Case Study: Monitoring an EOR Project to Document Sequestration Value

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CO2-EOR (Enhanced oil recovery), Field study-Cranfield-MS, Monitoring-downhole pressure, Monitoring-design

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Case Study: Monitoring an EOR Project to Document Sequestration Value

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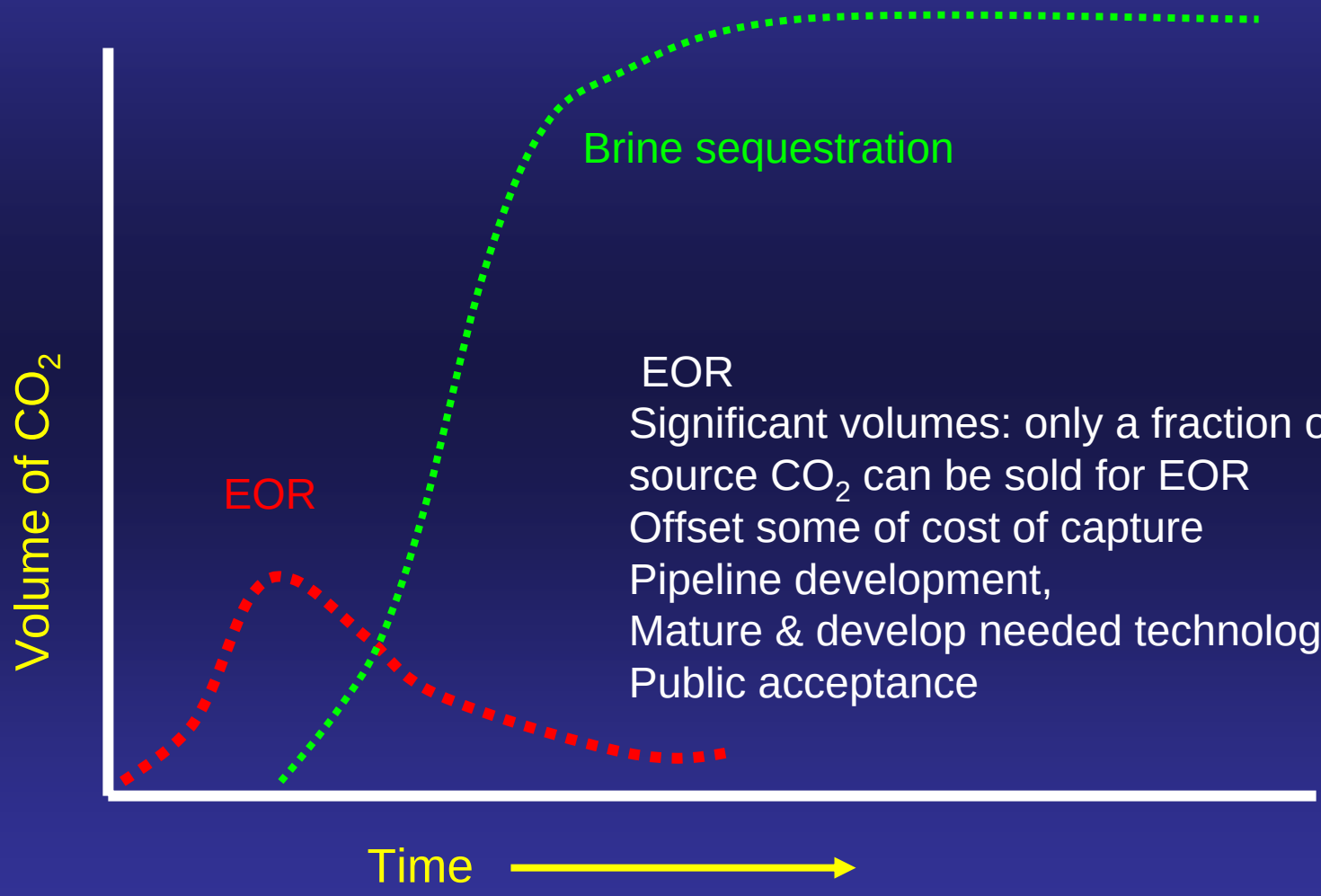
Monitoring Goals For Commercial Sequestration

- Storage capacity and injectivity are sufficient for the volume via history match between observed and modeled
- CO_2 will be contained in the target formation not damage drinking water or be released to the atmosphere
- Know aerial extent of the plume; elevated pressure effects compatible with other uses minimal risk to resources, humans, & ecosystem
- Advance warning of hazard allows mitigation if needed
- Public acceptance - provide confidence in safe operation

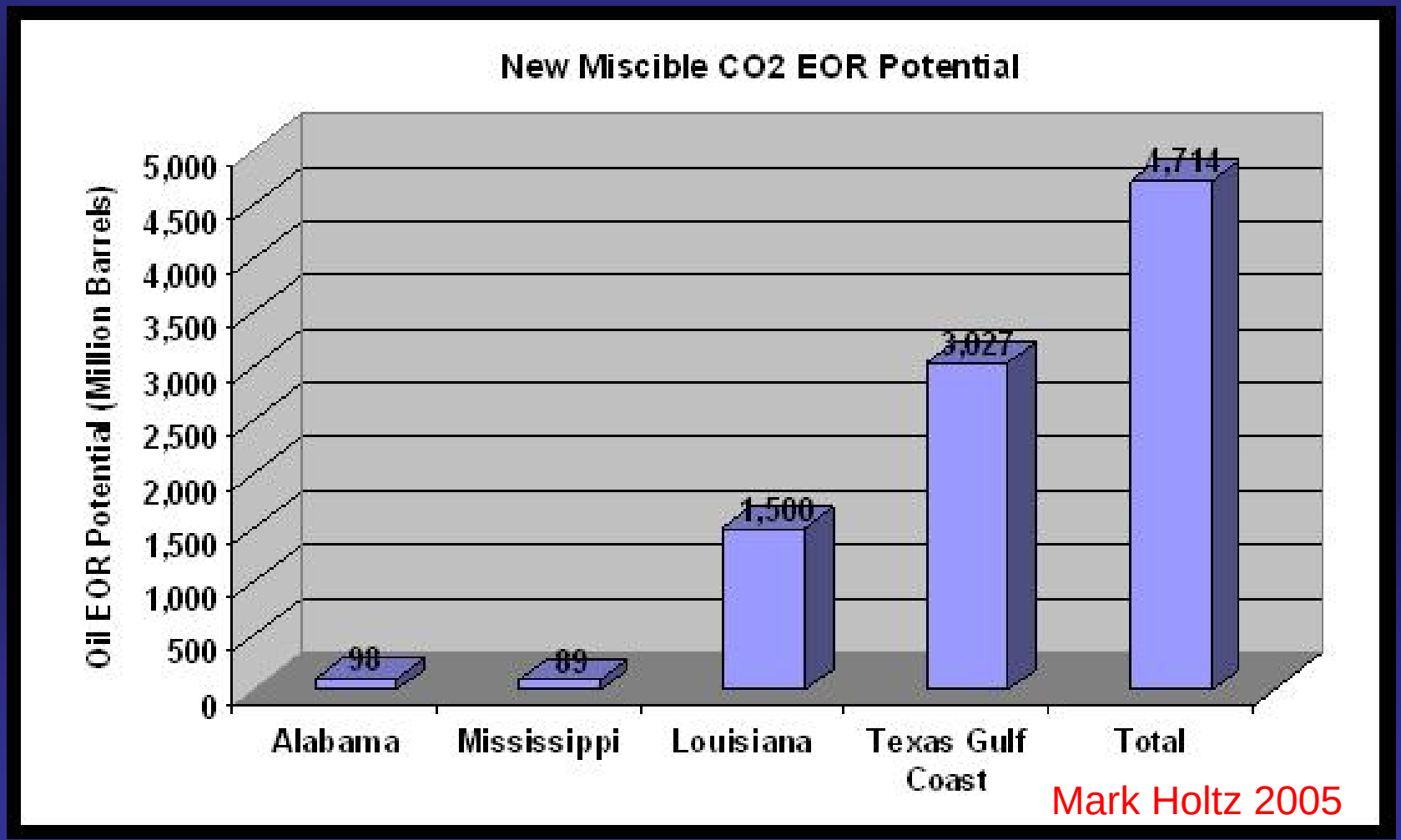
Modified from J. Litynski, NETL

Role of EOR in Sequestration



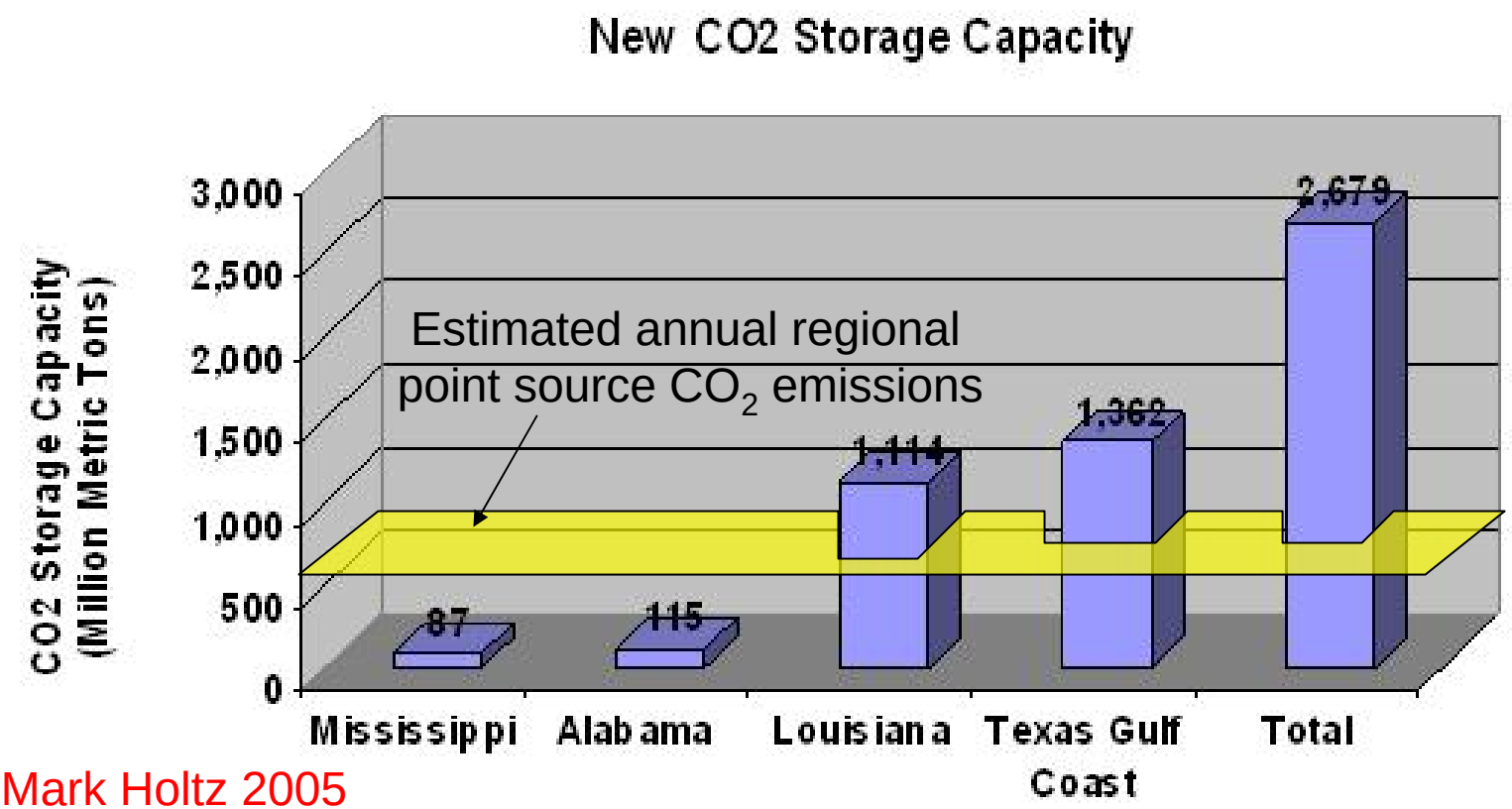
EOR
Significant volumes: only a fraction of all point source CO_2 can be sold for EOR
Offset some of cost of capture
Pipeline development,
Mature & develop needed technologies
Public acceptance

Miscible CO_2 EOR Resource Potential in the Gulf Coast



CO_2 Sequestration Capacity in Miscible Oil Reservoirs along the Gulf Coast

Bureau of Economic Geology



Mark Holtz 2005
NATCARB Atlas 2007

How does EOR compare to brine sequestration?

EOR

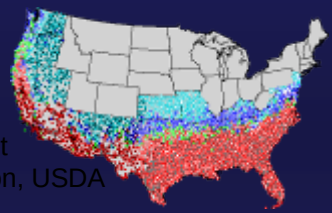
- Recycle with production
- Confined area
  - Trap
  - Pressure control
- Residual oil- CO_2 very soluble
- Many well penetrations =
  - Good subsurface knowledge
  - Some leakage risk

Brine Reservoir

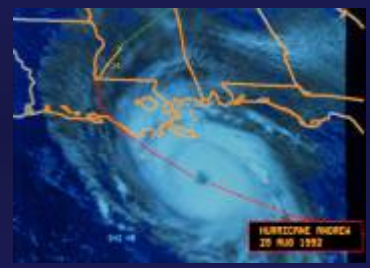
- Pure storage
- Large area
  - May not use a trap
  - Pressure area increase
- Brine – CO_2 weakly soluble
- Few well penetrations =
  - Limited subsurface knowledge
  - Lower leakage risk

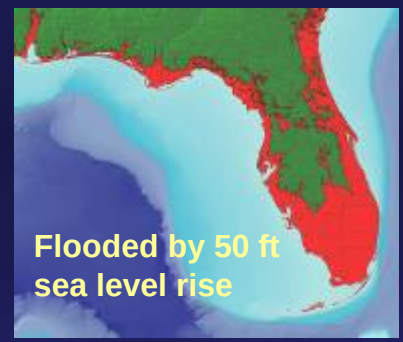
Southeast Regional Carbon Sequestration Partnership - SECARB

- Southeast US - climate change vulnerabilities
  - Hurricane landfalls
  - Tropical species invasion
  - Low relief coastline – sea level rise inundation



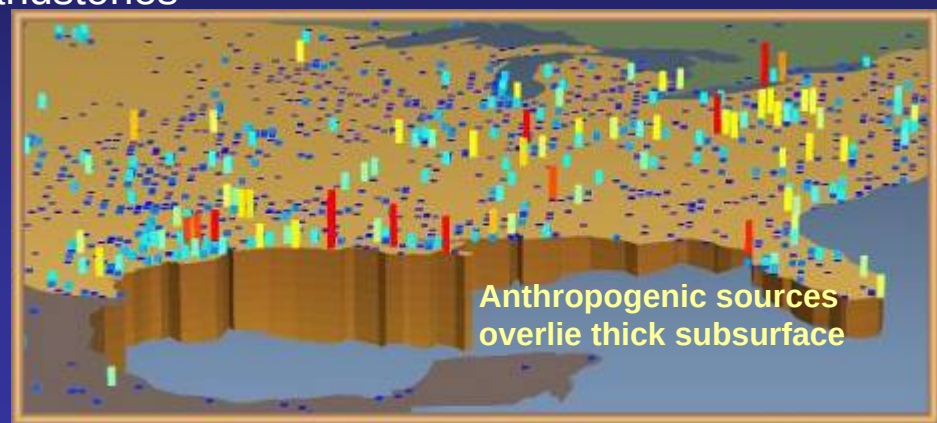
Fire ant Invasion, USDA



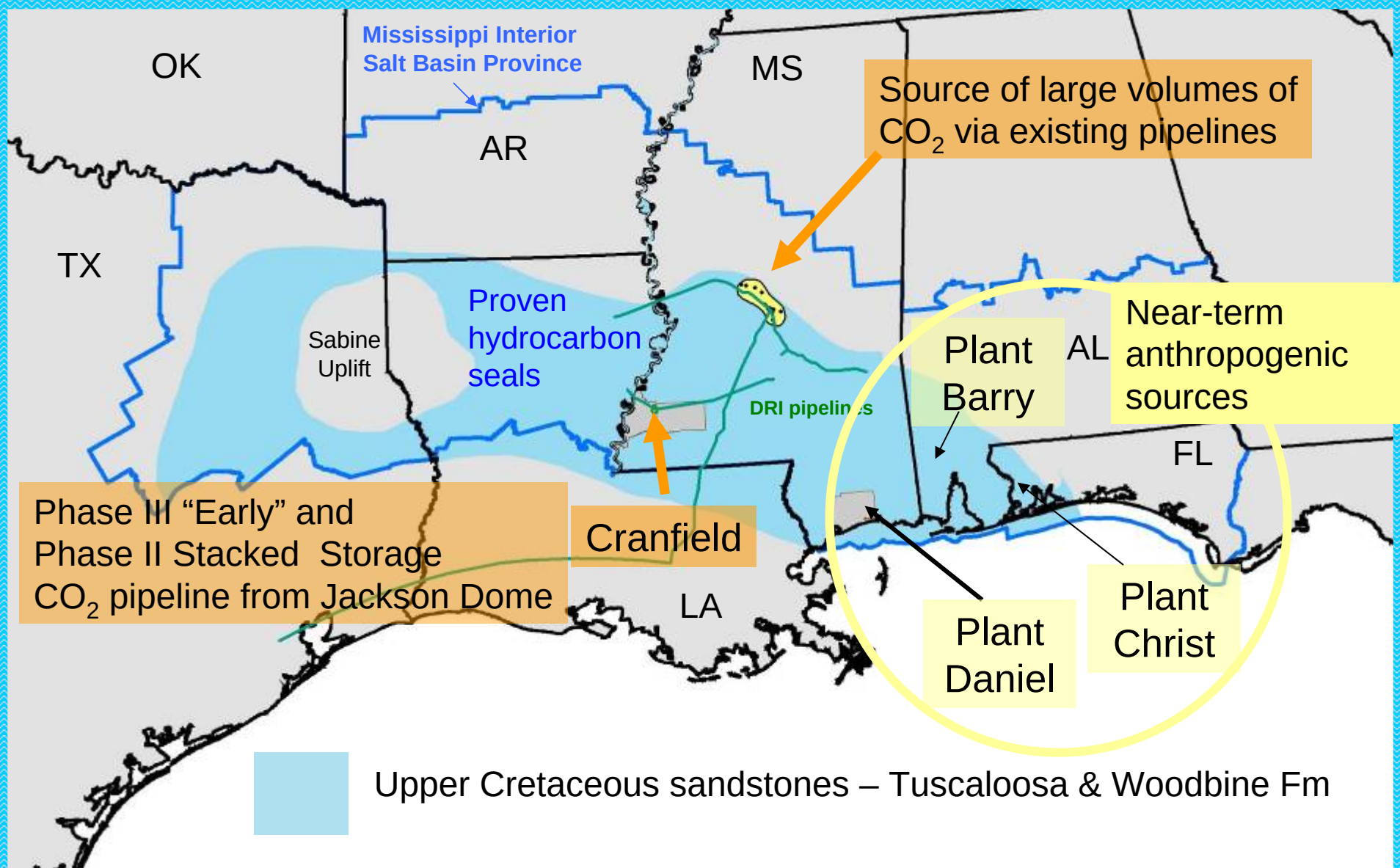


- Southeast US - unique storage potential
  - Energy industry center (refinery and oil production)
  - Very well known,
    - thick wedge -high permeability sandstones
    - excellent seals
  - Initiated by CO_2 EOR

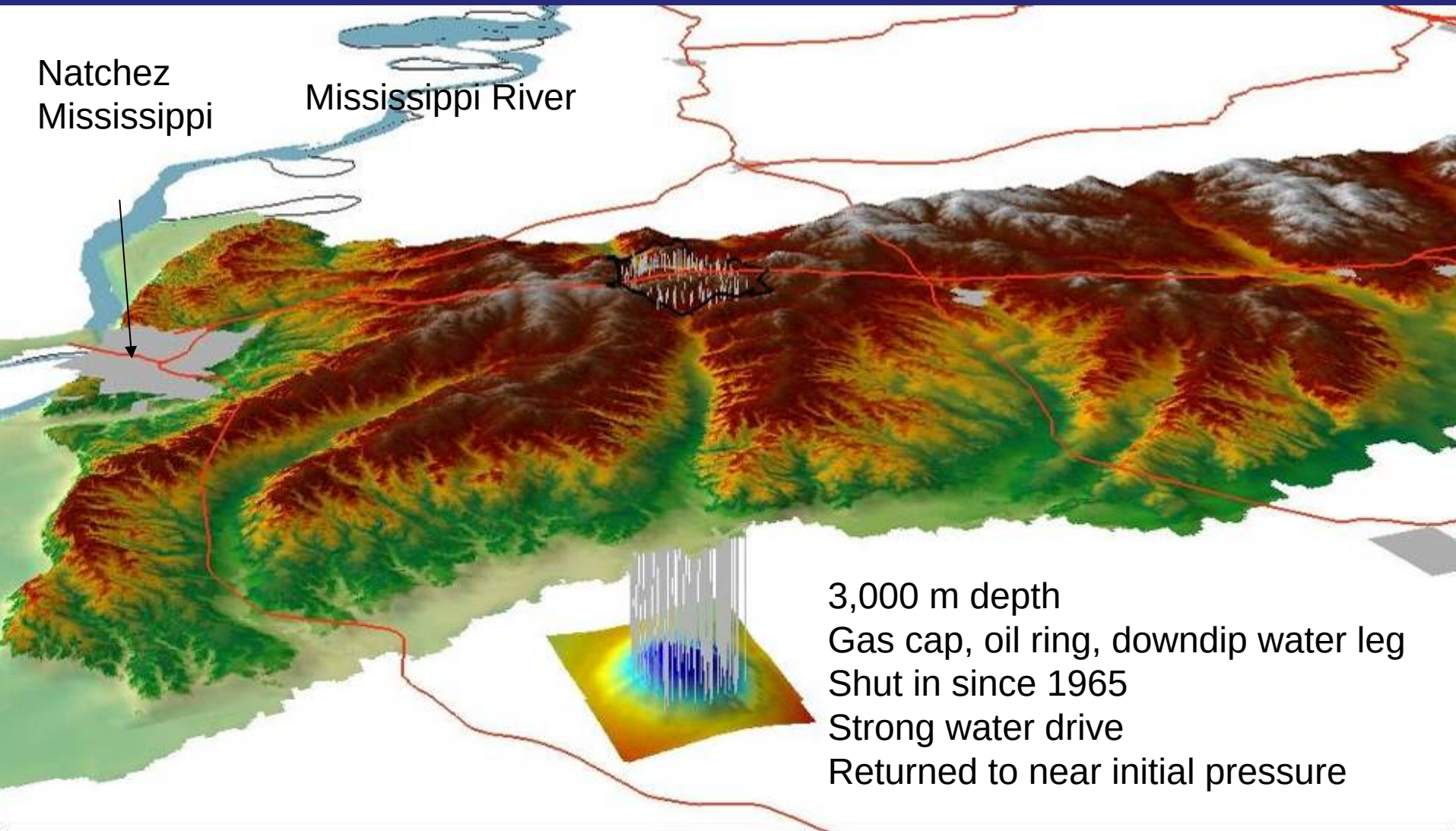
SECARB lead by
Southern States Energy Board
Funded by US DOE - NETL



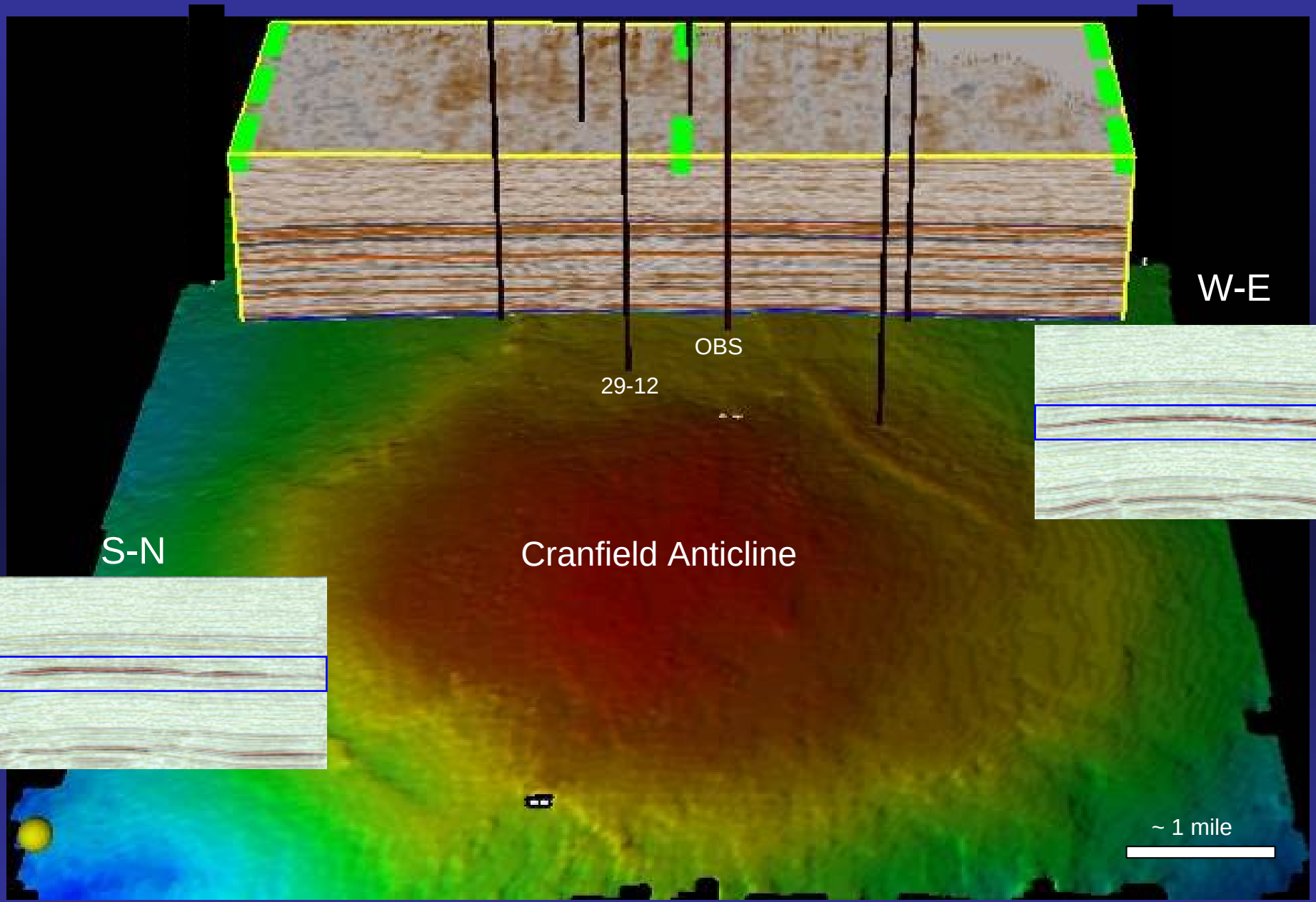
Sites for NETL-SECARB Phase II and III Linked to near-term CO_2 sources



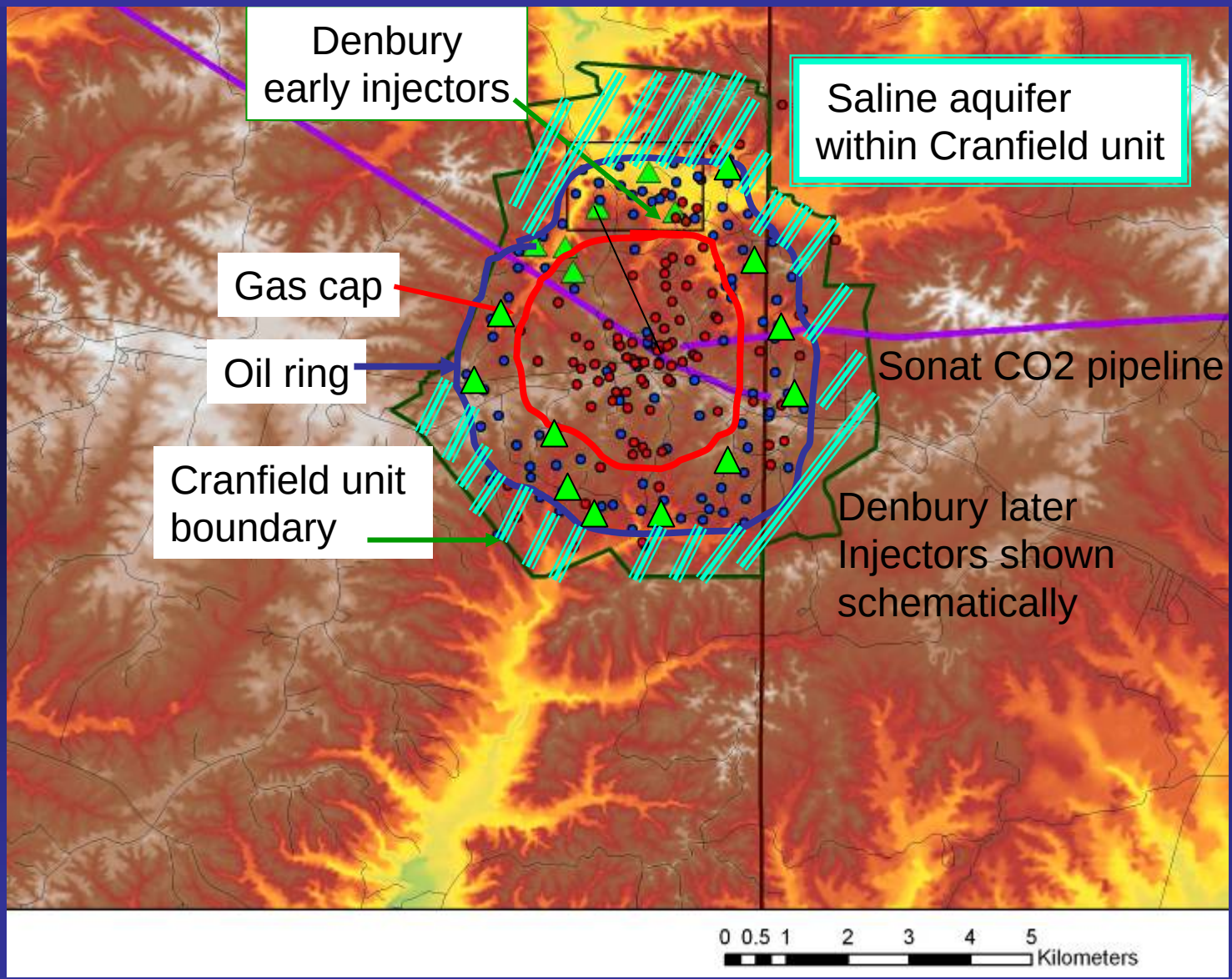
SECARB Phase III – “Early” test
Cranfield unit operated by Denbury Resources International

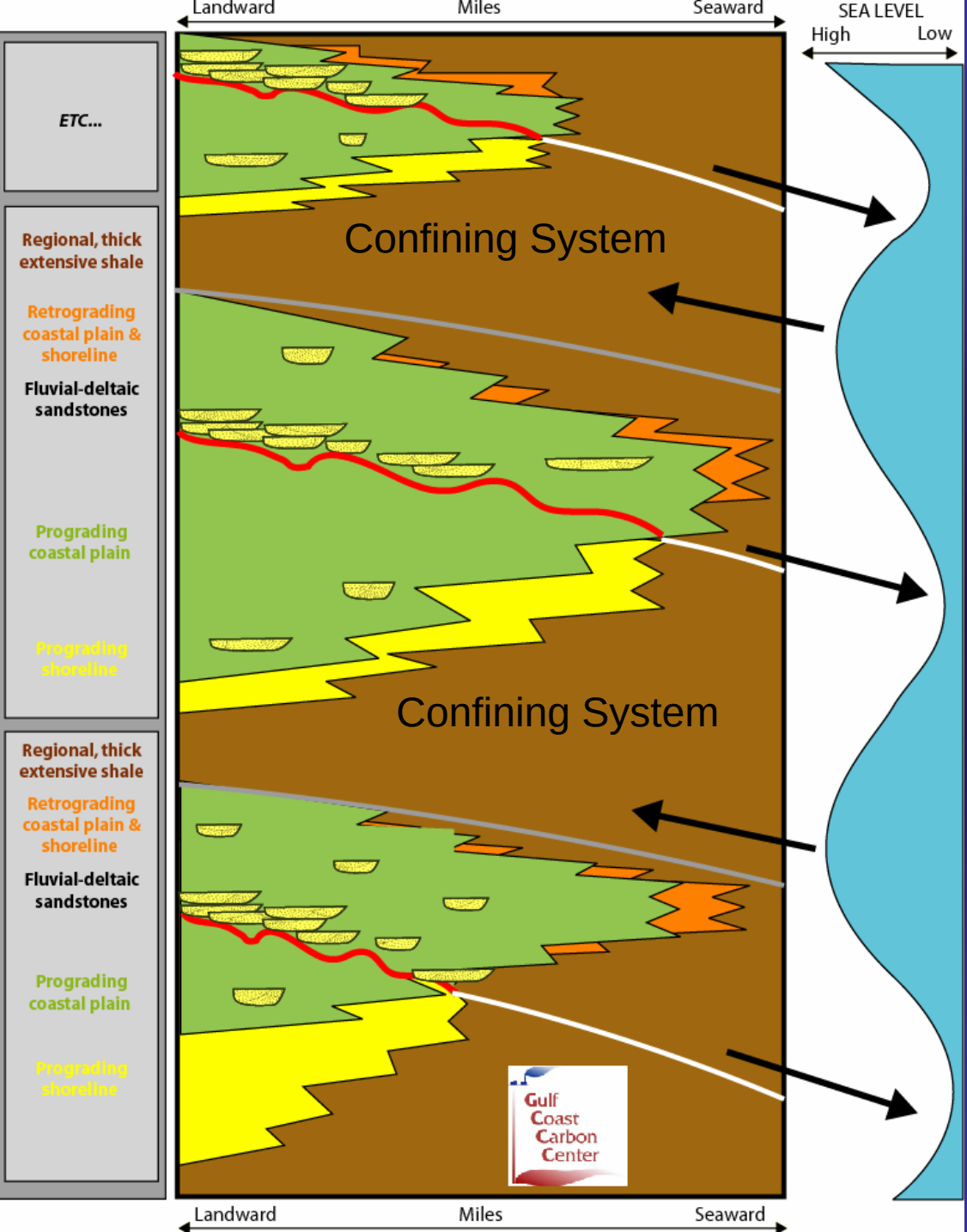


3,000 m depth
Gas cap, oil ring, downdip water leg
Shut in since 1965
Strong water drive
Returned to near initial pressure

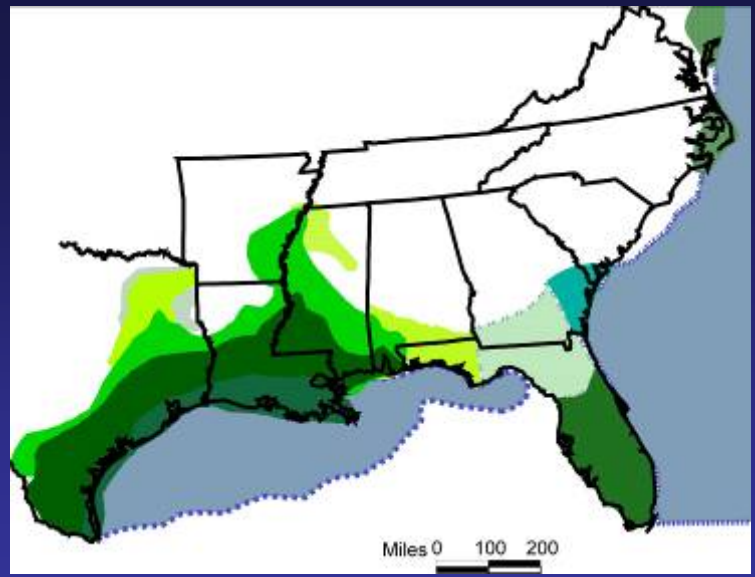

W-E
OBS
29-12
S-N
Cranfield Anticline
~ 1 mile

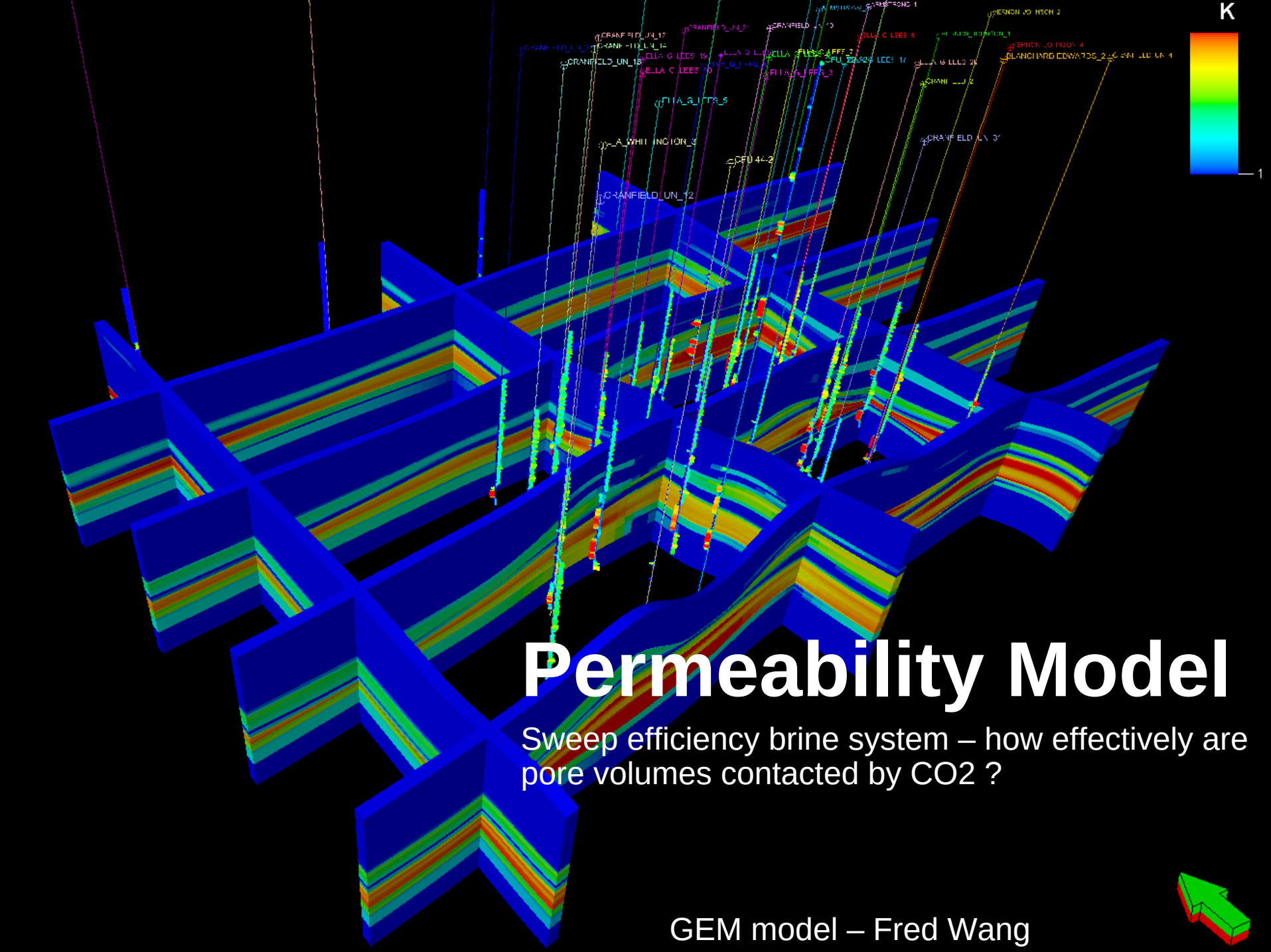
Cranfield Unit Setting





Repetitive depositional units in the Gulf Coast wedge mean that results from study of one can be easily transferred to both older and younger units and to other parts of the region.





Permeability Model

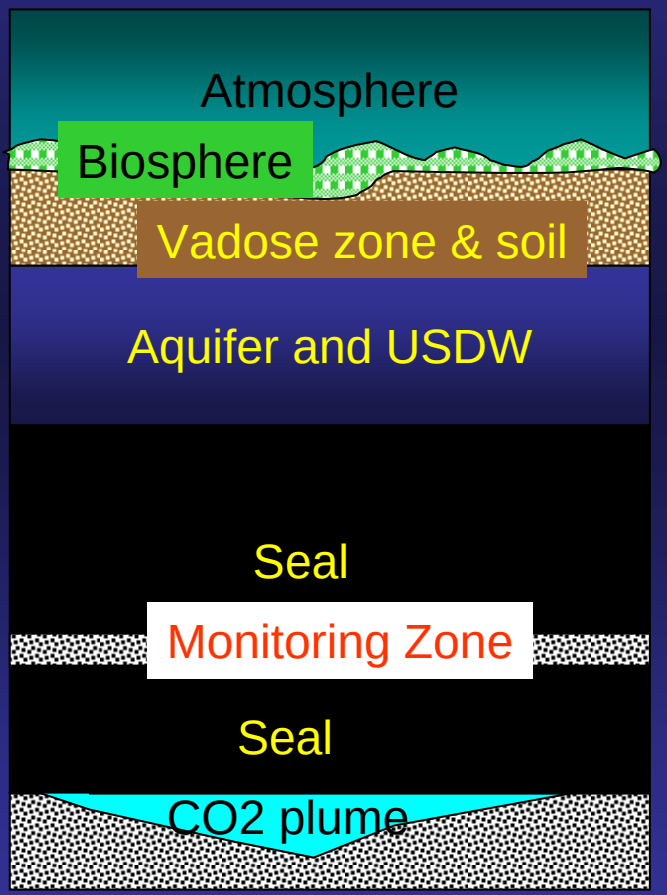
Sweep efficiency brine system – how effectively are pore volumes contacted by CO_2 ?

GEM model – Fred Wang

Techniques Currently Used to Assure Safe Injection of CO_2

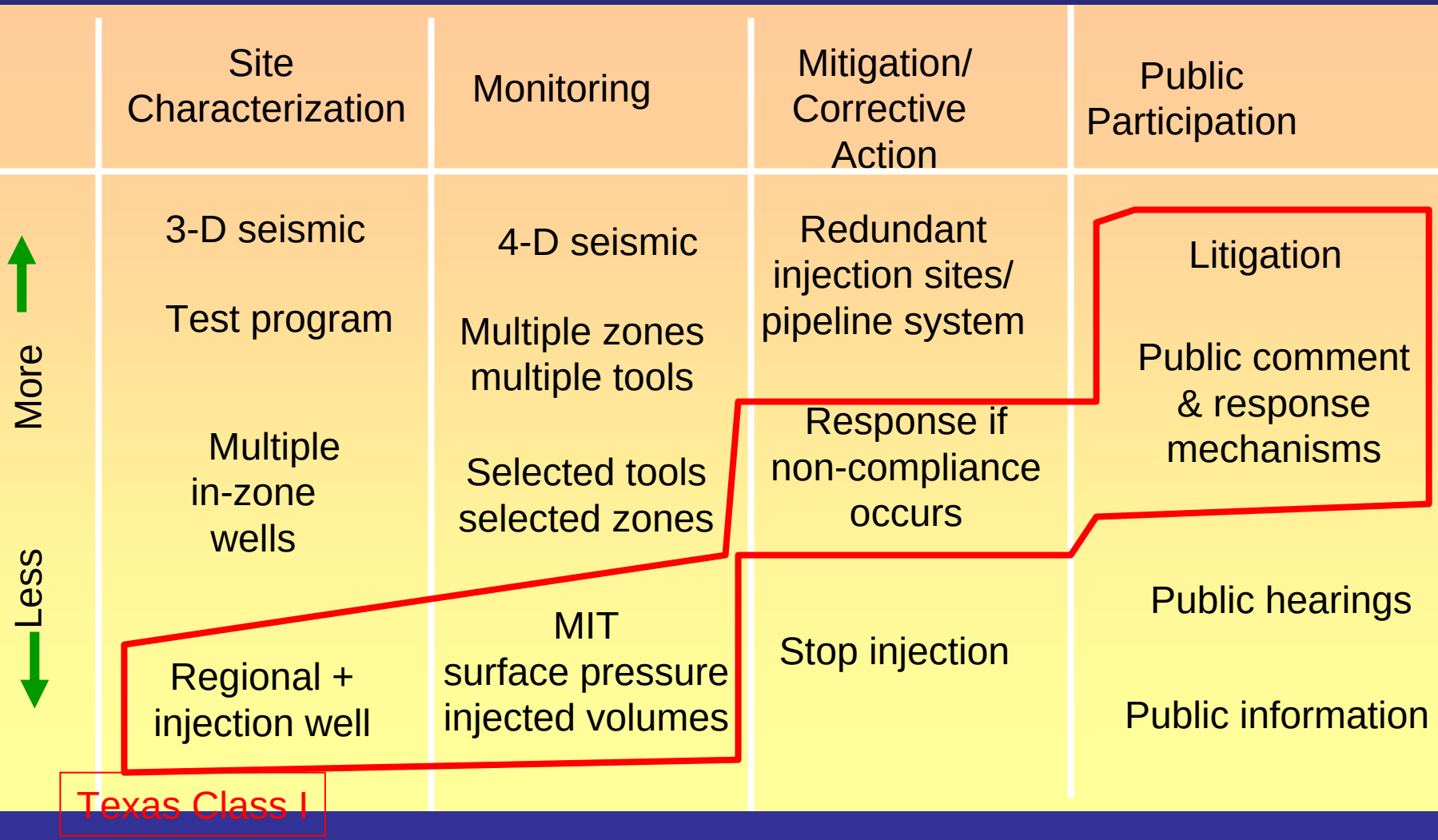
- CO_2 pipelines health and safety procedures - shipping, handling, storing
- Pre-injection characterization and modeling
- Injectate Isolated from Underground Sources of Drinking Water (USDW)
- Maximum allowable surface injection pressure (MASIP)
- Mechanical integrity testing (MIT) of engineered system
- Well completion / plug and abandonment standards
- Reservoir management

Monitoring Options



- Atmosphere
  - Ultimate receptor but dynamic
- Biosphere
  - Assurance of no damage but dynamic
- Soil and Vadose Zone
  - Integrator but dynamic
- Aquifer and USDW
  - Integrator, slightly isolated from ecological effects
- Above injection monitoring zone
  - First indicator, monitor small signals, stable.
- In injection zone - plume
  - Oil-field type technologies. Will not identify small leaks
- In injection zone - outside plume
  - Assure lateral migration of CO_2 and brine is acceptable

How Much is Enough?



SECARB Phase II (Cranfield Oil ring) Overarching Research Focuses

(1) Sweep efficiency – how effectively are pore volumes contacted by CO_2?
- Important in recovery efficiency in EOR
- Subsurface storage capacity?
- Plume size prediction

(2) Injection volume is sum of fluid displacement, dilatancy, dissolution, and rock+fluid compression
- Tilt to start to understand magnitude of dilatancy
- Bottom hole pressure mapping to estimate fluid displacement

(3) Effectiveness of Mississippi well completion regs. in retaining CO_2 in GHG context
- Above zone monitoring

SECARB Phase III (Downdip brine leg) Overarching Research Focuses

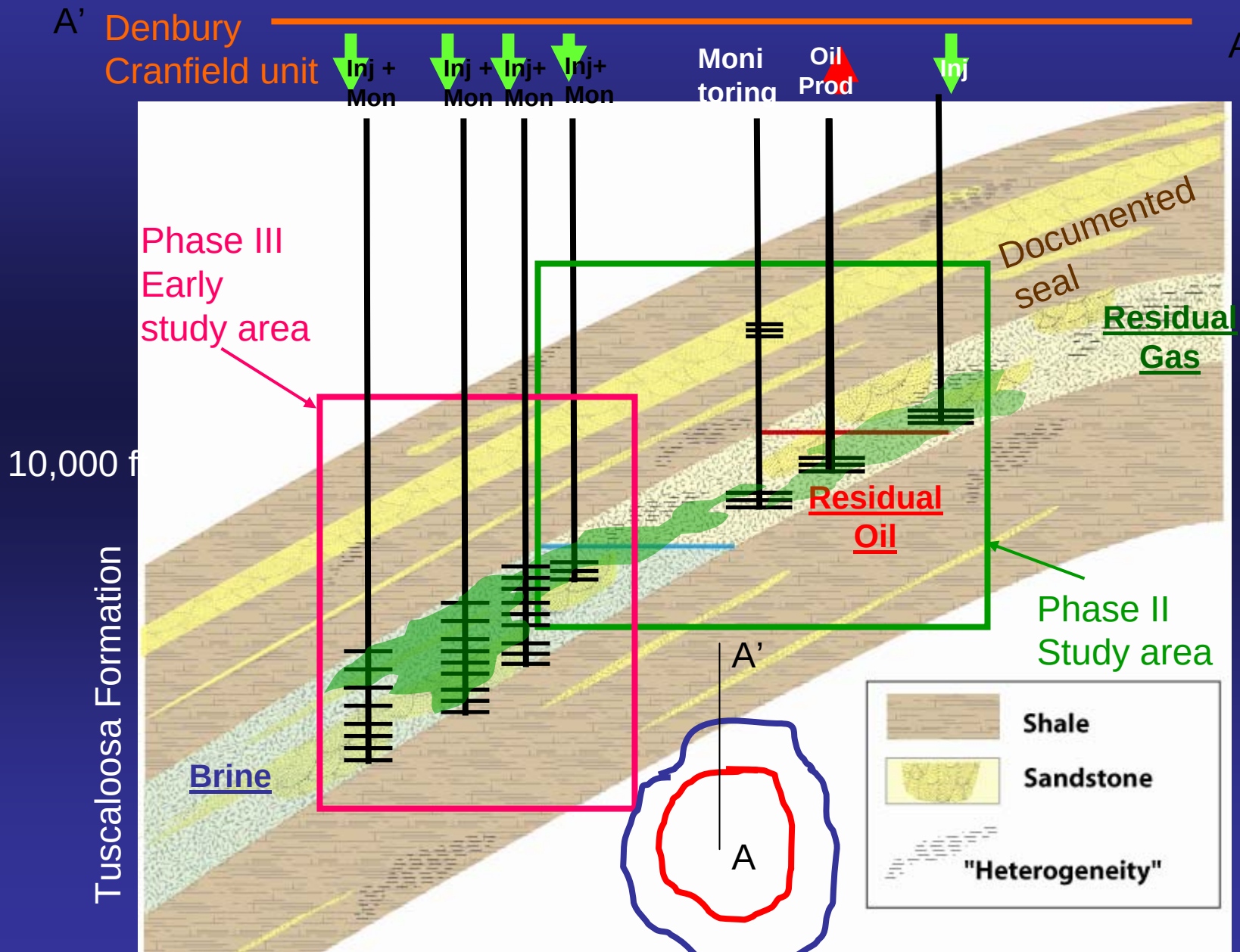
- Large volume - Multiple wells
- Brine downdip from production
- Follow-on from Phase II issues
  - Tilt, pressure, plume interaction
- Follow-on from Frio test results
  - Direct measurement of plume evolution with CASSM – a “trip wire technology”
  - Dissolution of CO2 into oil and brine

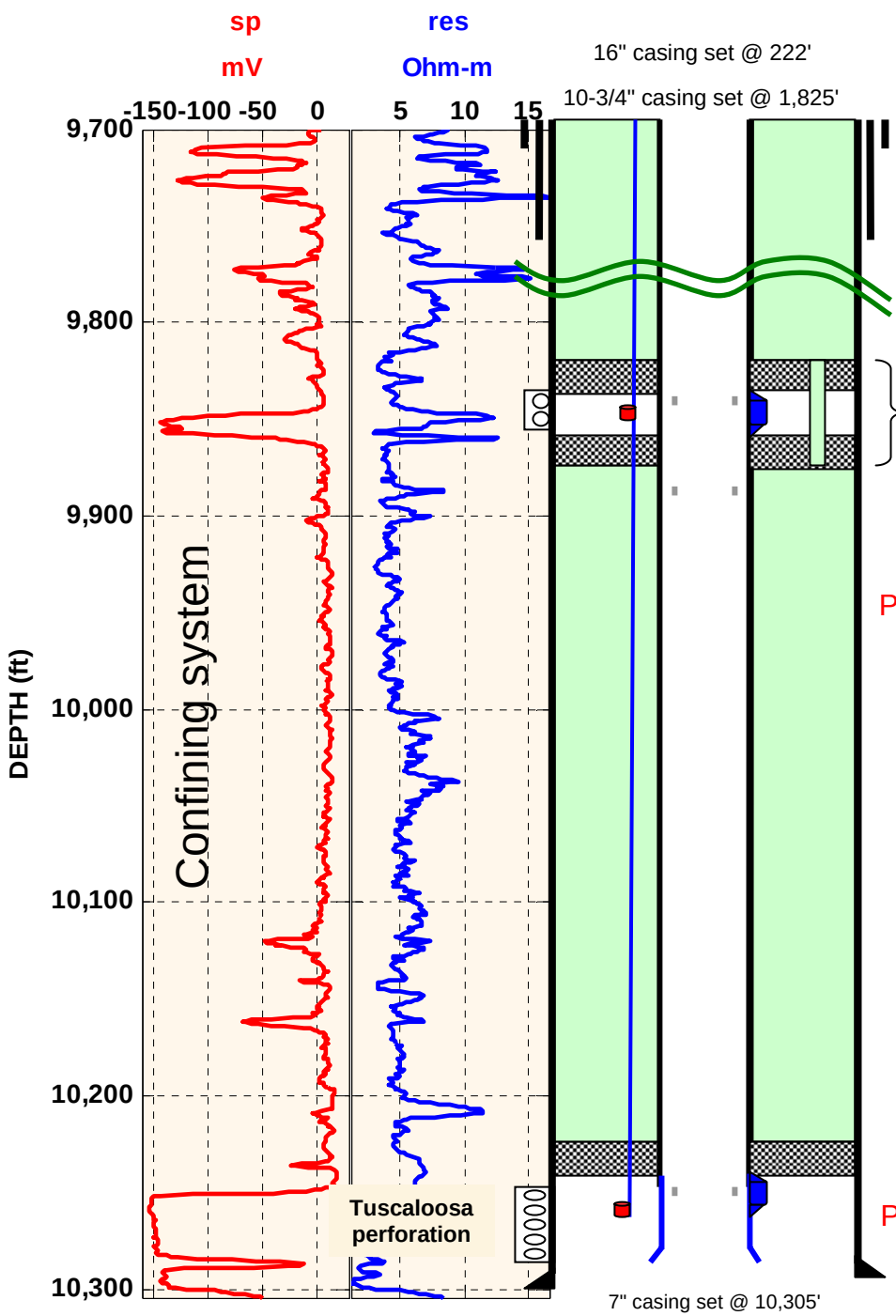
Integration of Research: Theoretical Approaches Through Commercialization

Commercial Deployment by Southern Co.

Toward commercialization	**Contingency plan Parsimonious public assurance monitoring**	**Subsurface perturbation predicted**	
Hypothesis tested	**CO_2 retained in-zone-document no leakage to air-no damage to water**	**CO_2 saturation correctly predicted by flow modeling**	**Pressure (flow plus deformation) correctly predicted by model**
Field experiments	**Surface monitoring: instrument verification Groundwater program CO_2 variation over time** **Above-zone acoustic monitoring (CASSM) & pressure monitoring**	**CO_2 saturation measured through time – acoustic impedance + conductivity Tomography and change through time** **3- D time lapse surface/ VSP seismic** **Dissolution and saturation measured via tracer breakthrough and chromatography**	**Tilt, microcosmic, pressure mapping** **Acoustic response to pressure change over time**
Theory and lab	**Sensitivity of tools; saturated-vadose modeling of flux and tracers**	**Lab-based core response to EM and acoustic under various saturations, tracer behavior**	**Advanced simulation of reservoir pressure field**

Cranfield Research Overview





Test adequacy of Mississippi well completions for CO_2 sequestration

Monitoring Zone

13-Chrome Isolation packer w/ feed through

13-Chrome Selective seat nipple

Pressure transducer Side Pocket Mandrel w/dummy gas valve

1/4" tubing installed between packers to Provide a conduit between isolation packers

CO_2 Injection Zone

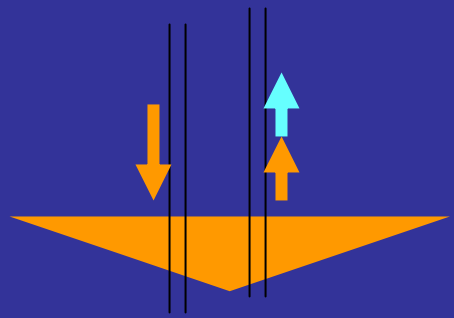
13-Chrome Production packer w/ feed thrus

Pressure transducer Side Pocket Mandrel w/dummy gas valve

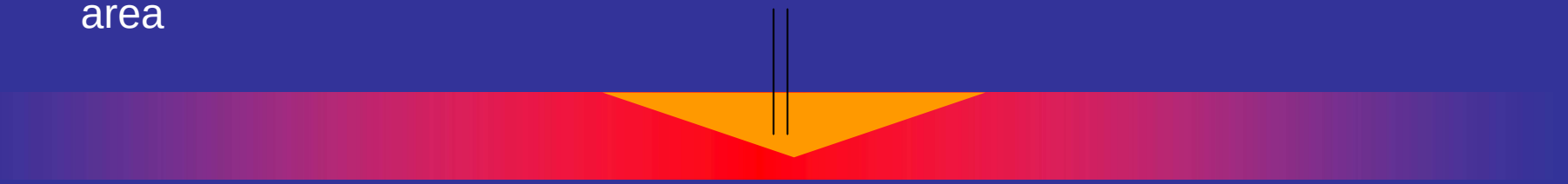
Well diagram from Sandia Technologies, LLC

Two areas need monitoring: CO_2 and pressure

In EOR, CO_2 injection is approximately balanced by oil, CO2, and brine production no pressure plume beyond the CO2 injection area



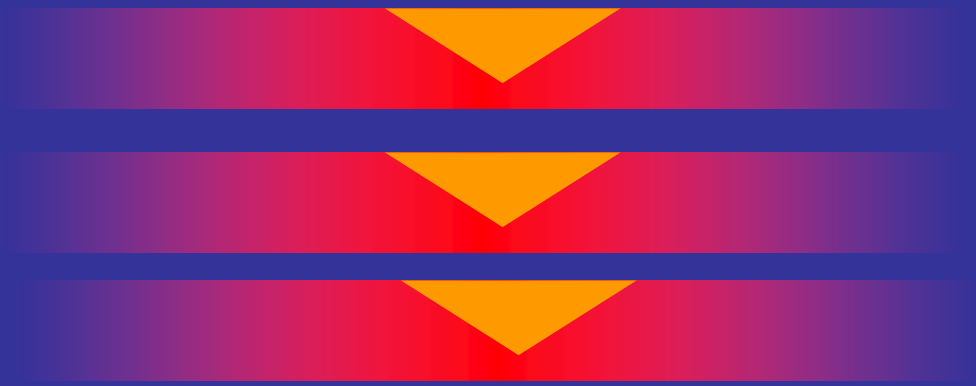
CO_2 injection (no production) pressure plume extends beyond the CO2 injection area



CO_2 plume

Elevated pressure

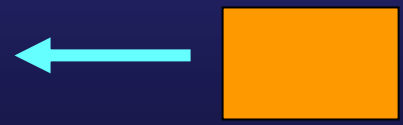
Stacked Storage



- By developing multiple injection zones beneath the EOR zone, the footprint of the CO_2 and pressure plume can be minimized

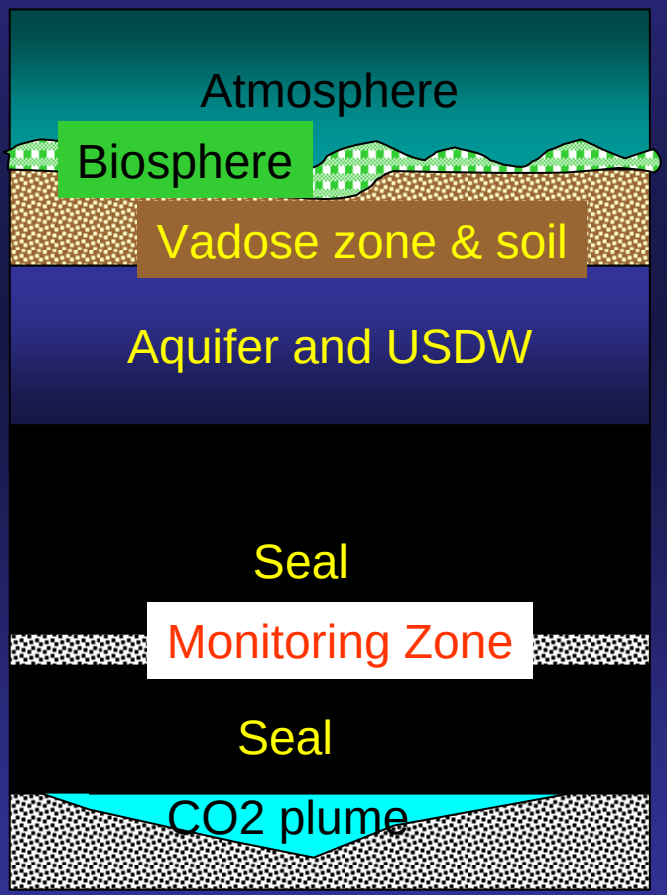
Role of Dissolution in Pressure Evolution

No dissolution: volume displaced = Volume injected



Volume displaced = Volume injected – volume dissolved + fluid expansion

Surface Monitoring Options



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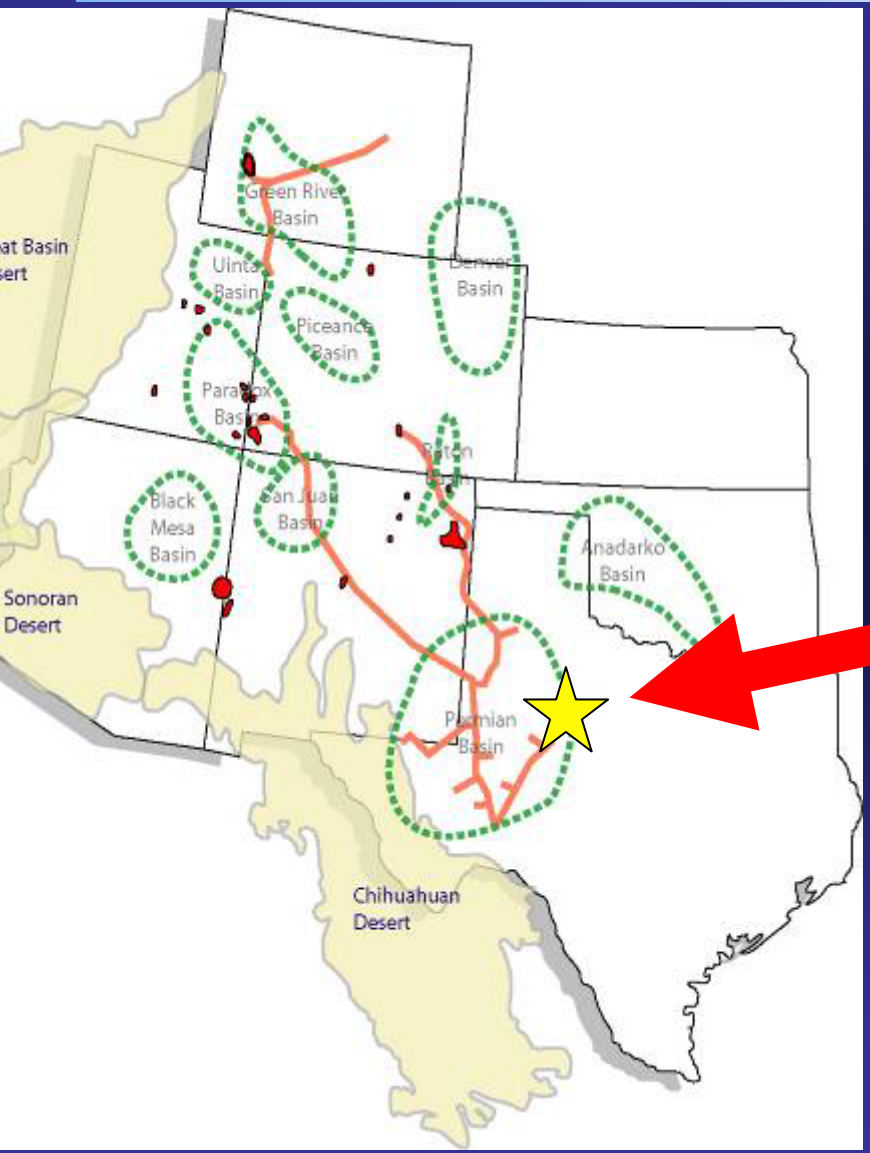
Three Surface Monitoring Studies

- Lab studies of effects of CO_2 leakage on freshwater – potential for risk? Potential for monitoring
- Field study at SACROC – any measurable perturbation after 35 years of EOR?
- Cranfield sensitivity analysis? Could leakage be detectable?

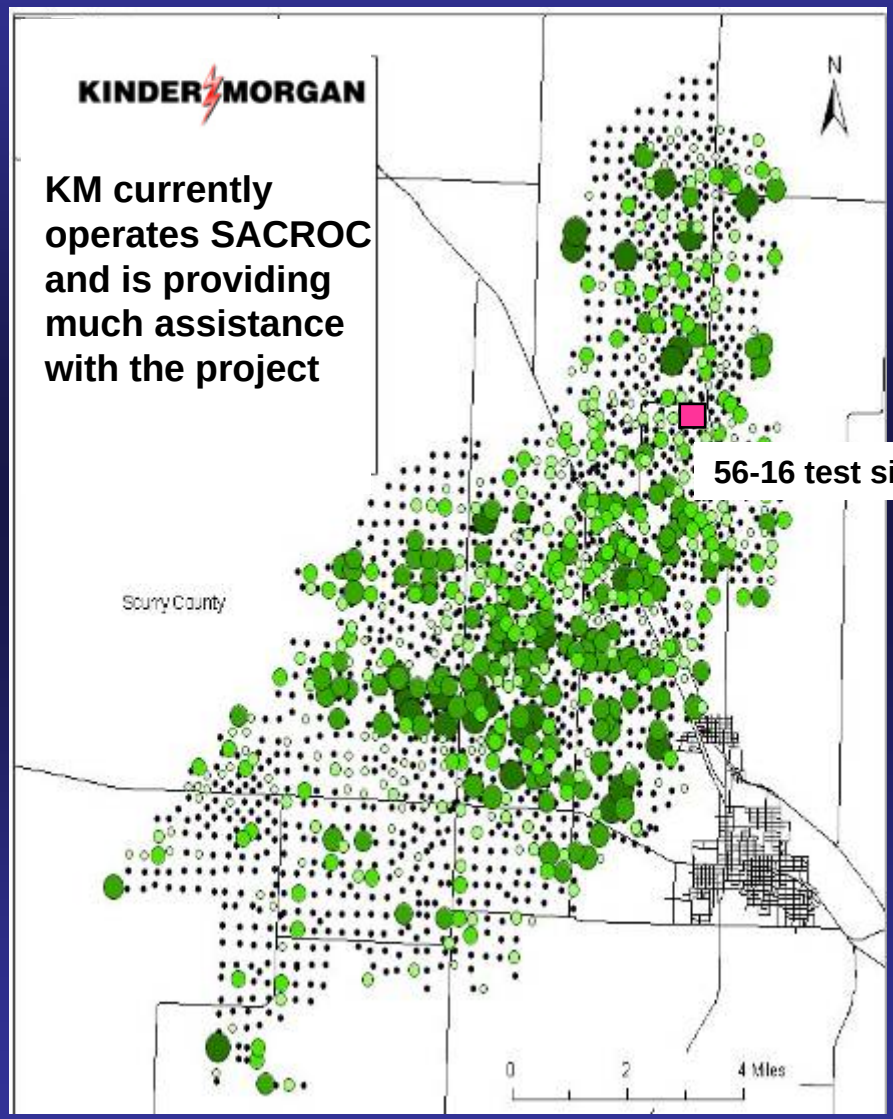
SACROC – eastern edge Permian Basin



Scurry Area Canyon Reef Operators Committee (SACROC) unitized oil field

- **Ongoing CO_2-injection since 1972**
- **Combined enhanced oil recovery (EOR) with CO_2 sequestration**
- **Depth to Pennsylvanian- Permian reservoir ~6,500 ft**

SACROC Previous CO_2 Injection



- **~140 million tons CO_2 injected for EOR since 1972 for EOR**
- **~60 million tons CO_2 recovered**
- **SWP researchers test if detectable CO_2 has leaked into groundwater**

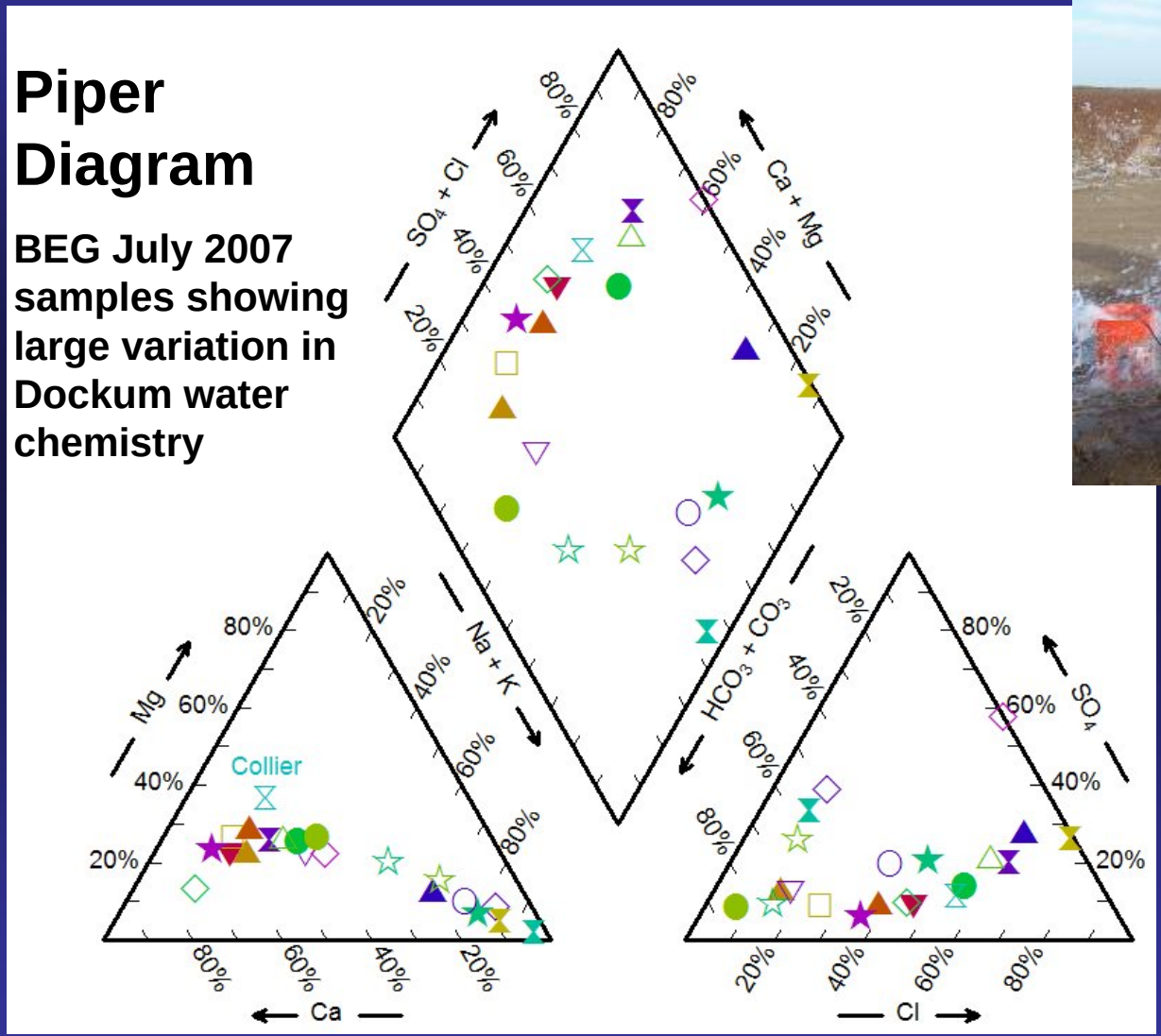
Rebecca Smyth BEG
Southwest Partnership
Led by New Mexico Tech / Utah
DOE / NETL

SACROC Access to Private Water Wells

Detecting Increased CO_2 in Groundwater

Piper Diagram

BEG July 2007 samples showing large variation in Dockum water chemistry



Need indirect measurement of CO_2 in groundwater

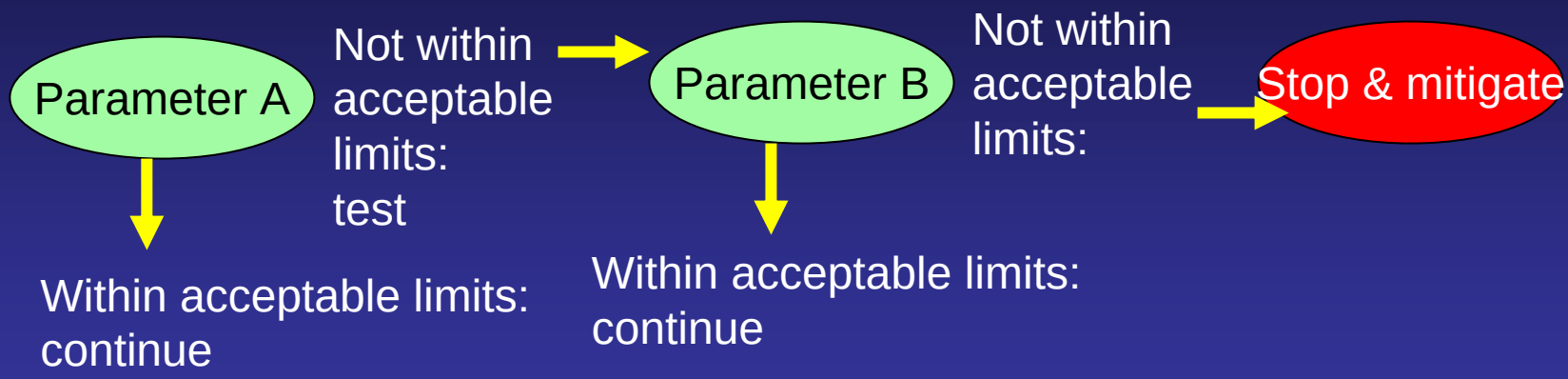
↑ **CO_2 =** ↓ **pH,**

↑ **Alkalinity,**

↑ **dissolved metals**

Need for Parsimonious Monitoring Program in a Mature Industry

- Standardized, dependable, durable instrumentation
  - reportable measurements
- Possibility above-background detection:
  - Follow-up testing program
  - assure public acceptance and safe operation
- Hierarchical approach:



GCCC Strategic Plan 2007-2010

- Goal 1: Educate next carbon management generation
- Goal 2: Develop commercial CO_2 site selection criteria
- Goal 3: Define adequate monitoring / verification strategy
- Goal 4: Evaluate potential risk and liability sources
- Goal 5: Evaluate Gulf Coast CO_2 EOR economic potential
- Goal 6: Develop Gulf Coast CCS market framework / economic models
- Goal 7: GCCC service and training to partners

www.gulfcoastcarbon.org