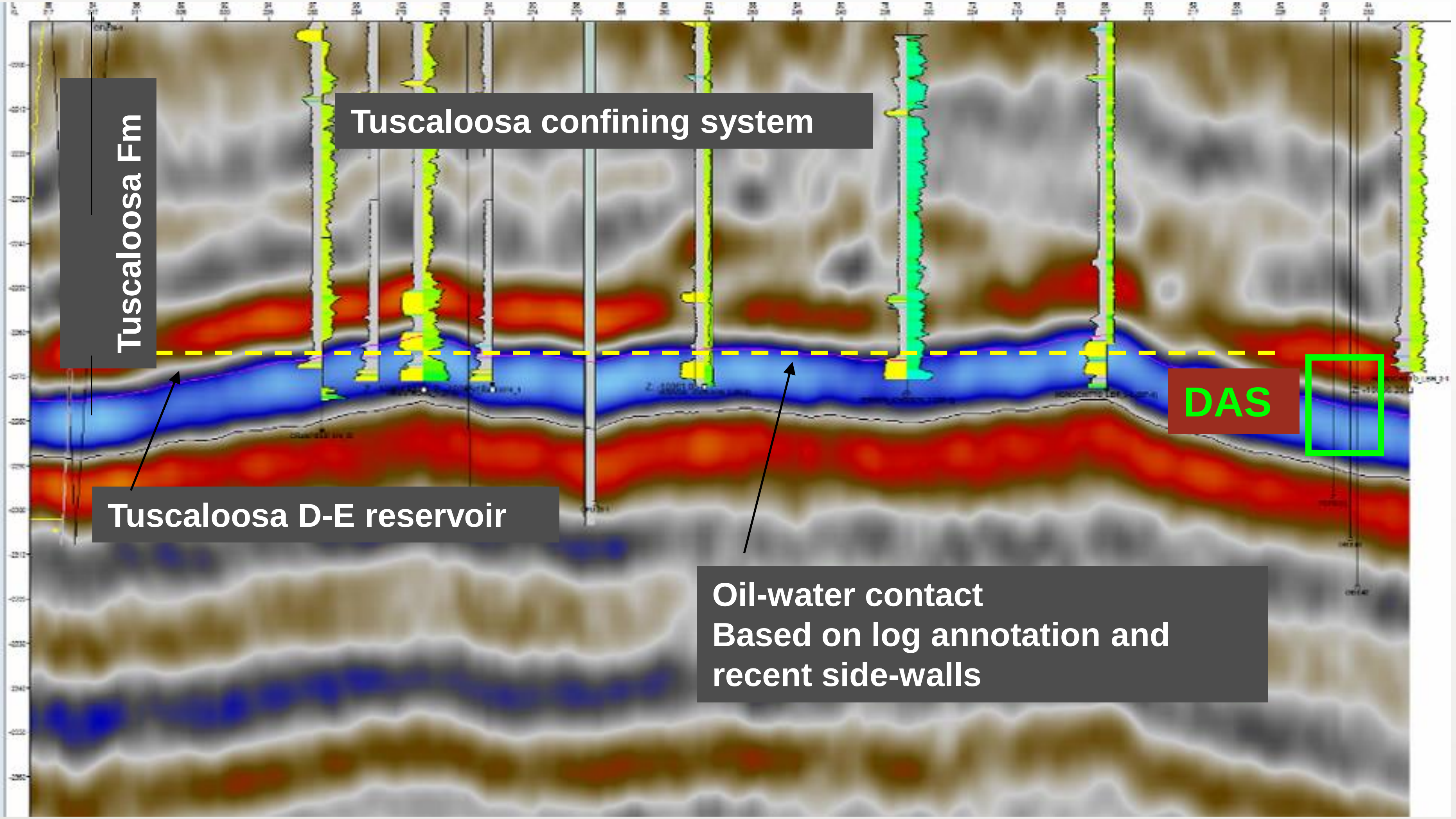
- ORNL
  PFT, Stable isotopes
- NRAP
  VSP& analysis
- NETL
  Rock-water interaction

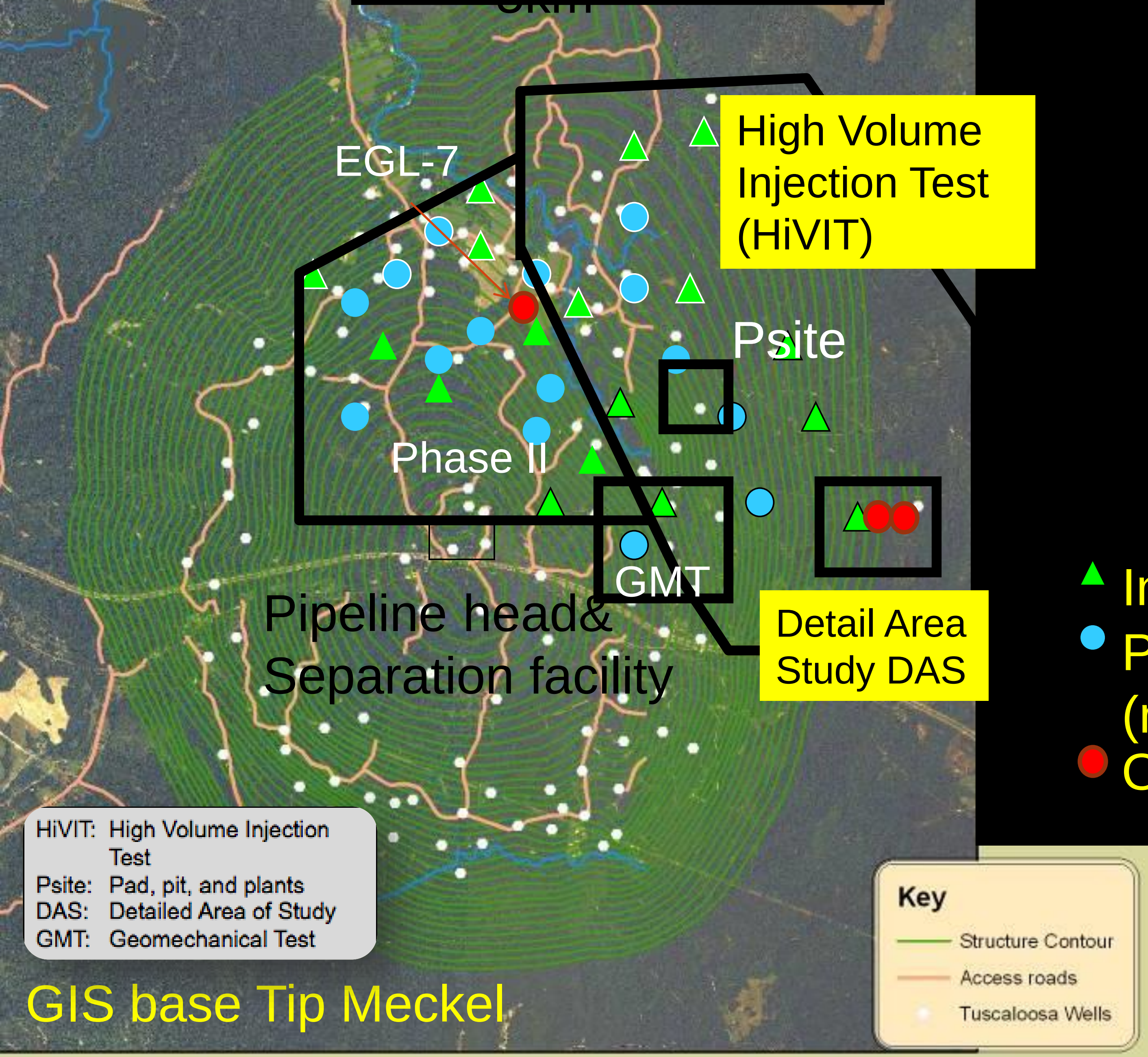
Stanford, Princeton, U Edinburgh, UT PGE & ICES (CFSES), U. Tennessee, USGS RITE, BP, CCP, Durham, AWWA

SECARB Test Site Location



Cranfield: geological location



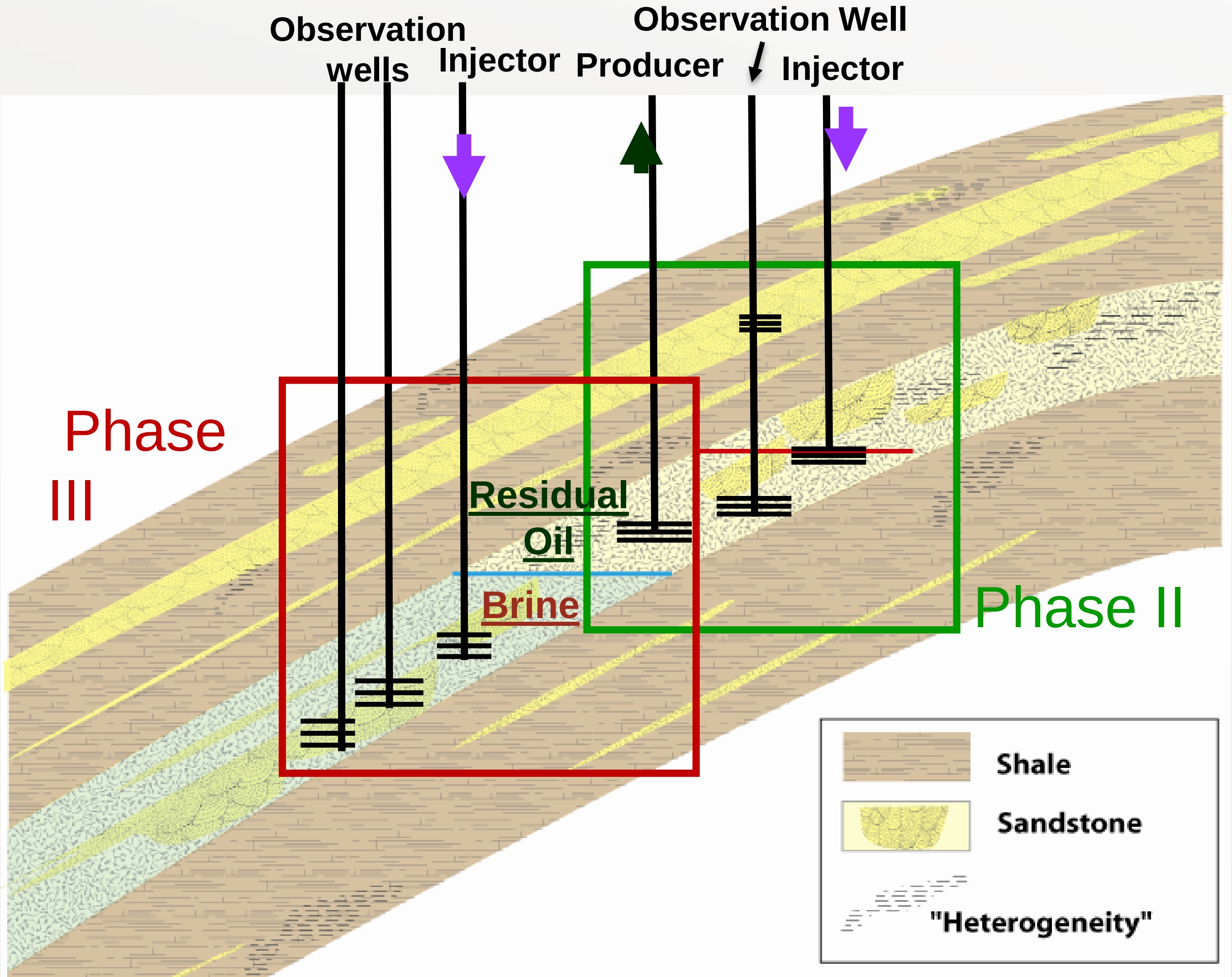


- Injector
- Producer (monitoring point)
- Observation Well

Overview

- > 1 Million metric tonne / yr injection
- Quick start up = "Early test" (bridge between pilot scale and SECARB's Plant Barry/Citronelle anthropogenic test)
- Of possible sites, Denbury's Cranfield field scheduled for 2008 CO_2 injection start was favorable:
  - Time to collect pre-injection data before injection
  - Build quickly to >1 MMT per year CO_2 injection rate (sufficient to assure project metrics were met & *exceeded*)
  - Experienced operator in CO_2 EOR – low risk of permitting delay: ***early results for RCSP program***
  - Field abandoned (40 years); pressure recovered and equilibrated

Favorable Characteristics of Cranfield for SECARB Early test



- Follow-on between Phase II and Phase III
- Phase III planned in water leg downdip of oil zone
- Provided RCSP experience with CO_2 EOR, (grew in importance)

Less than-ideal characteristics

- CO_2 from Jackson Dome (not anthropogenic)
- Field commercial EOR
  - operational aspects not under project's control
  - some data proprietary
- Research purpose only
  - Designed prior to EPA or international regulations
- Relatively complex geology both deep & near surface
- Modeling reservoir's injection response complicated
  - by oil presence
  - injection and withdrawal complexities – ***managed…***

Simplified by:

Focus on the DAS - ***brine only***

Early timing - ***production & recycle was minimal***

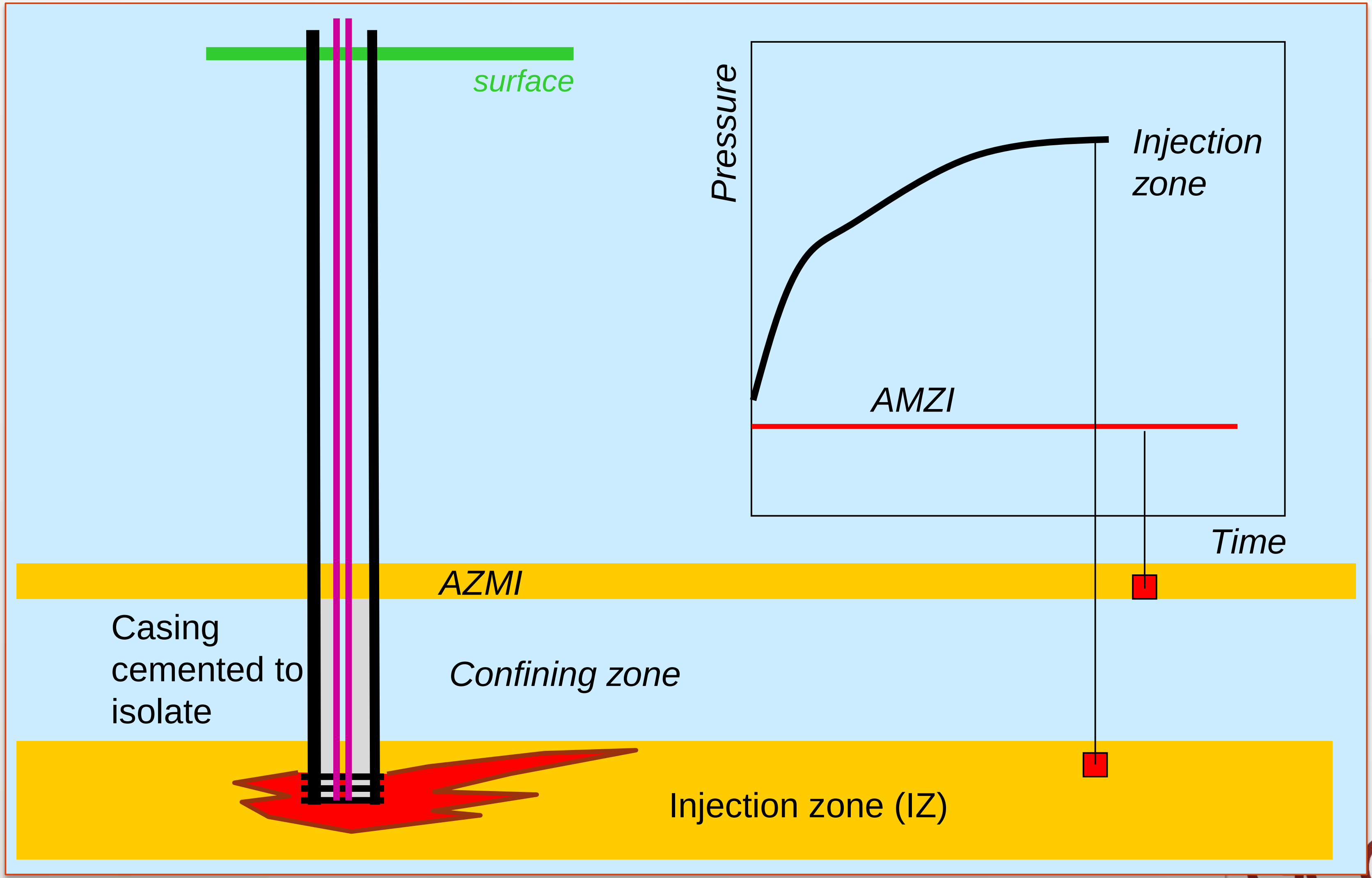
Developing the Experiment

- Year-long series of meetings (2007-2008)
  - designed plan
- Aligned general research objectives
  - well locations
  - selected team members
  - budget
- Designed detailed plans - major components
- Adapted to fast EOR field development
  - NEPA permitting (slow)
  - other timeline issues
    - equipment rental
    - procurement
    - cash flow (2009 “cash call”)

Project objectives

- Connect CO_2 plume development with pressure response
  - in far-field of reservoir ("in-zone")
- **A**bove-**Z**one **M**onitoring **I**nterval (**AZMI**) pressure response
  - first time in CCS
- Advance understanding of geomechanical response (deformation, microseismic)
- Advance understanding of
  - risk to groundwater / value of groundwater as a monitoring approach
  - soil gas methods as a monitoring approach

AZMI

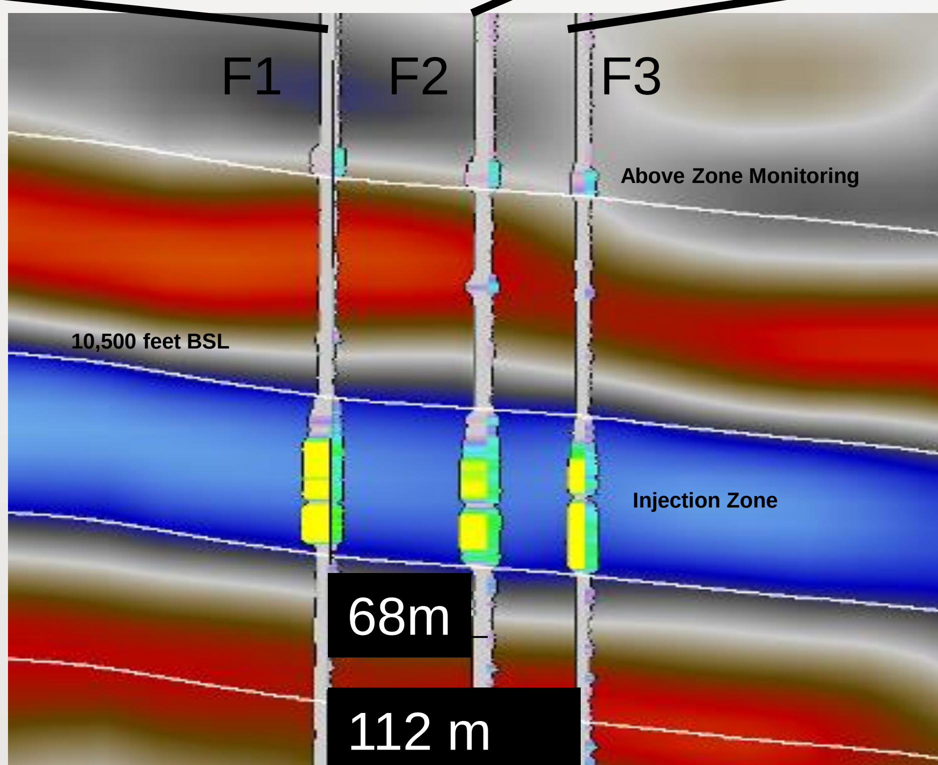

surface
Pressure
Injection zone
AMZI
Time
AZMI
Casing cemented to isolate
Confining zone
Injection zone (IZ)

Team contributions (2)

- LLNL
  - Multiphase geophysics
  - Cross-well EM fielding and interpretation
- USGS
  - reservoir fluid sampling & analyses
- Schlumberger Carbon Services
  - well logging
  - Cross well Seismic
  - AZMI fluid collection
- LBNL / NRAP
  - U-tube,
  - 3-D VSP
  - downhole fiber optic CASSM
- Oak Ridge NL
  - PFT and sampling
- University Edinburgh
  - Noble gasses
- Local landowners
  - access
- Walden Consulting
  - NEPA

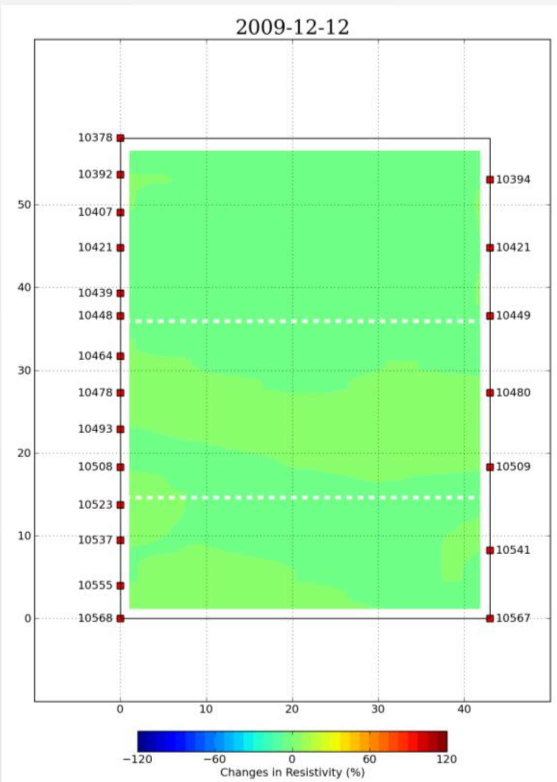
DAS Monitoring Site

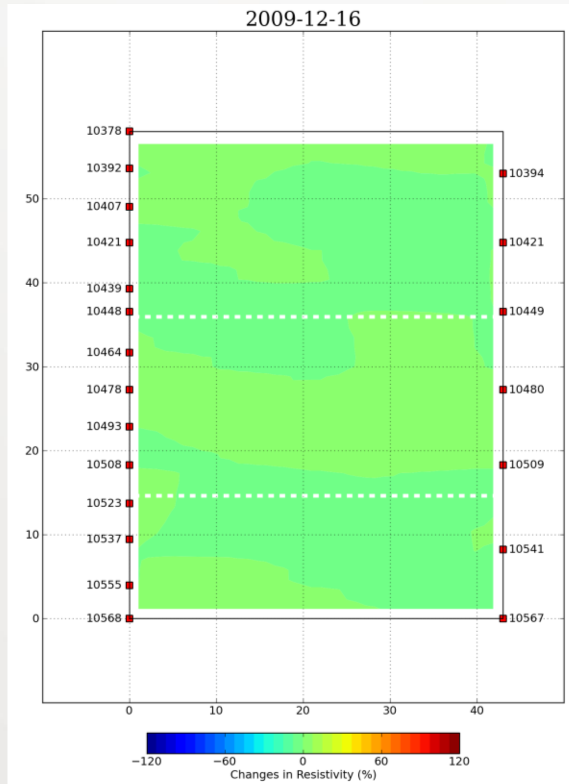
Closely spaced well array to examine flow in complex reservoir

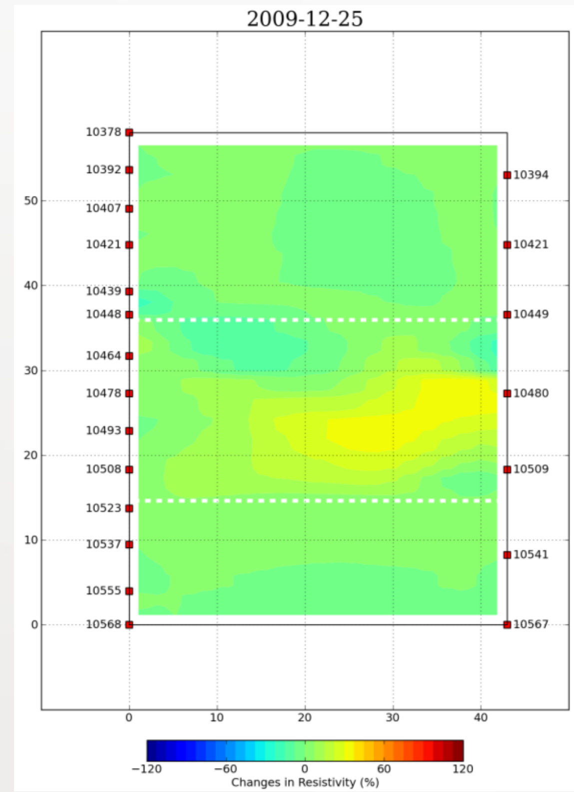


Petrel model Tip Meckel

Time Lapse Resistivity Changes







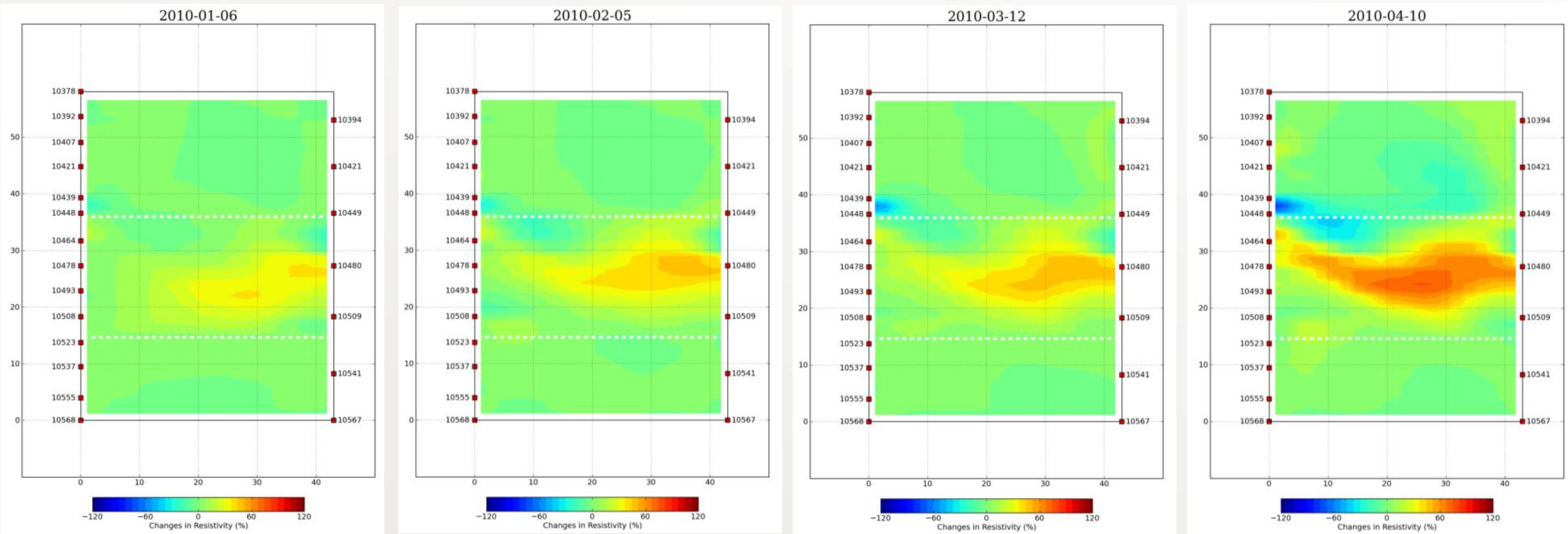
Initial CO_2 Breakthrough in F2

Initial CO_2 Breakthrough in F3

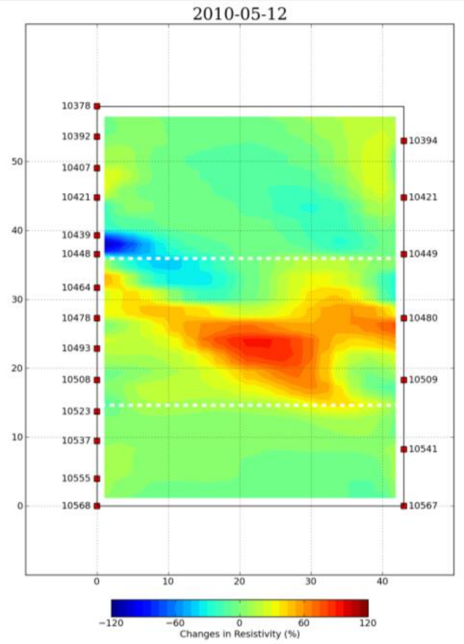
Lawrence Livermore National Laboratory

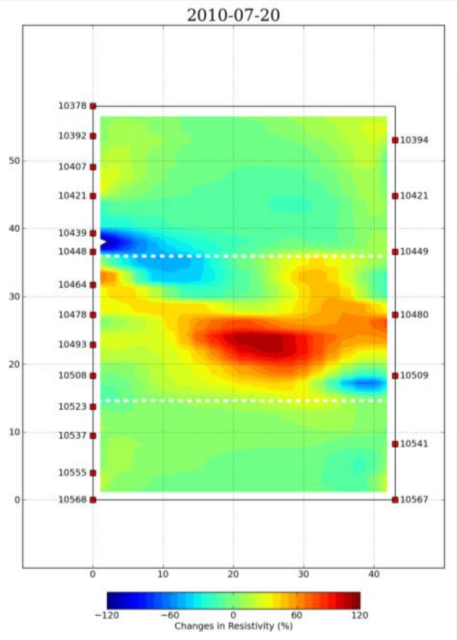
GCCC GULF COAST CARBON CENTER

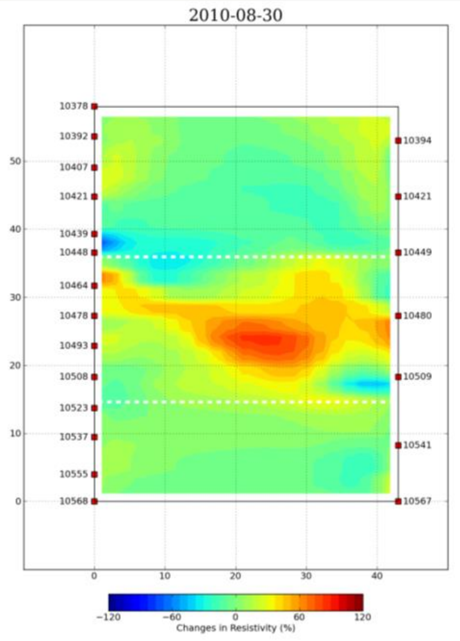
Time Lapse Resistivity Changes

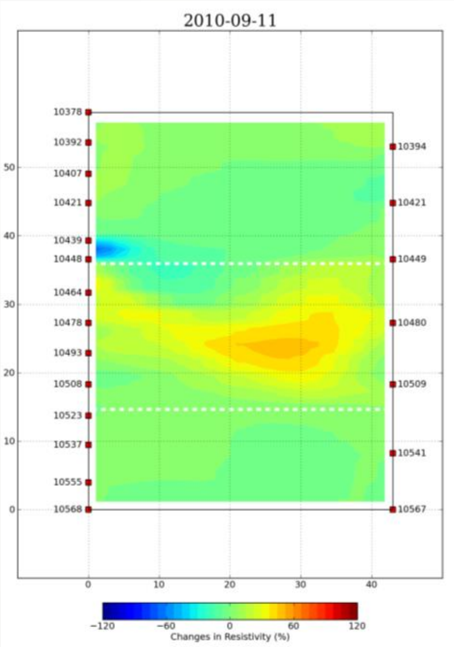


Time Lapse Resistivity Changes









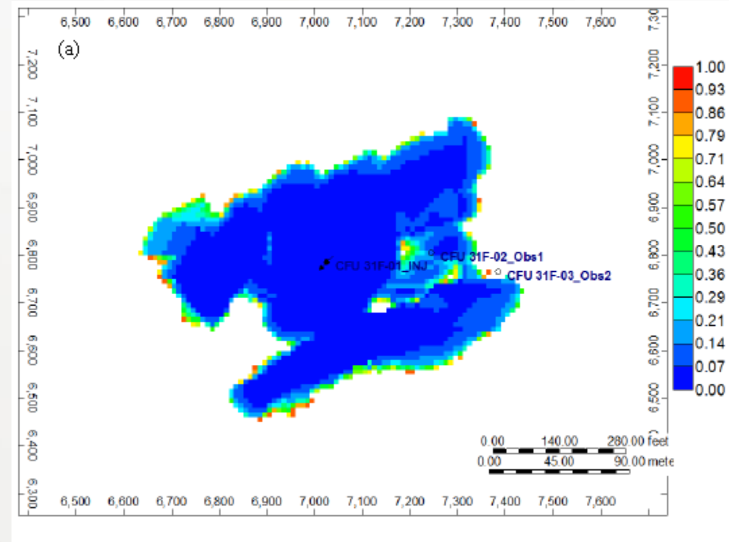
After Work-over in 9/2010

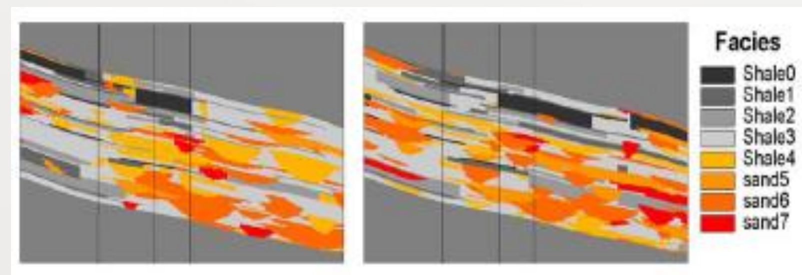
Contributions: Support Collaborators

- CFSES
  - rock samples for geomechanics
- NRAP
  - field site for 3D-VSP
- SIM SEQ
  - comparative modeling data set
- NETL
  - CO_2 EOR model data

Accomplishments

- Monitored CO_2 injection 2008 – 2015
- Injection through 23 wells, cumulative volume over 8 million metric tons
- First US test of ERT for GS (deepest)
- Time lapse plume imaging with cross well seismic, VSP, RST, & surface 3-D seismic
- RITE microseismic – none detected
- Groundwater sensitivity assessment (push-pull)
- Recognized by Carbon Sequestration Leadership Forum (CSLF) in 2010 for research contributions
- SIM-Seq inter-partnership model development test
- Knowledge sharing to Anthropogenic Test and other U.S./International CCS projects





"Early Test's" Major Contributions

- Large volume injection bridged RCSP to current & future anthropogenic sources
- Value of AZMI pressure monitoring in demonstrating reservoir fluid retention
- Probabilistic monitoring helps history-match fluid response to injection in a complex reservoir
- Process-based soil gas method developed and demonstrated for the first time
- Demonstrated utility and site-specific limitations of groundwater monitoring

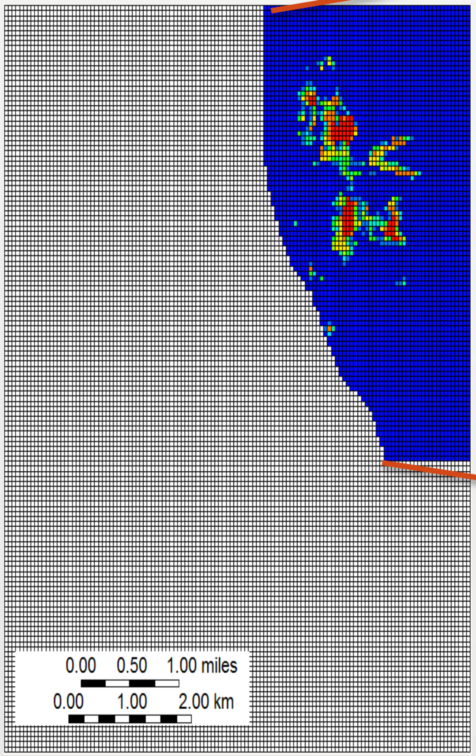
Ongoing (1)

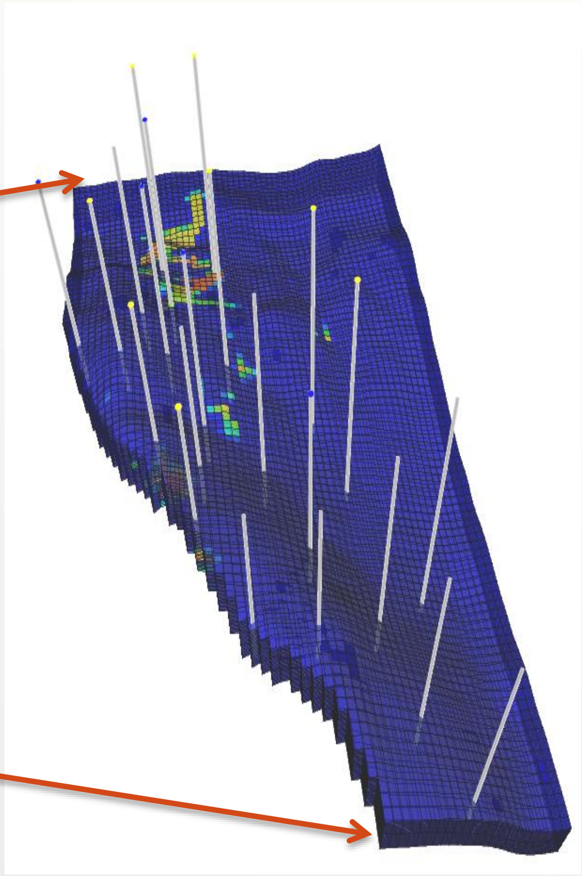
- **Model additional scenarios incorporating uncertainties**
- Forward-model seismic response
- Compare Cranfield ERT to Ketzin
- Evaluate ERT for long-term viability (distinguish noise from signal)
- Determine time-dependent capacity through modeling
- Participate in ISO 265
- **Further optimize process-based soil-gas method**
- Further optimize groundwater uncertainties

Ongoing (2)

- Technology transfer
  - Deployment of monitoring strategies developed at SECARB "Early" test as well as other RCSP and international CCUS sites
  - Support for maturation of monitoring for EOR as well as saline sites through international standards, best practices, critical reviews

Cranfield NE section model



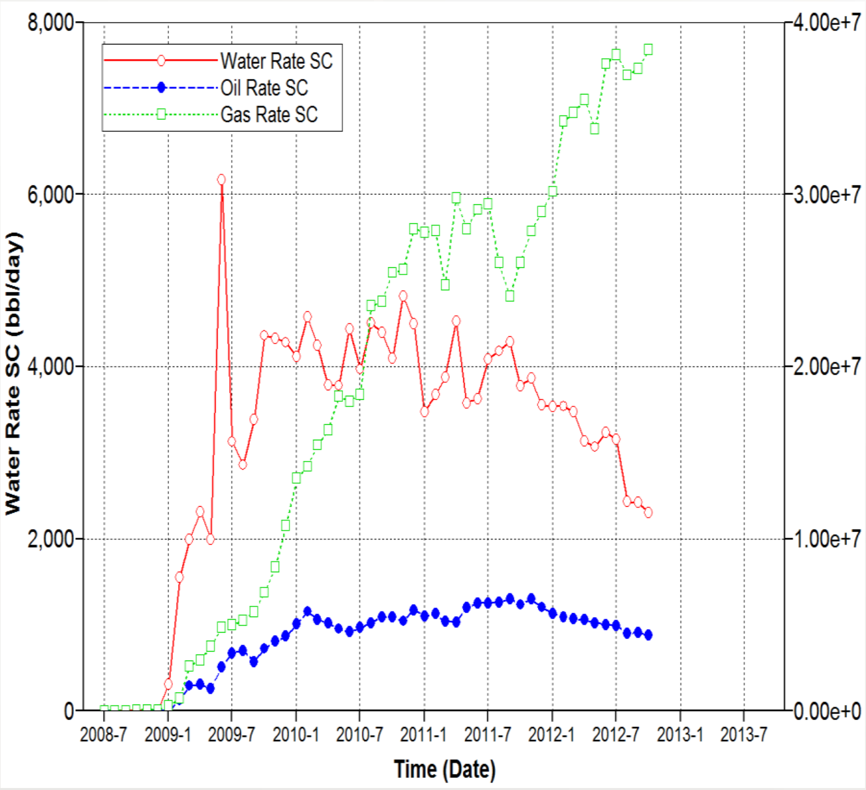


- Compositional simulation
- Total number of block = 82,500

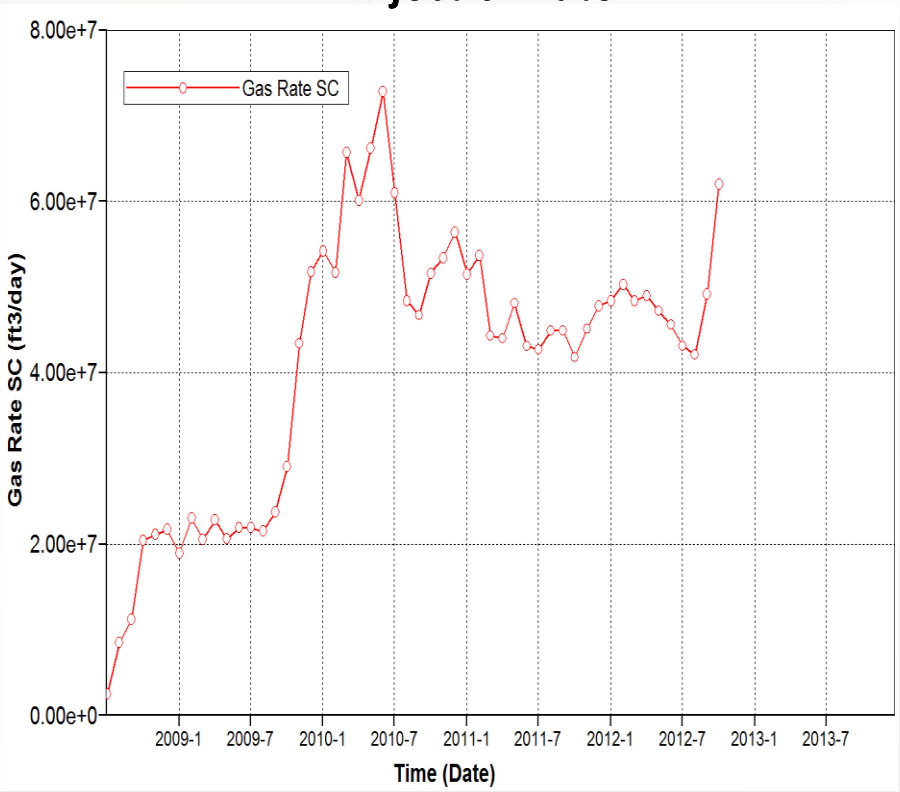
- CO_2 distribution:
  - Super critical phase: <u>?%</u>
  - Dissolved in oil: <u>?%</u>
  - Dissolved in brine: <u>?%</u>

Injection-Production data

Production rate



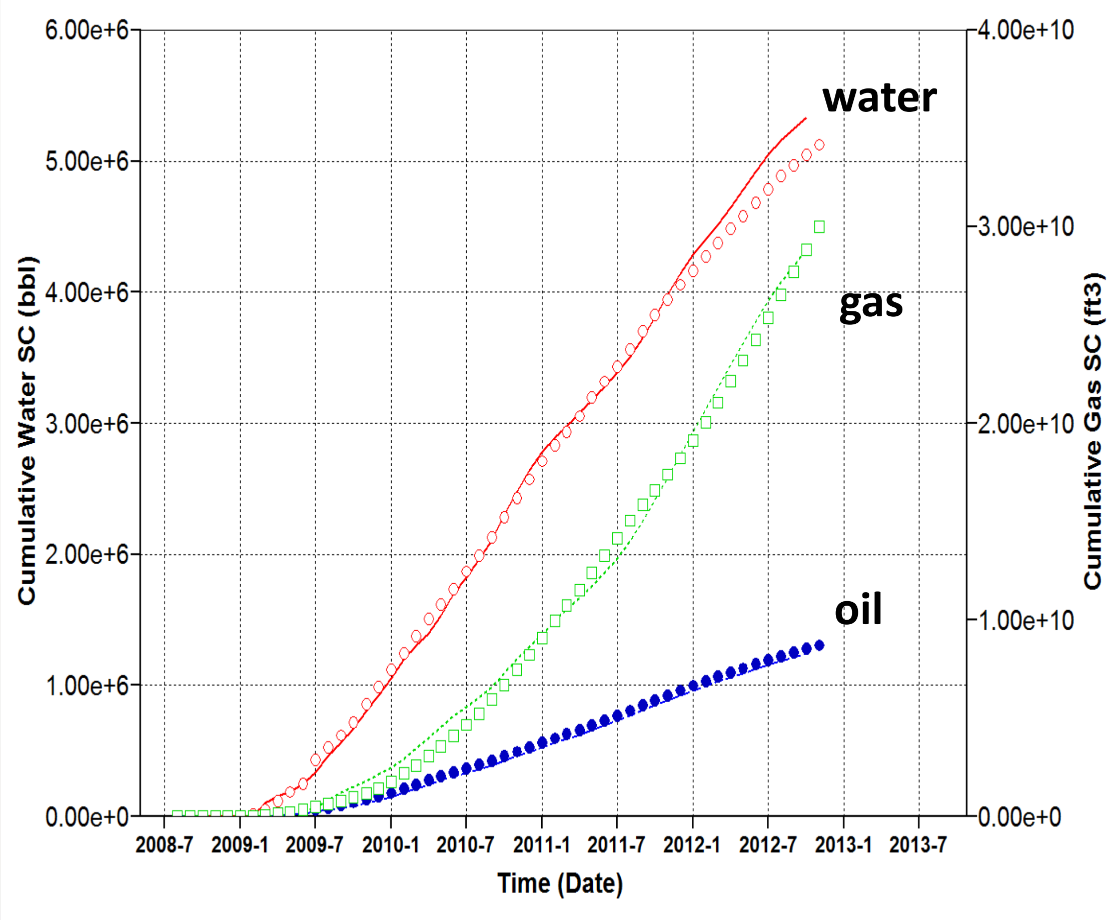
Injection rate



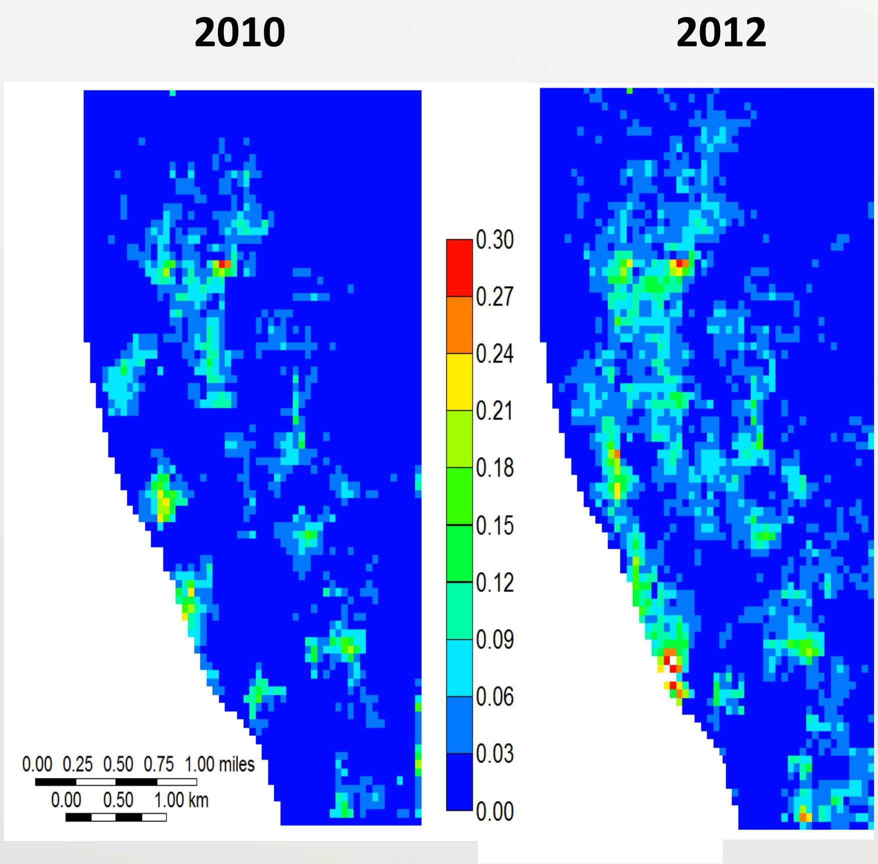
- **Available injection/production data:**
  - **Oil, gas, and water production rates**
  - **CO_2 injection rate**

- **Well constraints:**
  - **CO_2 injection rate, Oil production rate**
- **History match :**
  - **Gas and water production rates, breakthrough times**

History matching



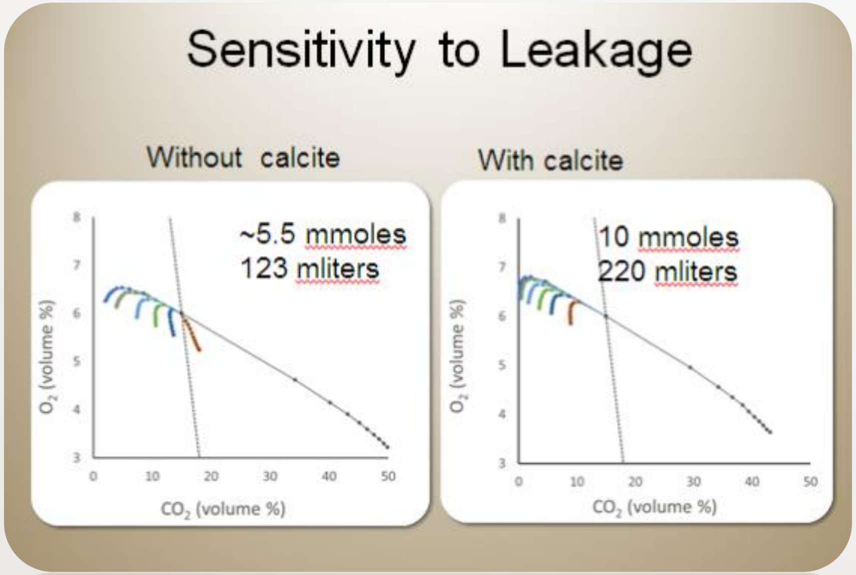
Results and future plans



- **CO_2 distribution (2012):**
  - Super critical phase: **56%**
  - Dissolved in oil: **26%**
  - Dissolved in brine: **18%**
- **Running extended simulations and scenarios**
- **Compare with 4D seismic**

Optimizing and Upscaling Process-Based Monitoring Technology

Understanding Complex Environments

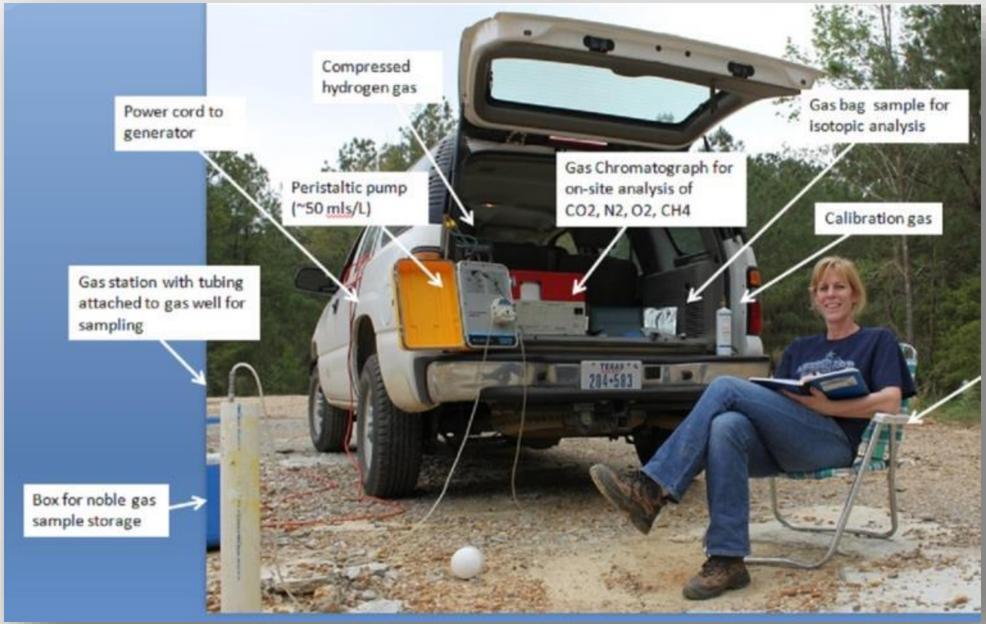


Testing and Developing Sensing Capabilities

- Continuous
- Real-time
- Smart

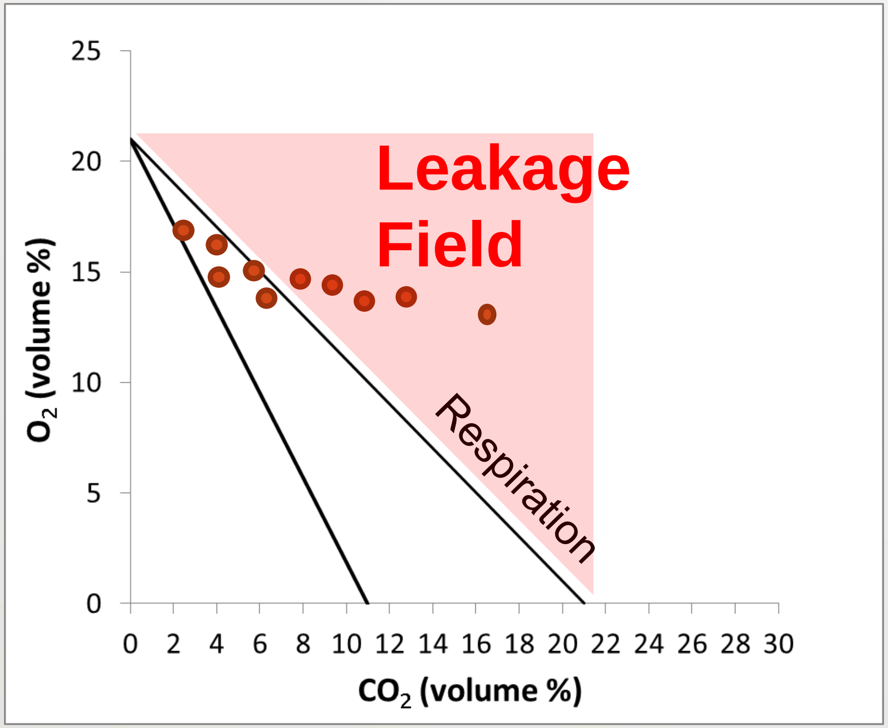
Current Method Shortfalls

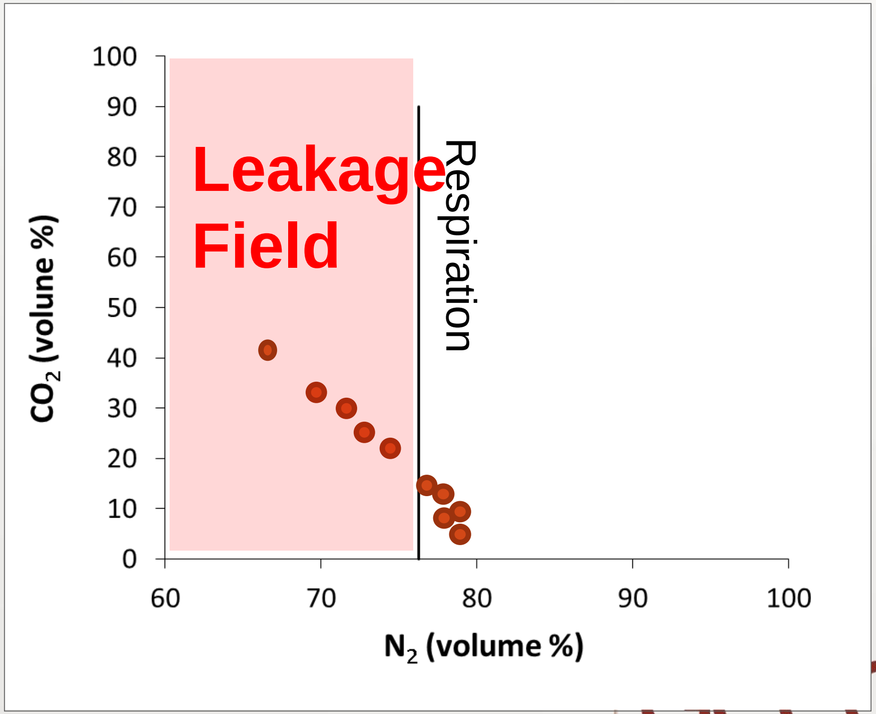
- Requires a manned gas chromatograph (GC)
- Time- and labor-intensive
- Requires consumable supplies
- No continuous real-time data



"User-Friendly" for Public Engagement

- Instant data reduction
- Reduces risk of false positives.
- Graphical analysis
- Continuous monitoring capability will give instant real-time leakage detection information.



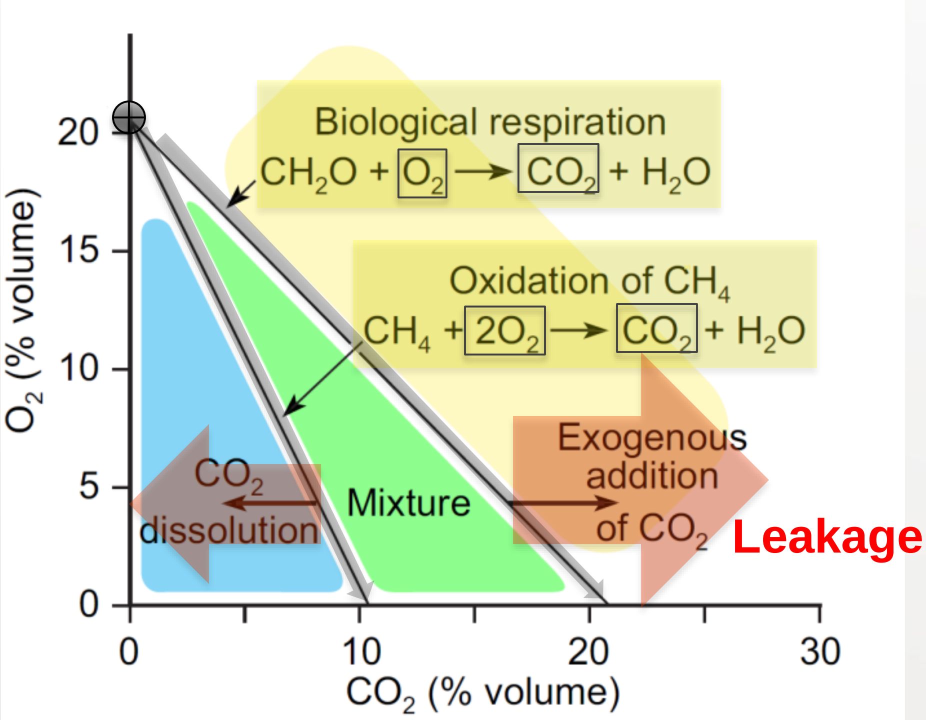


Extra Slides

Process-Based Gas Ratio - 1

O_2 vs. CO_2

- Indicates natural processes that affect CO_2 concentrations
- Distinguishes among respiration, CH_4 oxidation and dissolution
- Gives an initial assessment of leakage



Process-Based Gas Ratio - 2

CO_2 vs. N_2

- Identifies whether gas has migrated from depth.
- Indicates whether CO_2 is being added through leakage or lost through dissolution.