Gulf Coast Carbon Center

Role of CO_2 EOR in Sequestration for GHG emissions reduction

- Brief introduction to the Gulf Coast Carbon Center- Sue Hovorka
- Role of EOR in Carbon Capture and Storage - Sue Hovorka
- Monitoring EOR to Document Storage Value - Sue Hovorka
- Certification Framework – JP Nicot
- Update on Regulation and Policy - Ian Duncan

Presented to North American Carbon Capture & Storage Association , June 9, 2008, BEG, Austin TX

Gulf Coast Carbon Center (GCCC)

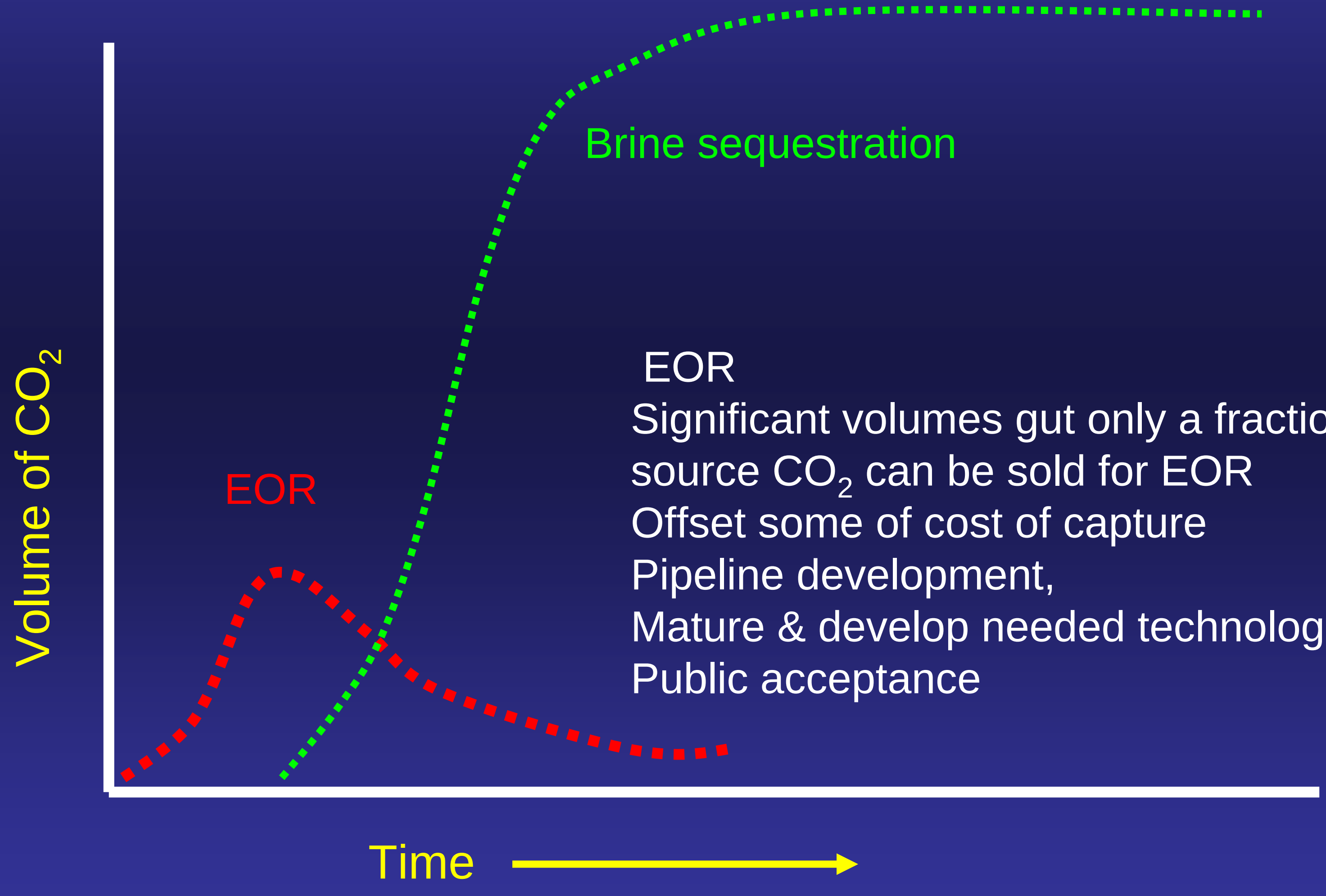
GCCC Research Team:
Susan Hovorka, Tip Meckel, J. P. Nicot, Ramon Trevino, Jeff Paine, Becky Smyth;
Post-docs and students
Associate Director Ian Duncan
Director Scott Tinker

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

Role of CO_2 EOR in Sequestration



EOR

Significant volumes gut 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

CO_2 Sequestration Capacity in Miscible Oil Reservoirs along the Gulf Coast

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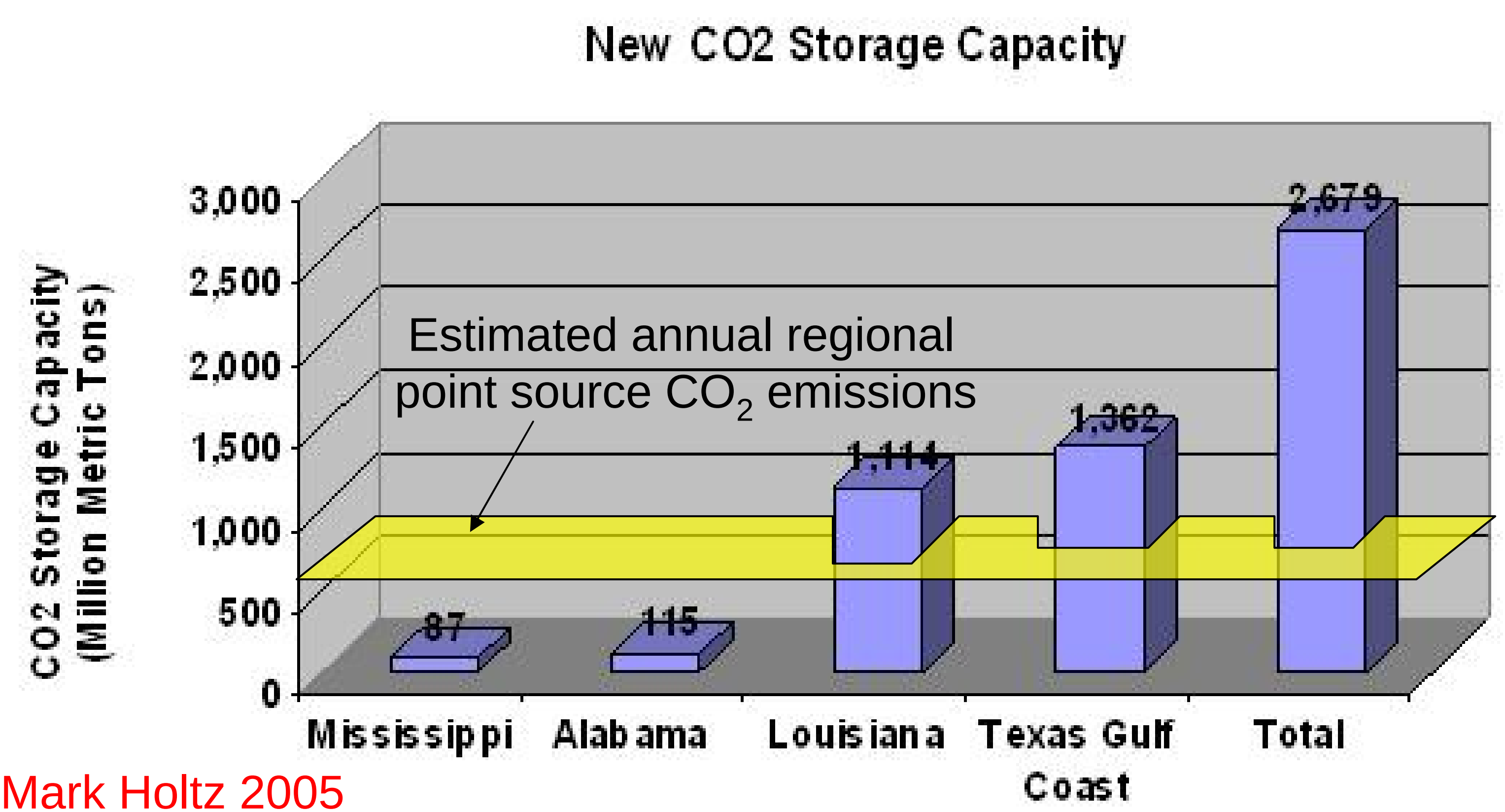
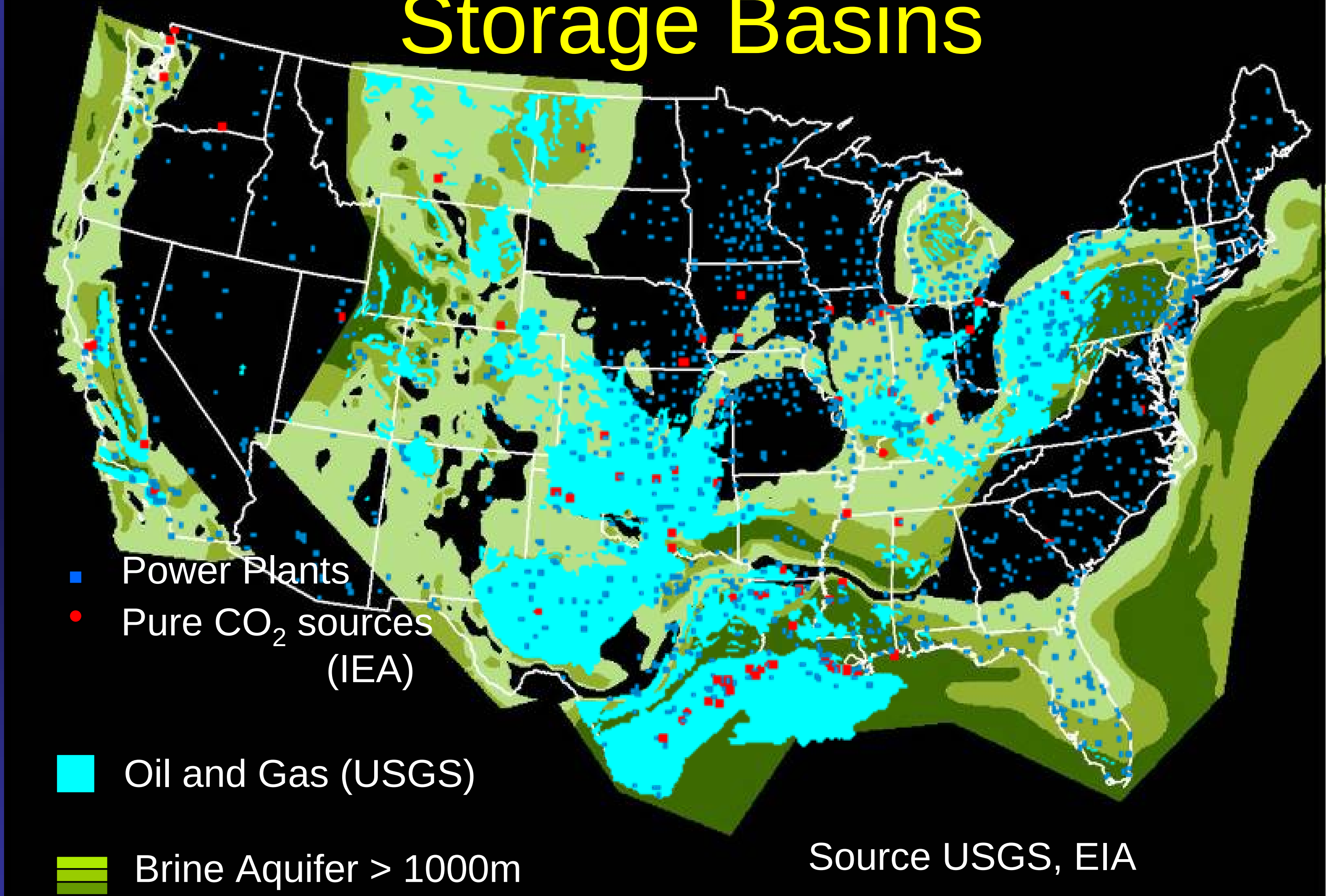
Bureau of Economic Geology



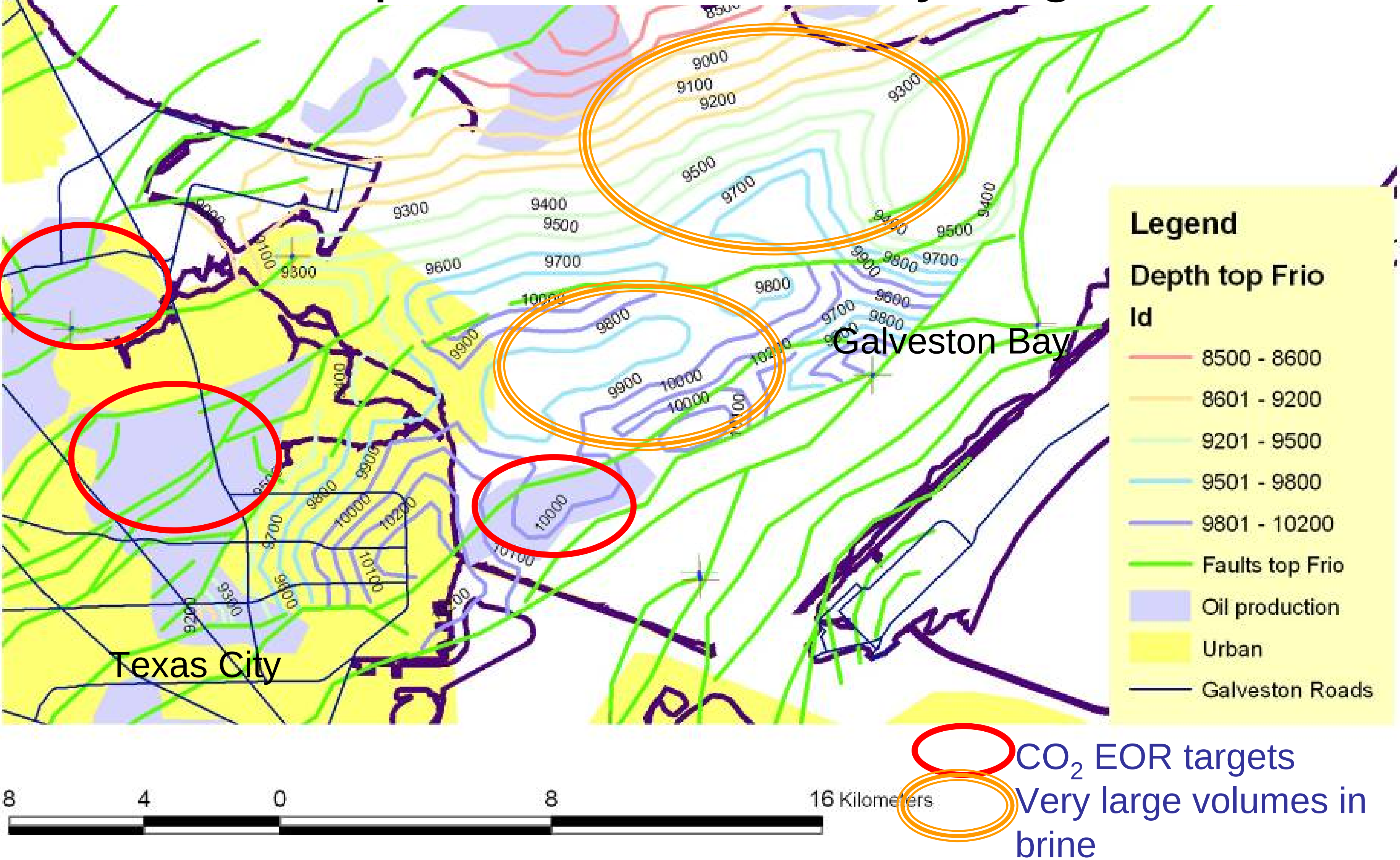
Mark Holtz 2005
NATCARB Atlas 2007

Coincidence of Hydrocarbons and Storage Basins

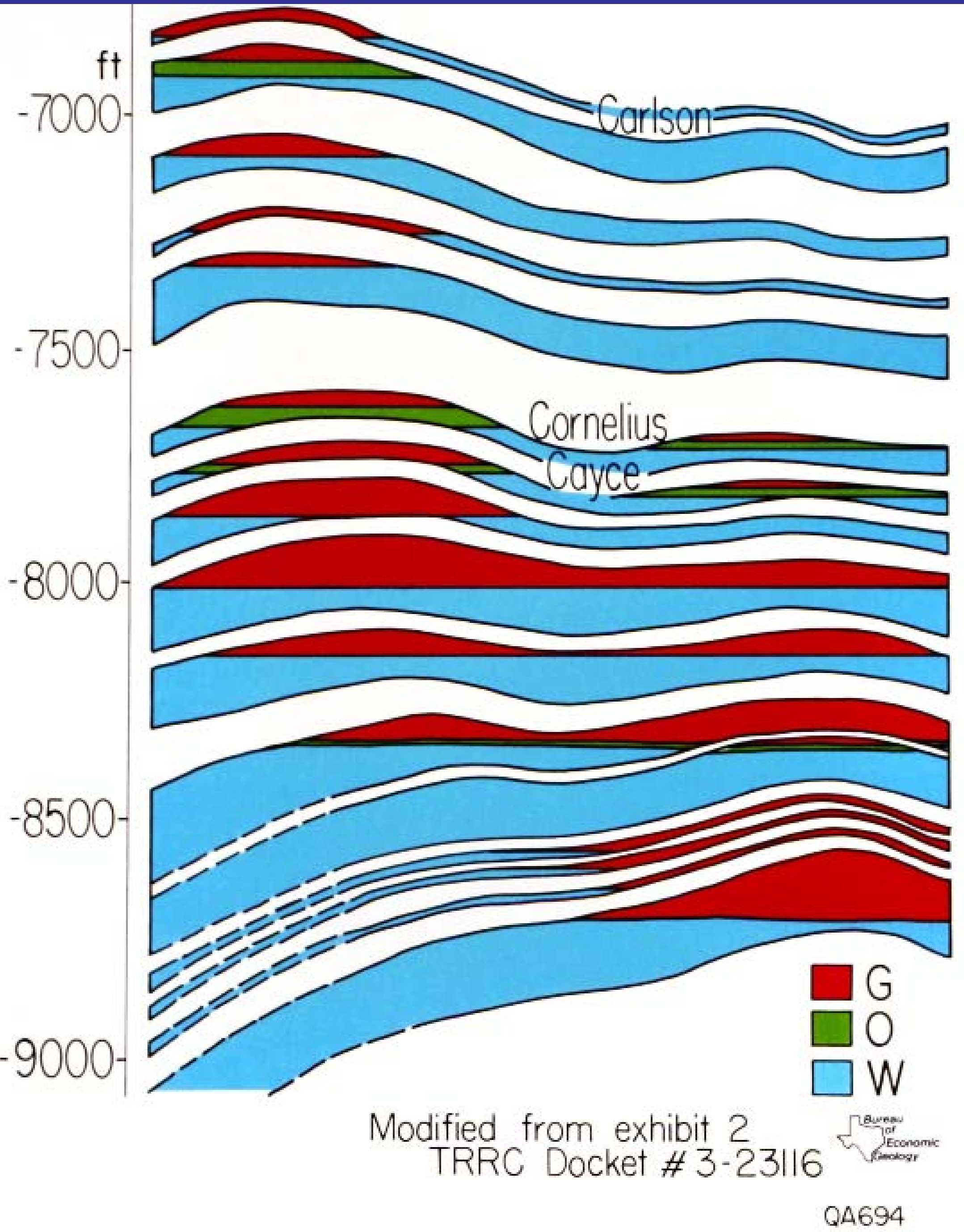


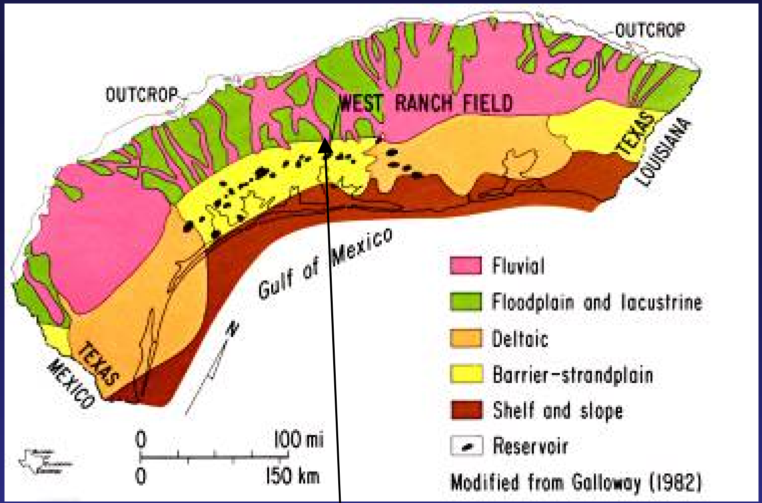
Source USGS, EIA

EOR to develop infrastructure - Injection into a down-dip brine to store very large volumes



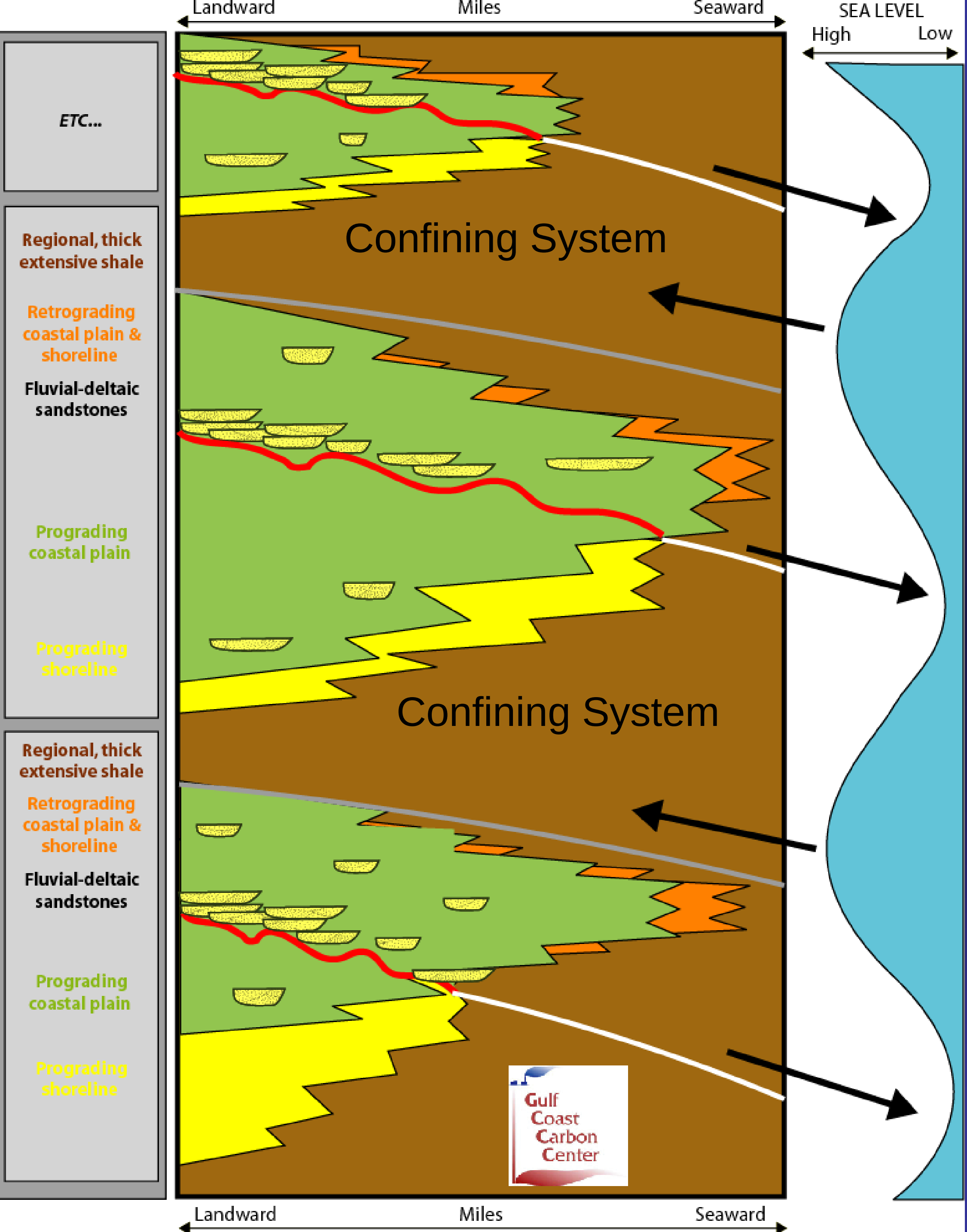
Stacked reservoirs in a sequence of sandstones and shales





Markham North-
Bay City North field

Modified from Tyler and Ambrose (1986)

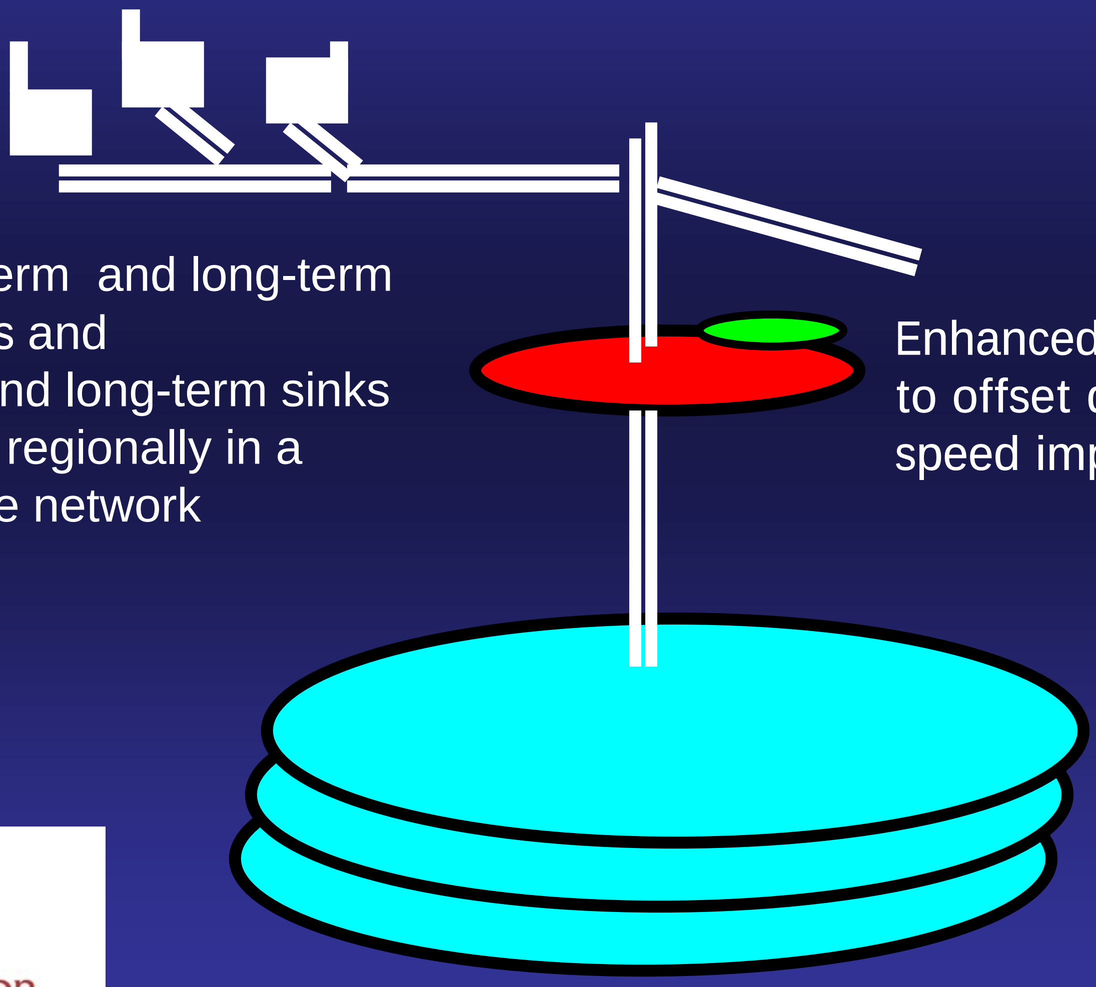


Stacked Reservoirs in a sequence of sandstones and shales

Repetitive depositional units in the Gulf Coast wedge – stacked porous and permeable sandstones

Tip Meckel, GCCC

Stacked Storage in Gulf Coast



Near-term and long-term sources and
Near and long-term sinks
linked regionally in a pipeline network

Enhanced oil and gas production to offset development cost and speed implementation

Very large volume storage in stacked brine formations beneath reservoir footprints

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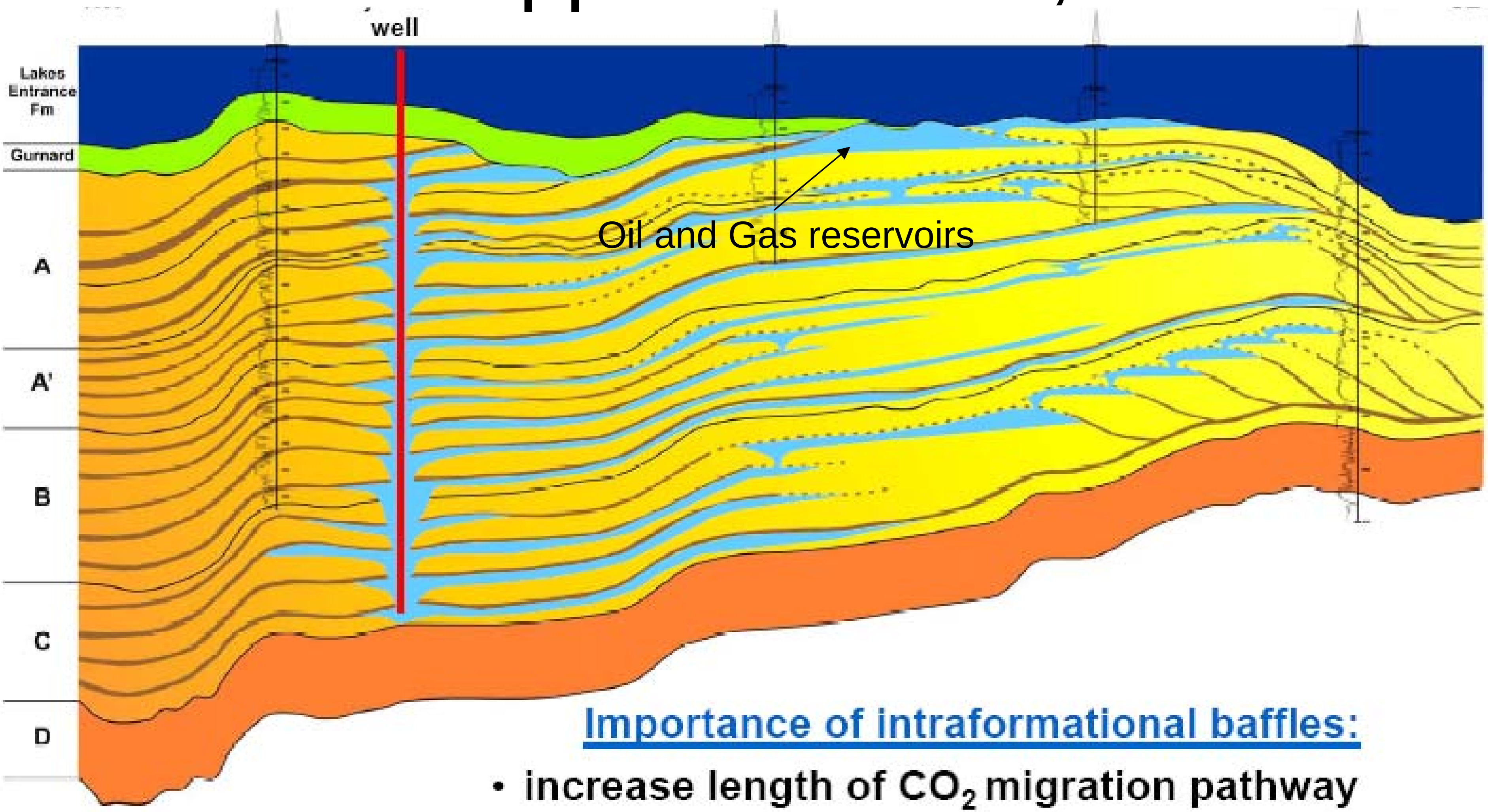
Stacked Storage is a Common Theme: Gippsland Basin, Australia



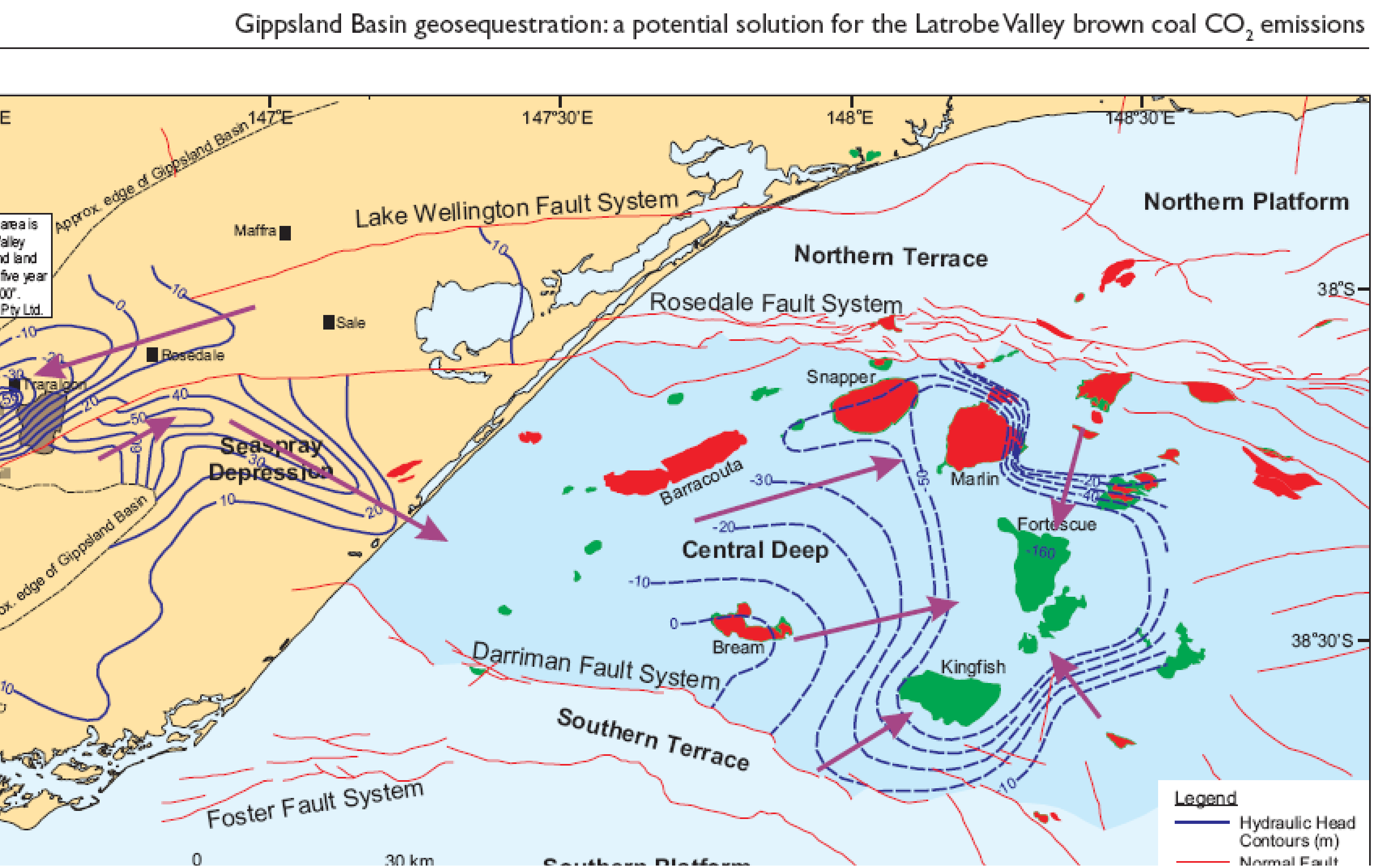
Importance of intraformational baffles:

- increase length of CO_2 migration pathway
- increase volume of pore space moved through

= greater residual gas trapping & dissolution

Gibson-Poole and others
Environmental Geoscience
June 2008

mproved containment as a product of pressure depletion
Gippsland Basin, Australia



oson-Poole and others
vironmental Geoscience

EOR Provides Experience in Handling CO_2

From Peter Cook, CO2CRC

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

How does EOR compare to brine sequestration?

EOR

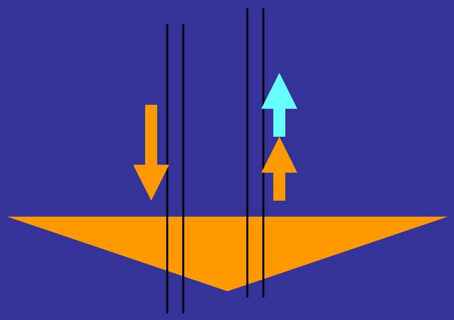
- Recycle with production
- Confined area
  - Trap
  - Pressure control
- Residual oil- CO_2 very soluble
- Many well penetrations =
  - Good subsurface knowledge
  - Some leakage risk

Brine Reservoir

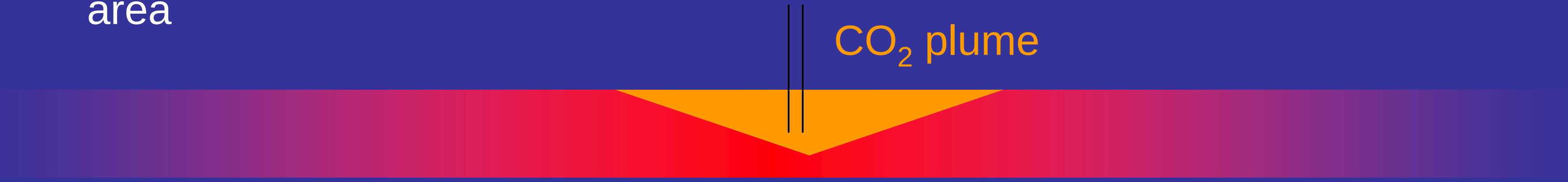
- Storage only
- Large area
  - May not use a trap
  - Pressure area increase
- Brine – CO_2 weakly soluble
- Few well penetrations =
  - Limited subsurface knowledge
  - Lower leakage risk

EOR and Sequestration-only have Different Footprints

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

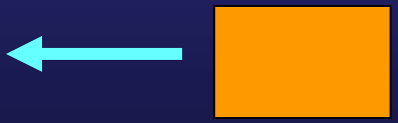


CO_2 injection (no production) pressure plume extends beyond the CO_2 injection area



Role of Dissolution in Plume and Pressure Evolution

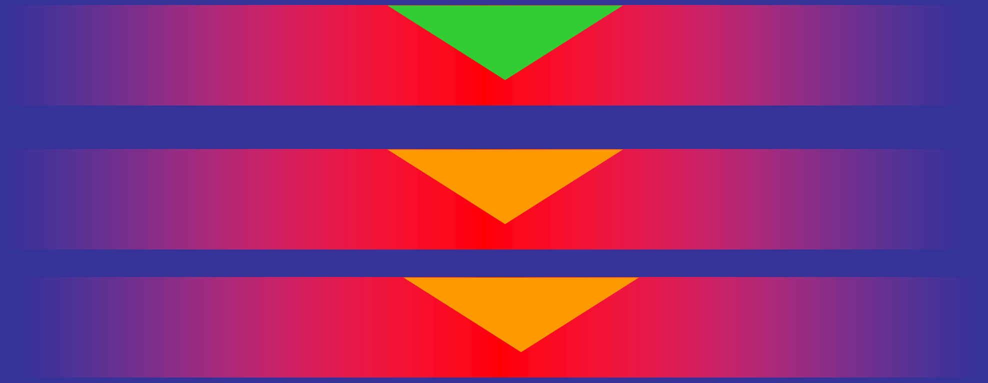
No dissolution: volume displaced = Volume injected



Volume displaced = Volume injected – volume dissolved + fluid expansion

In miscible CO_2 EOR, a large amount of CO_2 is dissolved in oil – CO_2 migration is greatly retarded compared to brine, where dissolution is much less.

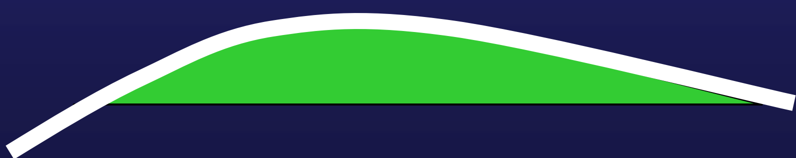
Stacked Storage



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

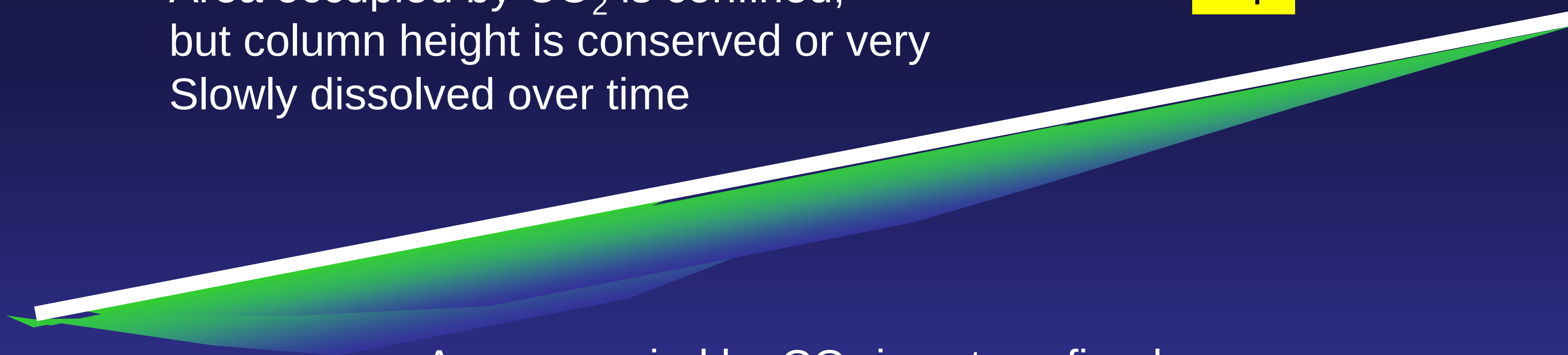
Injection in a Trap vs. Injecting on Dip

Trap



Area occupied by CO_2 is confined,
but column height is conserved or very
Slowly dissolved over time

Dip



Area occupied by CO_2 is not confined,
but column height is quickly reduced and CO2 is trapped by
capillary processes and dissolved over time
= Reduced leakage risk

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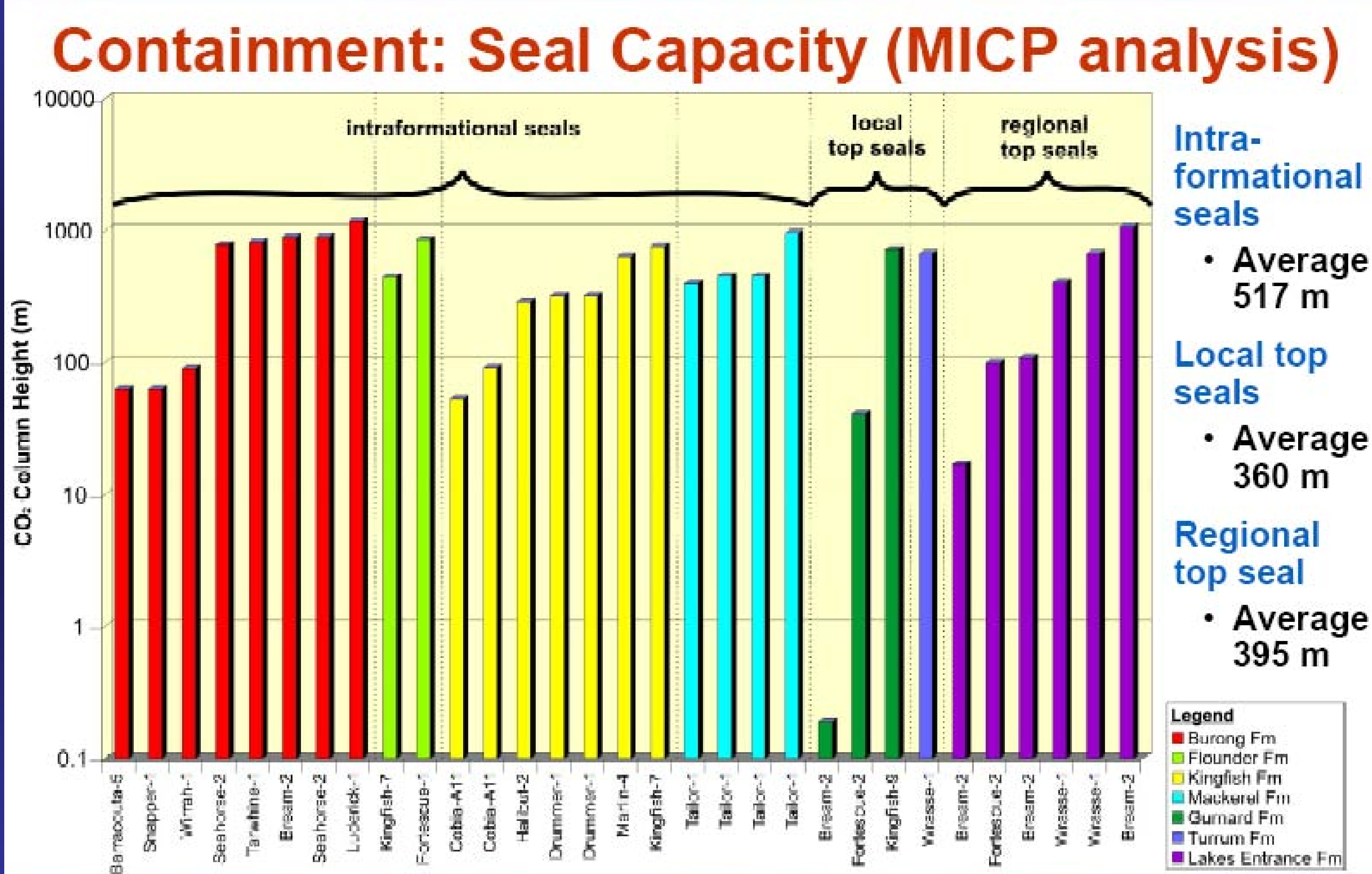
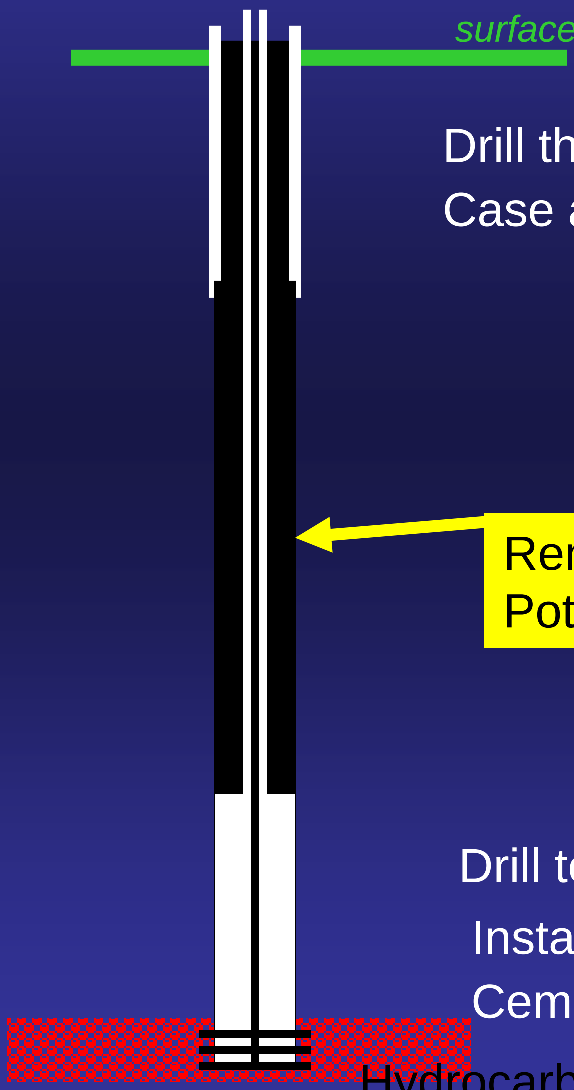
Storage where there has been production supported by dense data



Gibson-Poole and others
CSIRO

UNSW CSIRO ASP Australian School of Petroleum THE UNIVERSITY OF ADELAIDE AUSTRALIA CO2CRC

What is the Risk From Oil and Gas Wells?



Drill through Freshwater

Case and cement to seal off freshwater 2000 ft in Gulf Coast

Remaining open annulus between rock and casing=
Potential leakage path for CO_2 or displaced brine

Drill to hydrocarbon production interval

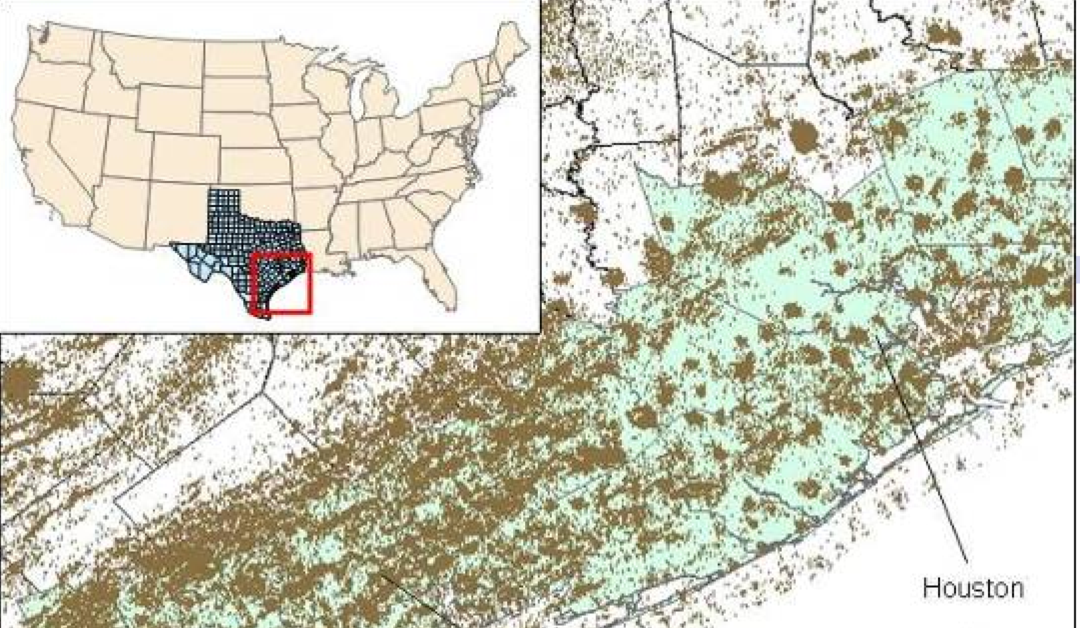
Install production casing

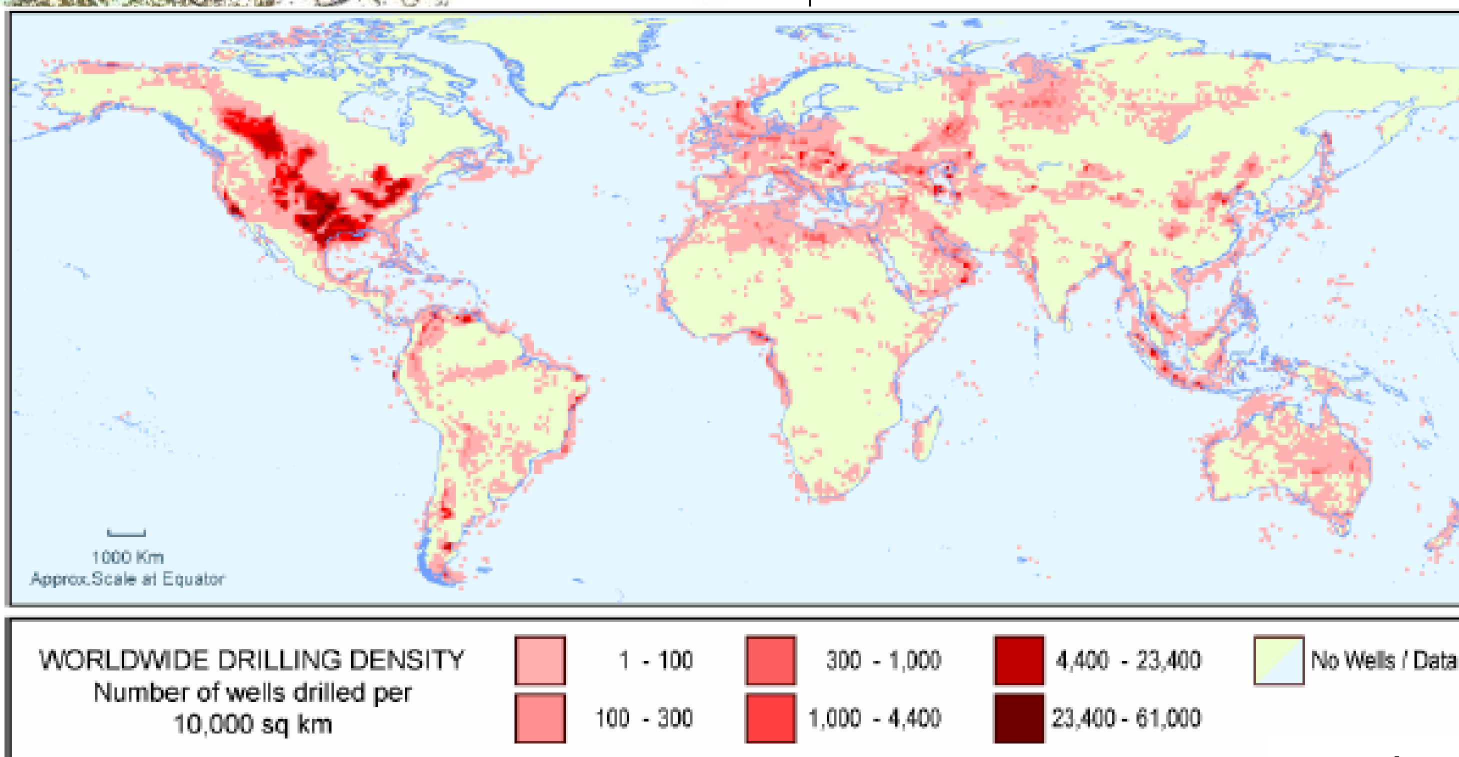
Cement above production zone

Well Density

Bureau of Economic Geology

Texas:	1.6 well/km^2
Texas Gulf Coast:	2.4 well/km^2
Alberta Basin:	0.5 well/km^2
Most O&G provinces:	<<1 well/km^2



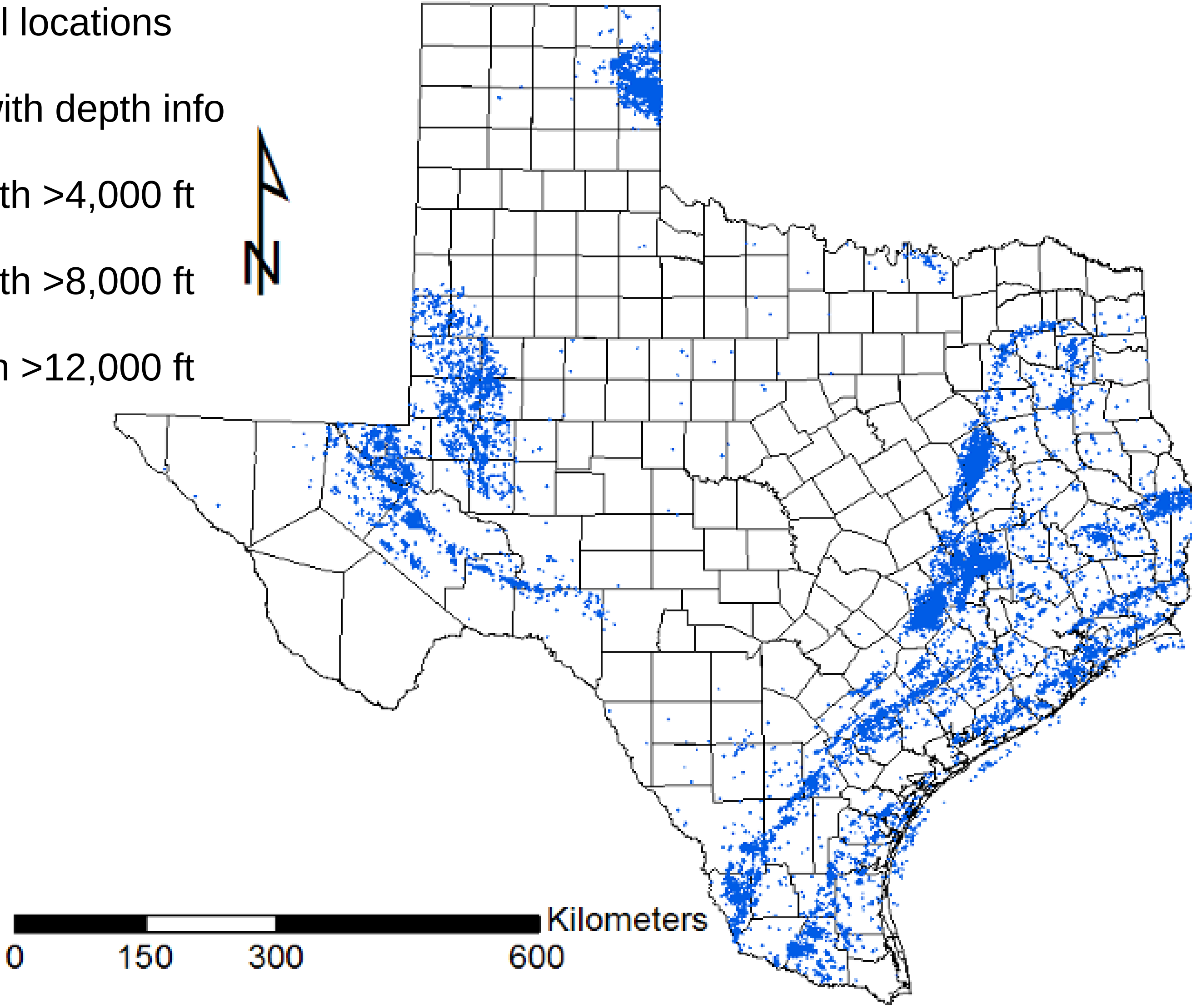


JP Nicot

Gulf Coast Carbon Center

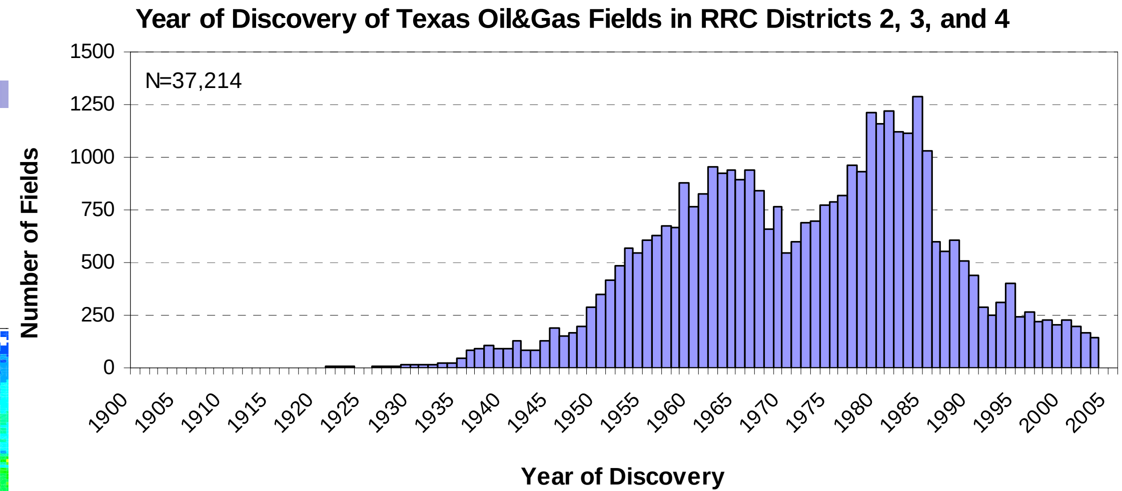
Well Density Varies with Depth

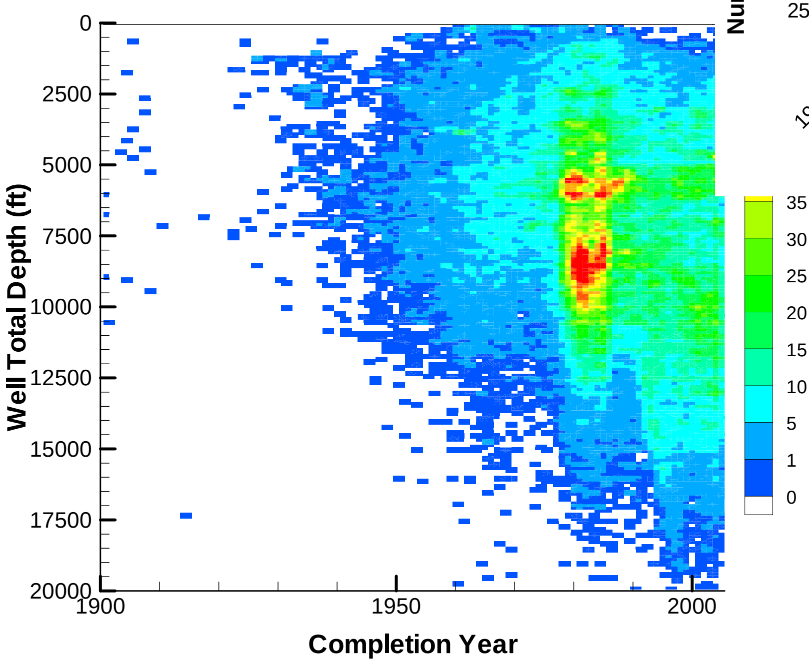
- 1,110,000 known well locations
- 720,000 well locations with depth info
- >320,000 wells w/ depth >4,000 ft
- >112,000 wells w/ depth >8,000 ft
- >20,000 wells w/ depth >12,000 ft

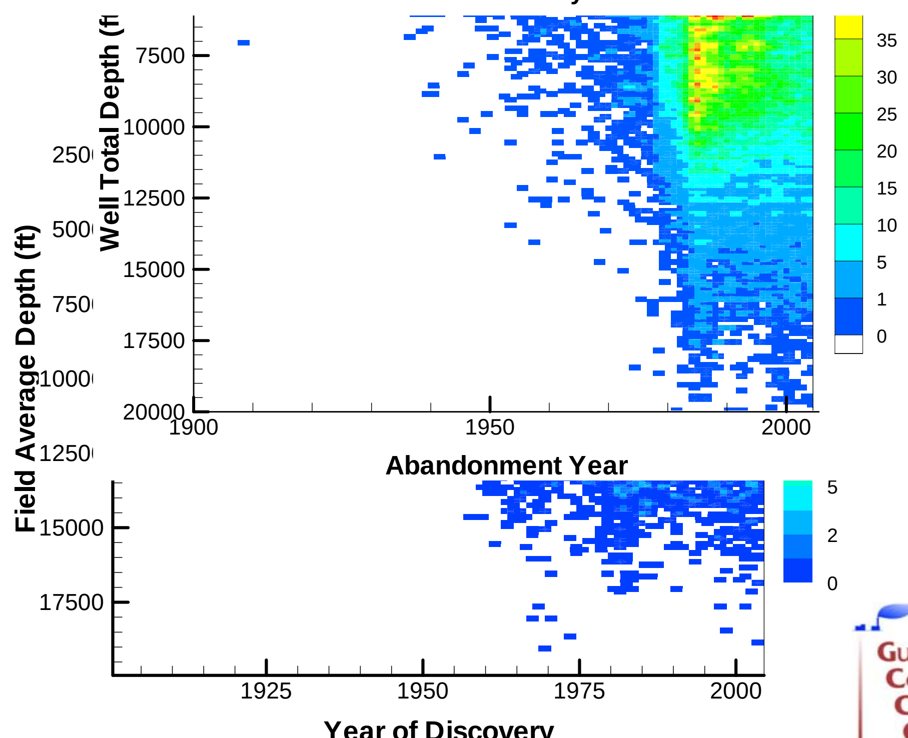


JP Nicot

Well Depth Varies with Completion Year







Texas Gulf Coast data only

JP Nicot

Well Penetrations Statistics

	In a 1-km Radius Area	In a 4-km Radius Area	In an 8-km Radius Area
All wells (Depth > 0 m or ft) [Digital Map Data]	Entire area: 2.28 well/km^2 29% of area w/ no well and 3.23 well/km^2 in a 1-km radius for remainder	Entire area: 2.30 well/km^2 0% of area with no well	Entire area: 2.28 well/km^2 0% of area with no well
All wells (Depth > 0 m or ft) [API well database]	Data ***very biased*** by lack of depth information on older wells		
	Entire area: >0.98 well/km^2 *<55% of area w/ no well and >2.16 well/km^2 in a 1-km radius for remainder*	*Entire area: >0.98 well/km^2* *<6.5% of area w/ no well and >1.05 well/km^2 in a 4-km radius for remainder*	*Entire area: >0.98 well/km^2* *<0.3% of area w/ no well and >0.98 well/km^2 in a 8-km radius for remainder*
Depth > 1,220 m (4,000 ft)	Data ***somewhat biased*** by lack of depth information on older wells		
	Entire area: >0.81 well/km^2 <56% of area w/ no well and >1.85 well/km^2 in a 1-km radius for remainder	Entire area: >0.81 well/km^2 <7% of area w/ no well and >0.87 well/km^2 in a 4-km radius for remainder	Entire area: >0.81 well/km^2 <0.4% of area w/ no well and >0.81 well/km^2 in a 8-km radius for remainder
Depth > 2,440 m (8,000 ft)	Data ***minimally biased*** by lack of depth information on older wells		
	Entire area: 0.27 well/km^2 73% of area w/ no well and 1.0 well/km^2 in a 1-km radius for remainder	Entire area: 0.27 well/km^2 19% of area w/ no well and 0.34 well/km^2 in a 4-km radius for remainder	Entire area: 0.27 well/km^2 3% of area w/ no well and 0.30 well/km^2 in a 8-km radius for remainder
Depth > 3,660 m (12,000 ft)	Data ***not biased*** by lack of depth information on older wells		
	Entire area: 0.05 well/km^2 92% of area w/ no well and 0.55 well/km^2 in a 1-km radius for remainder	Entire area: 0.05 well/km^2 52% of area w/ no well and 0.093 well/km^2 in a 4-km radius for remainder	Entire area: 0.05 well/km^2 21% of area w/ no well and 0.06 well/km^2 in a 8-km radius for remainder

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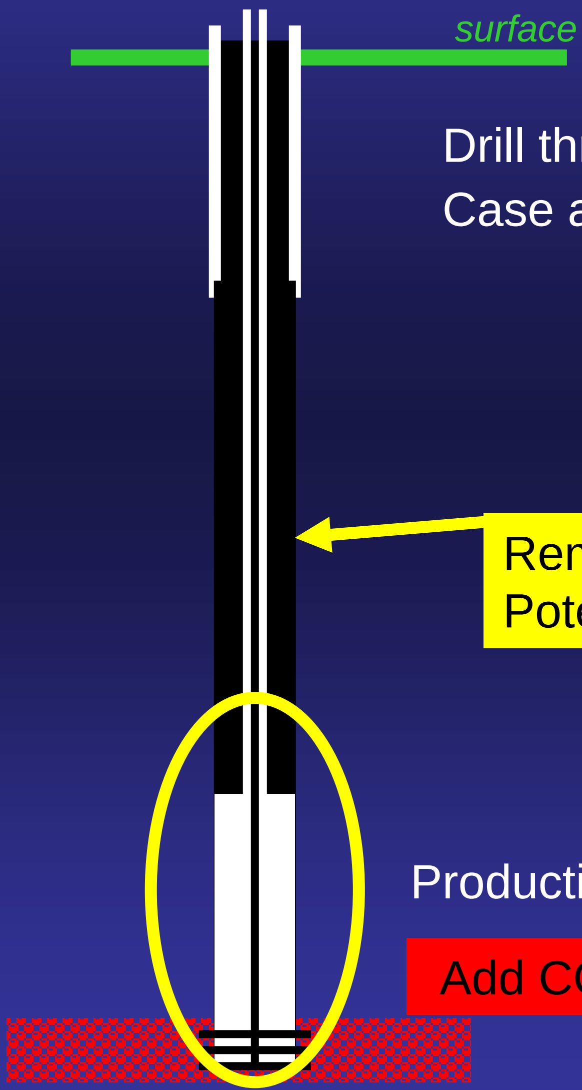
So How Good is Cement?



Drill through Freshwater

Case and cement to seal off freshwater 2000 ft in Gulf Coast

Remaining open annulus between rock and casing=
Potential leakage path for CO_2 or displaced brine

Production casing and cement above production zone

Add CO_2 for Tertiary production of hydrocarbon resource

What is known and not known about cement performance

- CO_2 + water = weak acid, in the lab in open cells consumes cement in months
- CO_2 EOR has been conducted with standard well completions for decades
- Several “dissected” multi-decade old CO_2 wells cement appears OK
- What will happen over hundreds of years?
- Research by CCP2, Princeton, Schlumberger etc.

Case Study: Monitoring an EOR Project to Document Sequestration Value

Susan D. Hovorka
Gulf Coast Carbon Center
Bureau of Economic Geology
Jackson School of Geoscience
The University of Texas at Austin

Presented to North American Carbon Capture & Storage Association ,
June 9, 2008, BEG, Austin TX

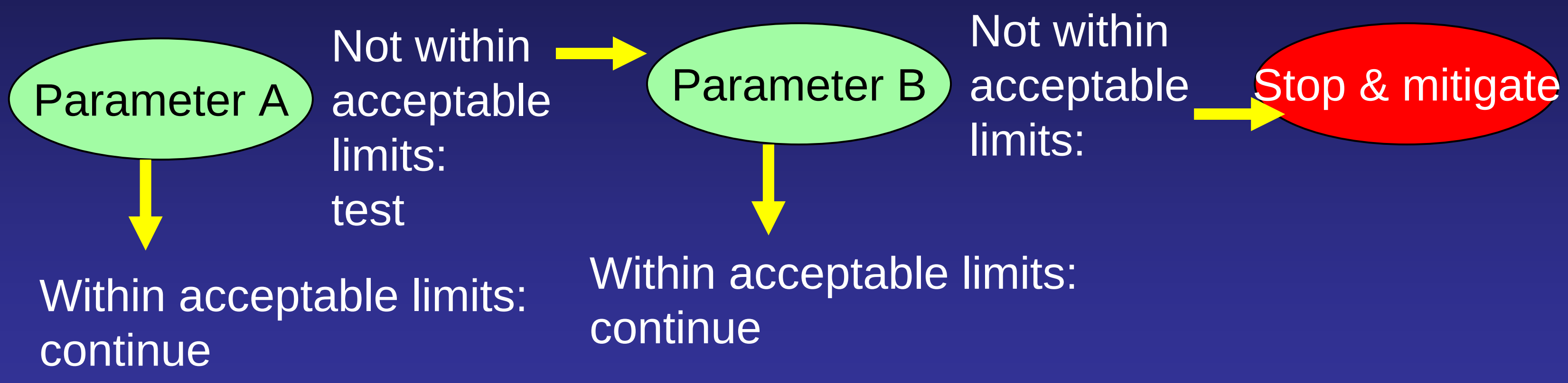
Monitoring Goals For Commercial Sequestration

- 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

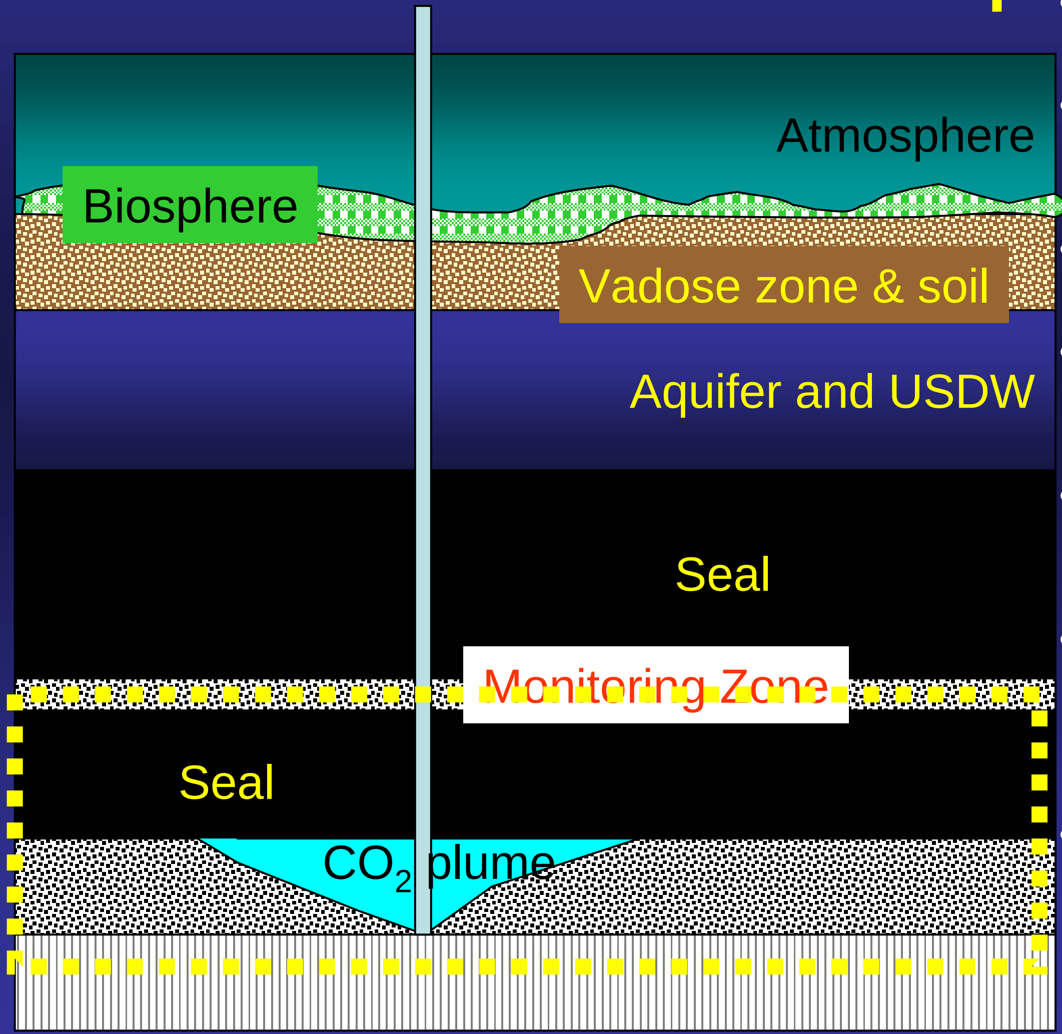
Modified from J. Litynski, NETL

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:



Monitoring to Assure that CO_2 remains where it is placed



- 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

Complex!

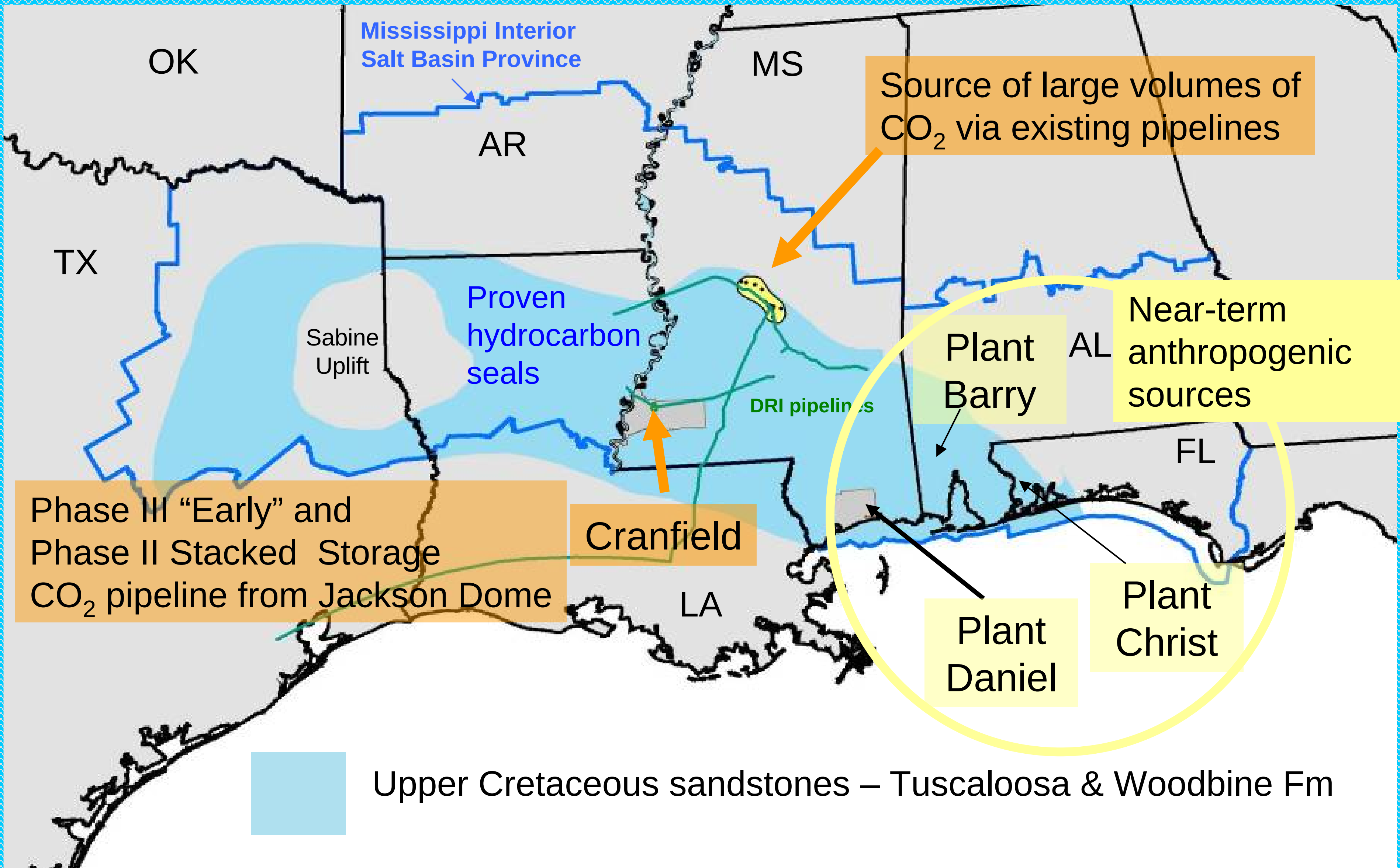
- Above injection monitoring zone
  - First indicator, monitor small signals, stable.
- In injection zone - plume
  - Oil-field type technologies. Will not identify small leaks

Complex!

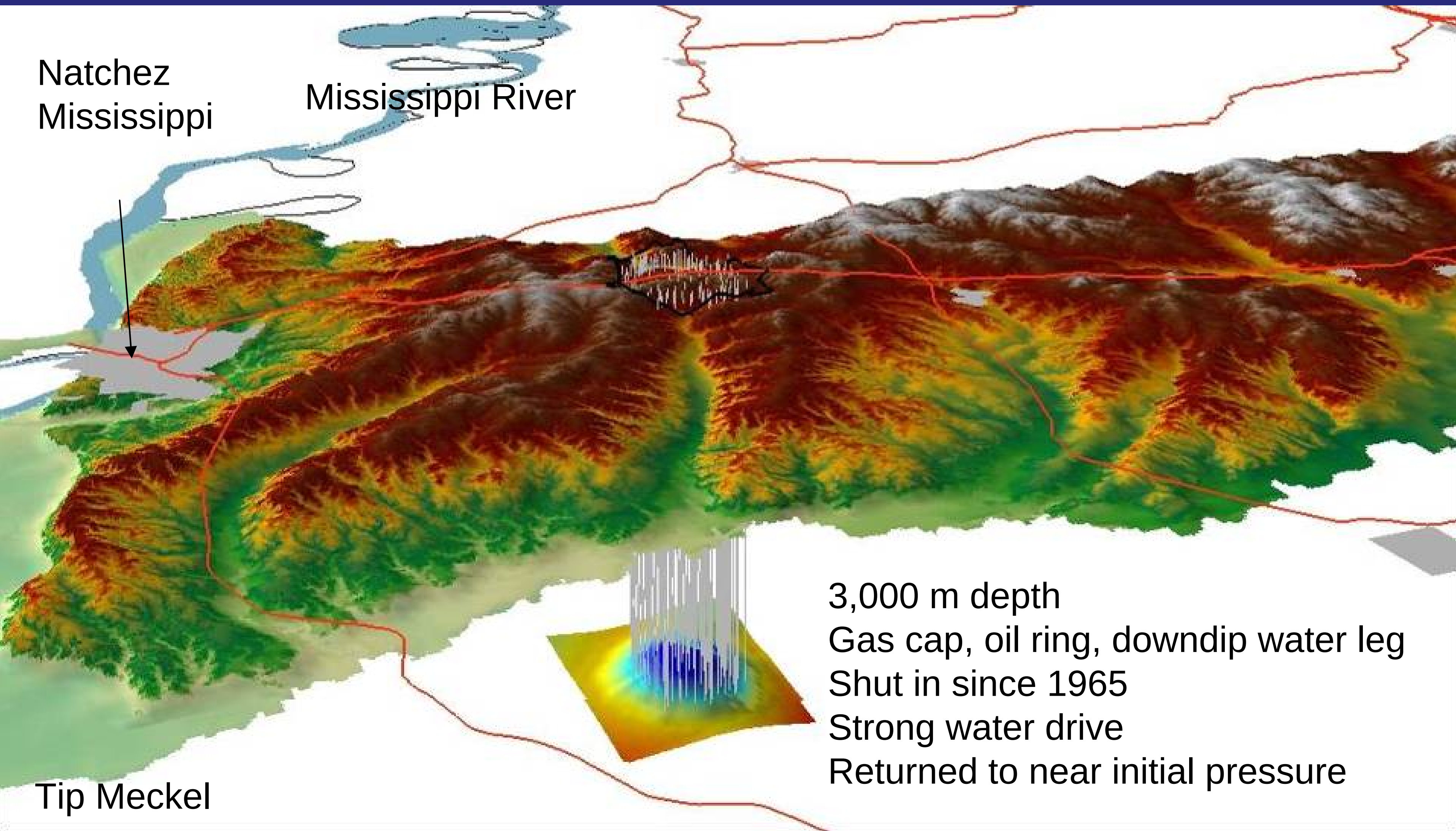
- In injection zone - outside plume
  - Assure lateral migration of CO_2 and brine is acceptable

Pressure monitoring “box”

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



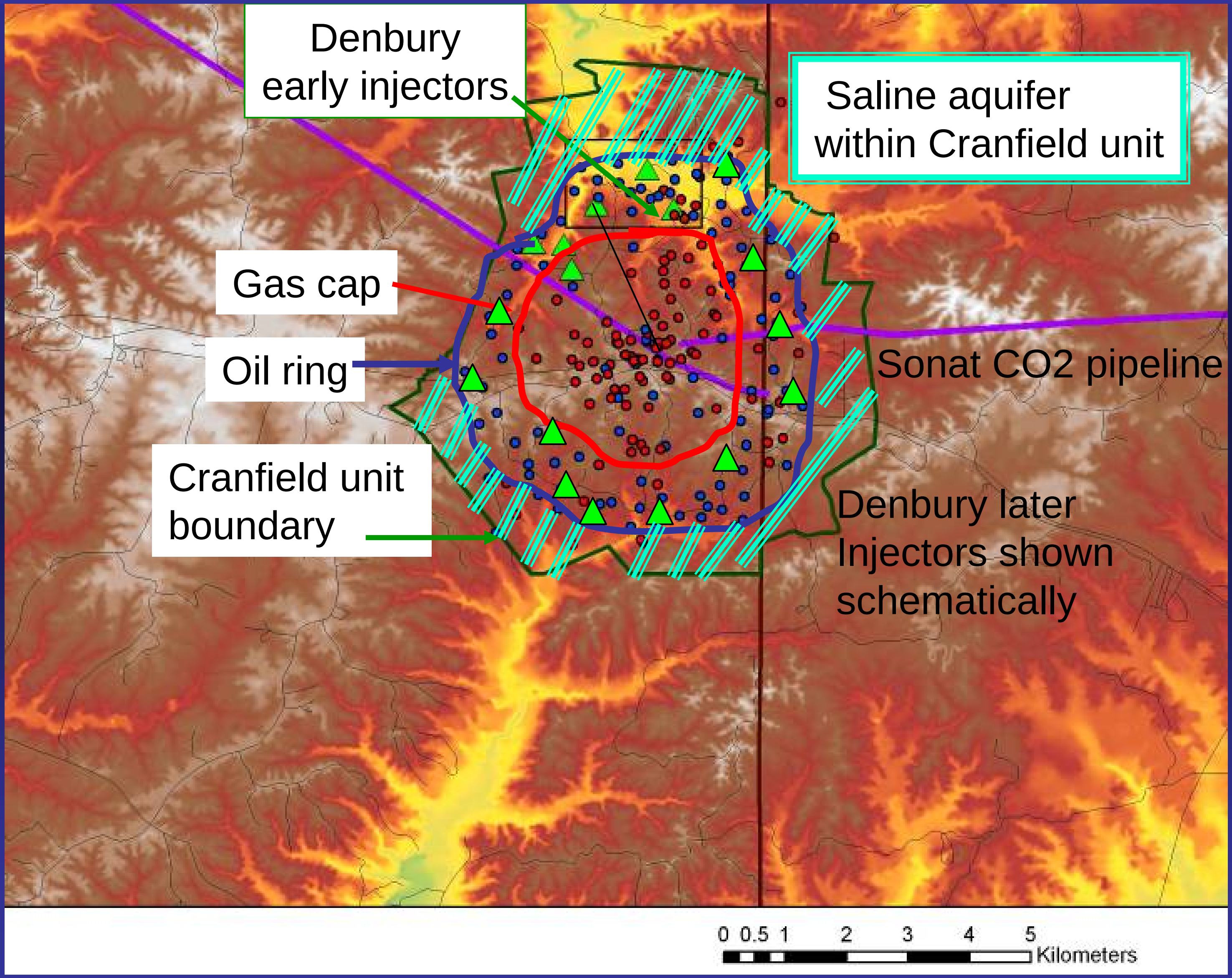
SECARB Phase III – “Early” test Cranfield unit operated by Denbury Resources International



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

Tip Meckel

CO_2 used for EOR – bringing old fields back to life



SECARB Phase II (Cranfield Oil ring) Overarching Research Focuses

(1) Sweep efficiency – how effectively are pore volumes contacted by CO_2?

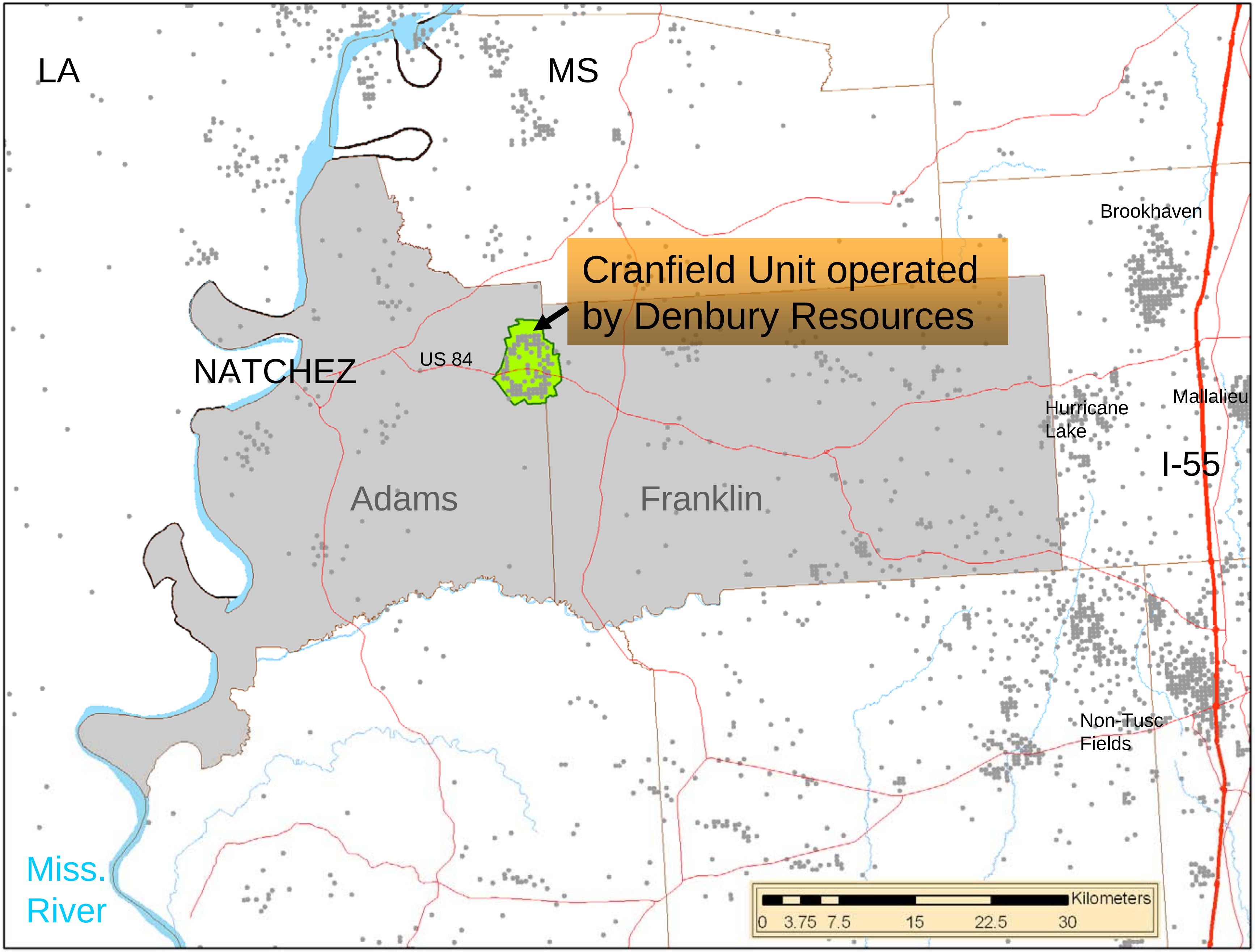
- Important in recovery efficiency in EOR
- Subsurface storage capacity?
- Plume size prediction

(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

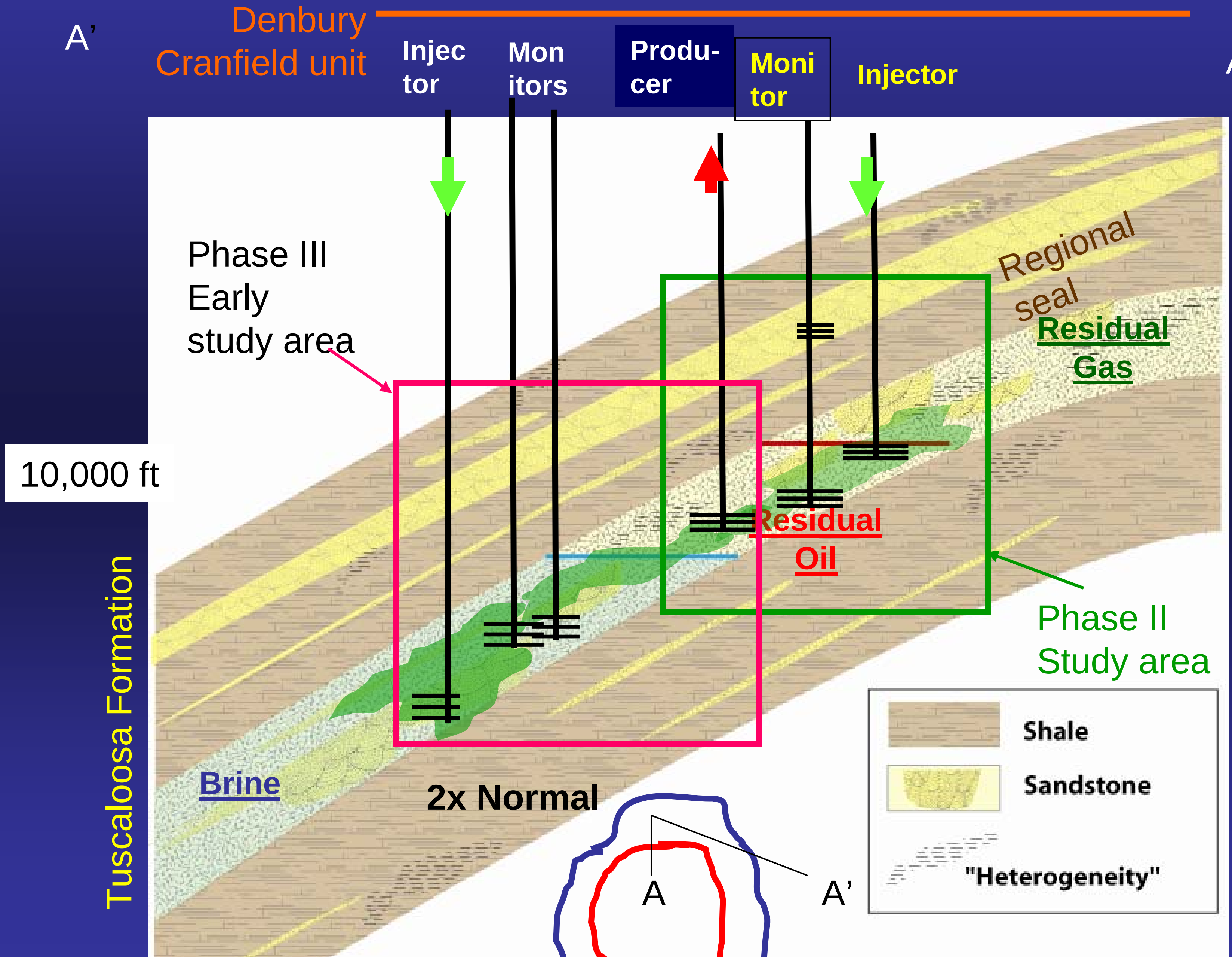
(3) Effectiveness of Mississippi well completion regs. in retaining CO_2 in GHG context

- Above zone monitoring



LA
MS
Cranfield Unit operated by Denbury Resources
NATCHEZ
US 84
Brookhaven
Mallalieu
Hurricane Lake
I-55
Adams
Franklin
Non-Tusc Fields
Miss. River
Kilometers
0 3.75 7.5 15 22.5 30

Cranfield Geometric Overview

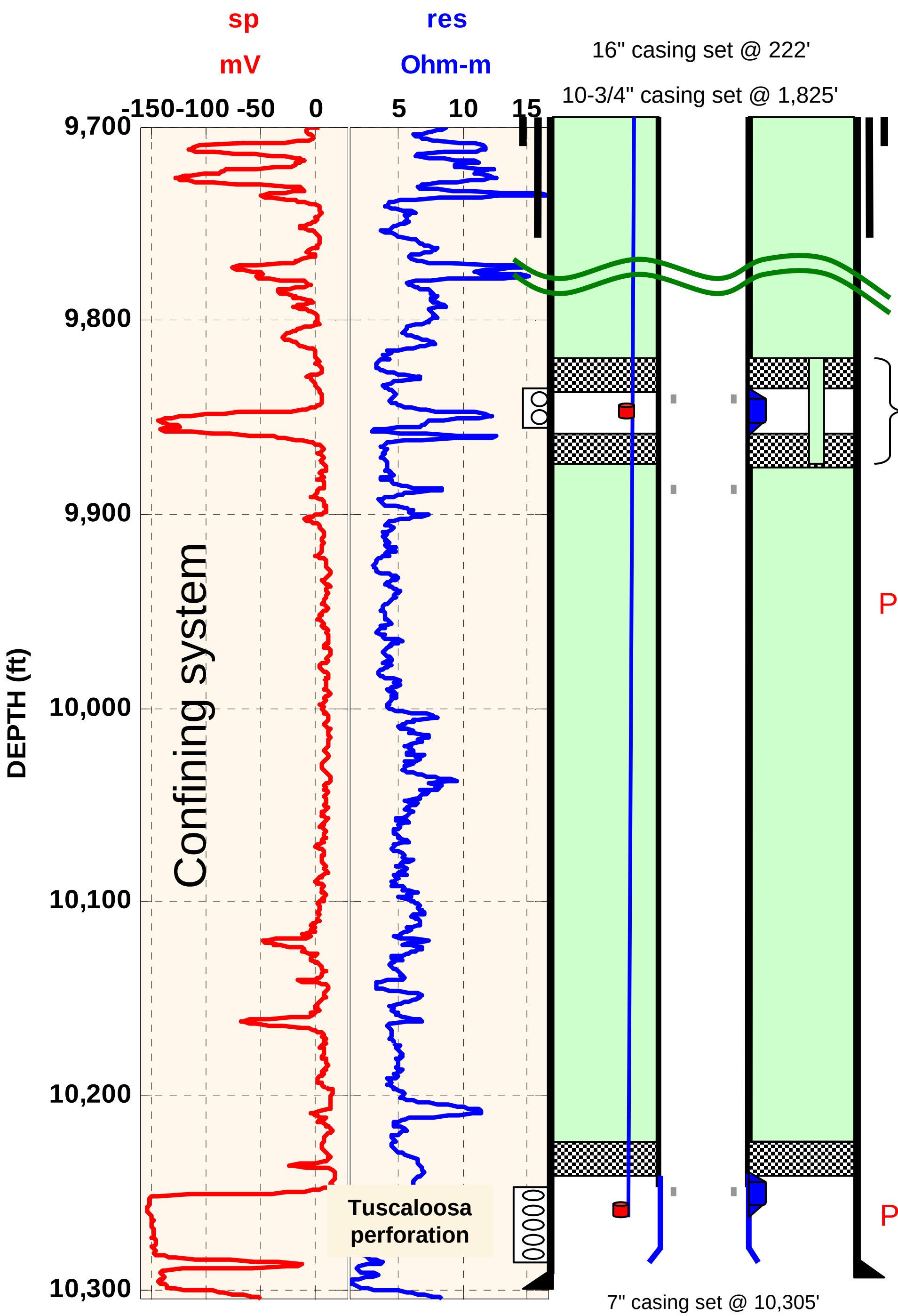


Phase III : Theoretical Approaches Through Commercialization

Commercial Deployment by Southern Co.

Toward commercia-lization	**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**

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

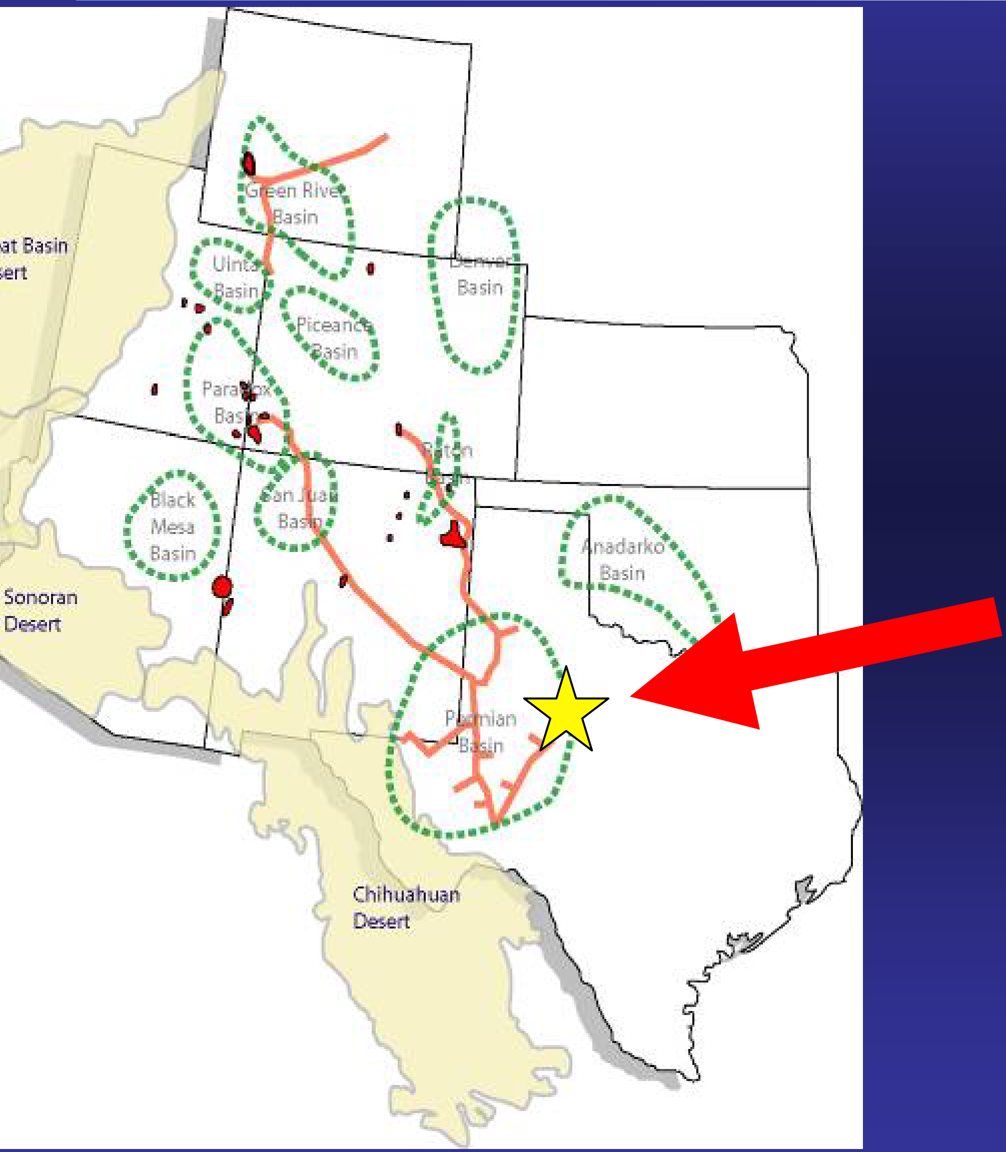
Pressure transducer Side Pocket Mandrel w/dummy gas valve

Well diagram from Sandia Technologies, LLC

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?

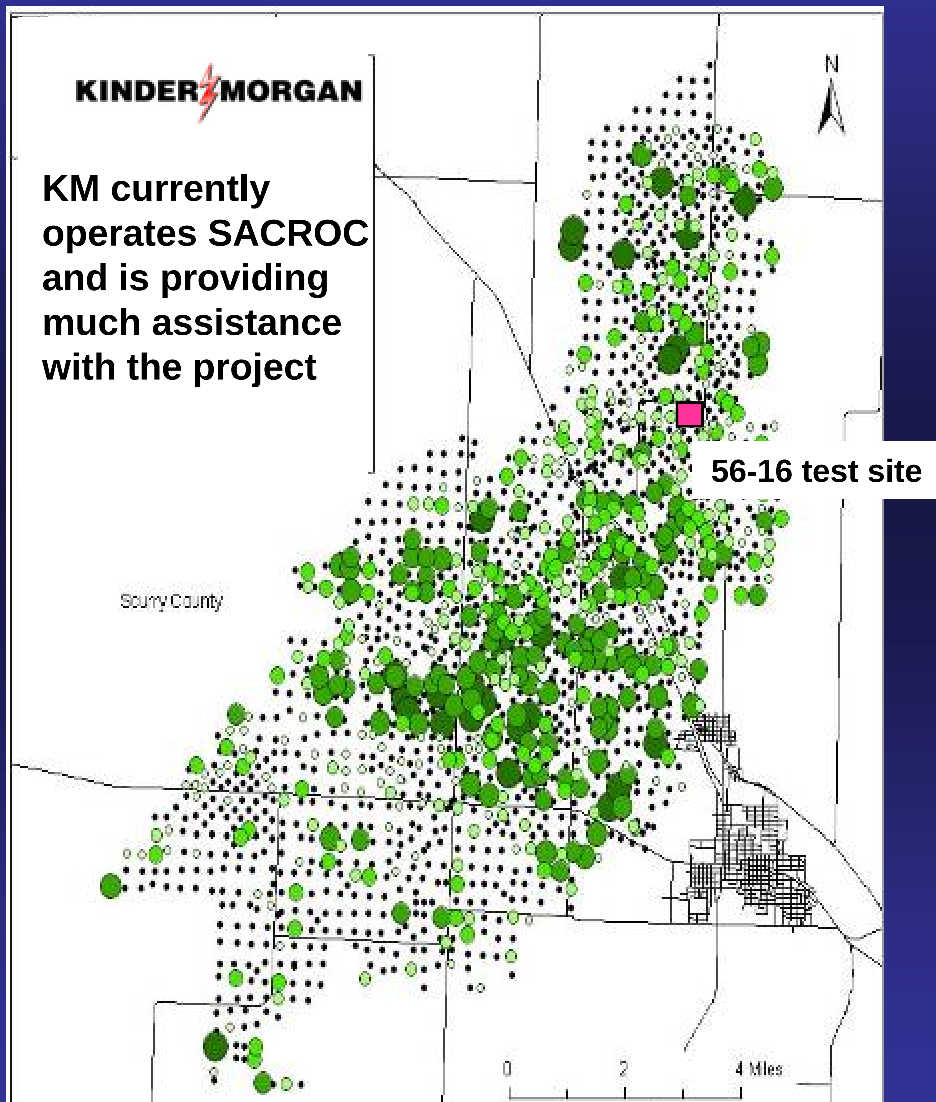
SACROC – eastern edge Permian Basin



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



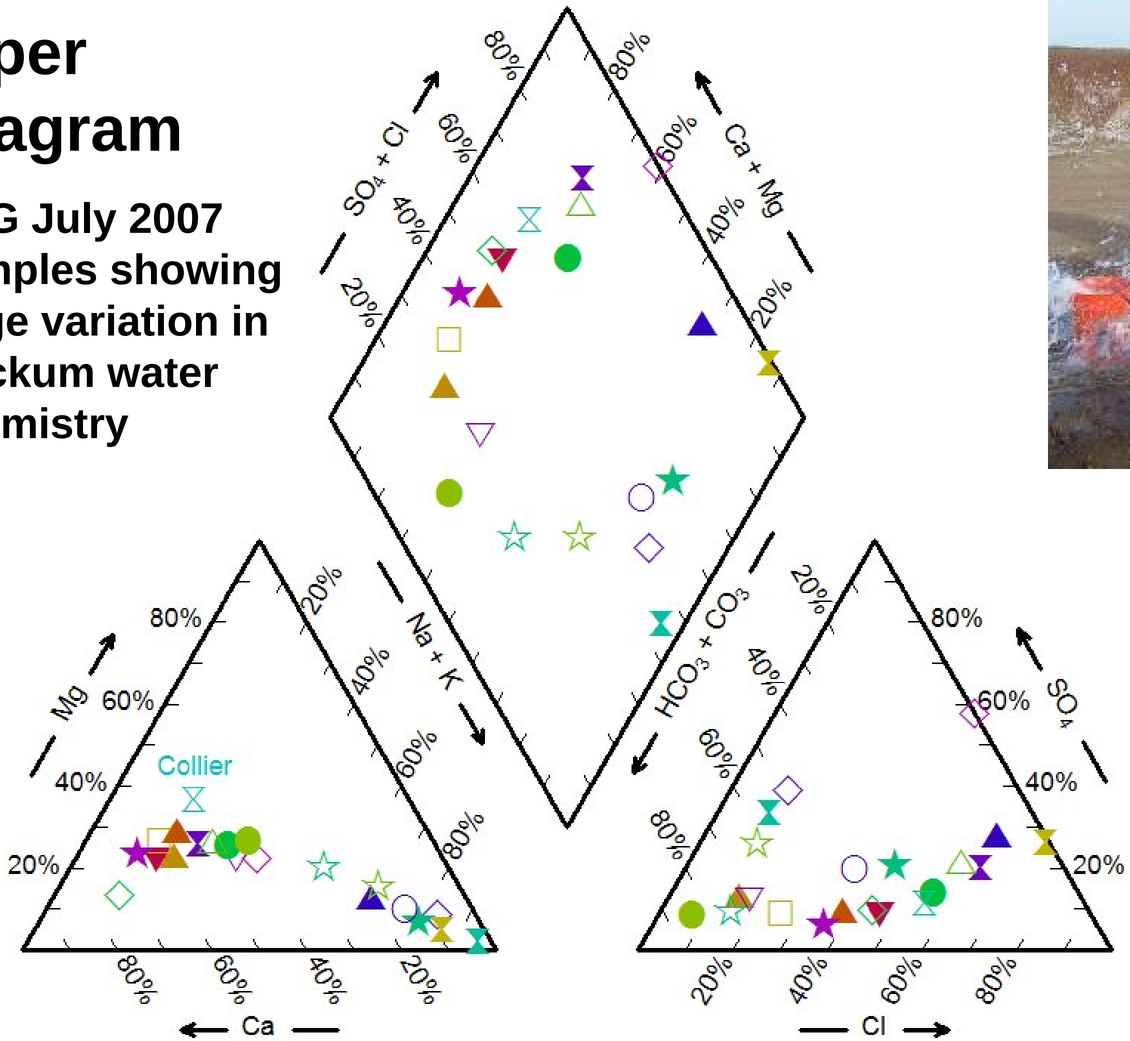
- ~140 million tons CO_2 injected for EOR since 1972 for EOR
- ~60 million tons CO_2 recovered
- SWP researchers test if detectable CO_2 has leaked into groundwater

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

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,

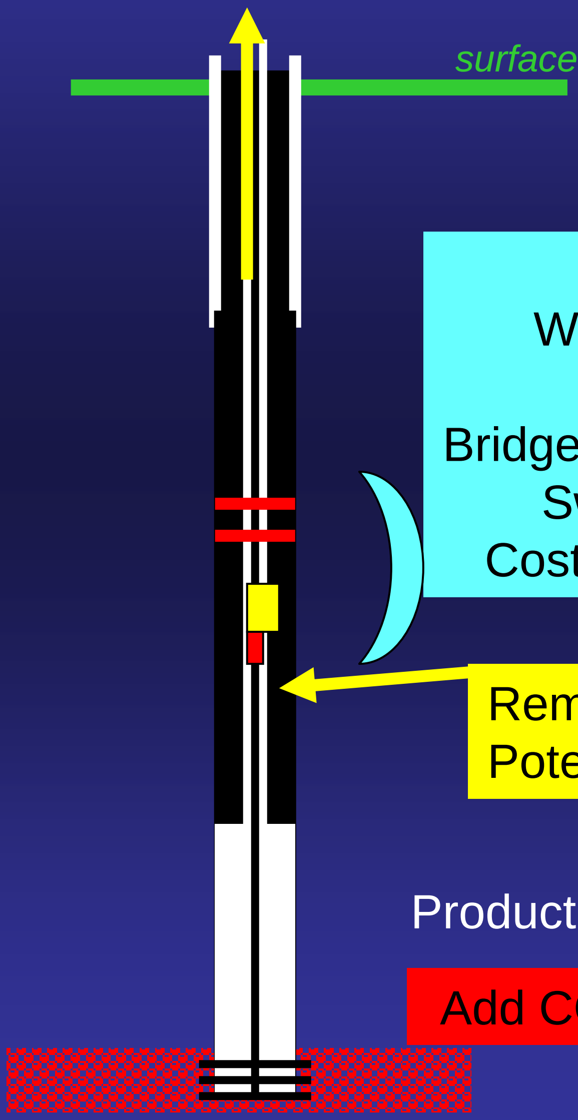
↑ Alkalinity,

↑ dissolved metals

Conclusions

- EOR is an intrinsic part of geologic sequestration in many basins
  - Pluses
    - Economic and public acceptance
    - Managed pressure and fluid flow, small footprint
    - CO_2 dissolves in oil – a trapping mechanism
    - Well known subsurface environment – reduces risk
  - Minuses
    - Well leakage risk – magnitude unknown
    - CO_2 in trap – less capillary trapping and dissolution in brine, prolongs leakage risk
    - Limited volumes
    - Consider long term storage in “stacked’ settings (large volume brine-bearing formations in same footprint)

Call to Action – How well do wells perform?



Test program:
Well scheduled for Plug and Abandon
Perforate above cement
Bridge plug with pressure gauge hung below it
Swab – Does cement hold pressure?
Cost <$50K but need a population of wells

Remaining open annulus between rock and casing=
Potential leakage path for CO_2 or displaced brine

Production casing and cement above production zone

Add CO_2 for Tertiary production of hydrocarbon resource

Non-technical issues enter in the discussion of what ‘counts’ as sequestration

- US domestic production
- Coal and hydrocarbons as competing fuels
- EOR opportunities are unequally distributed
- Public opinion