CarbonSAFE: Establishing an Early CO_2 Storage Complex in Kemper County, Mississippi: Project ECO_2S

Project Number DE-FE0029465

U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:

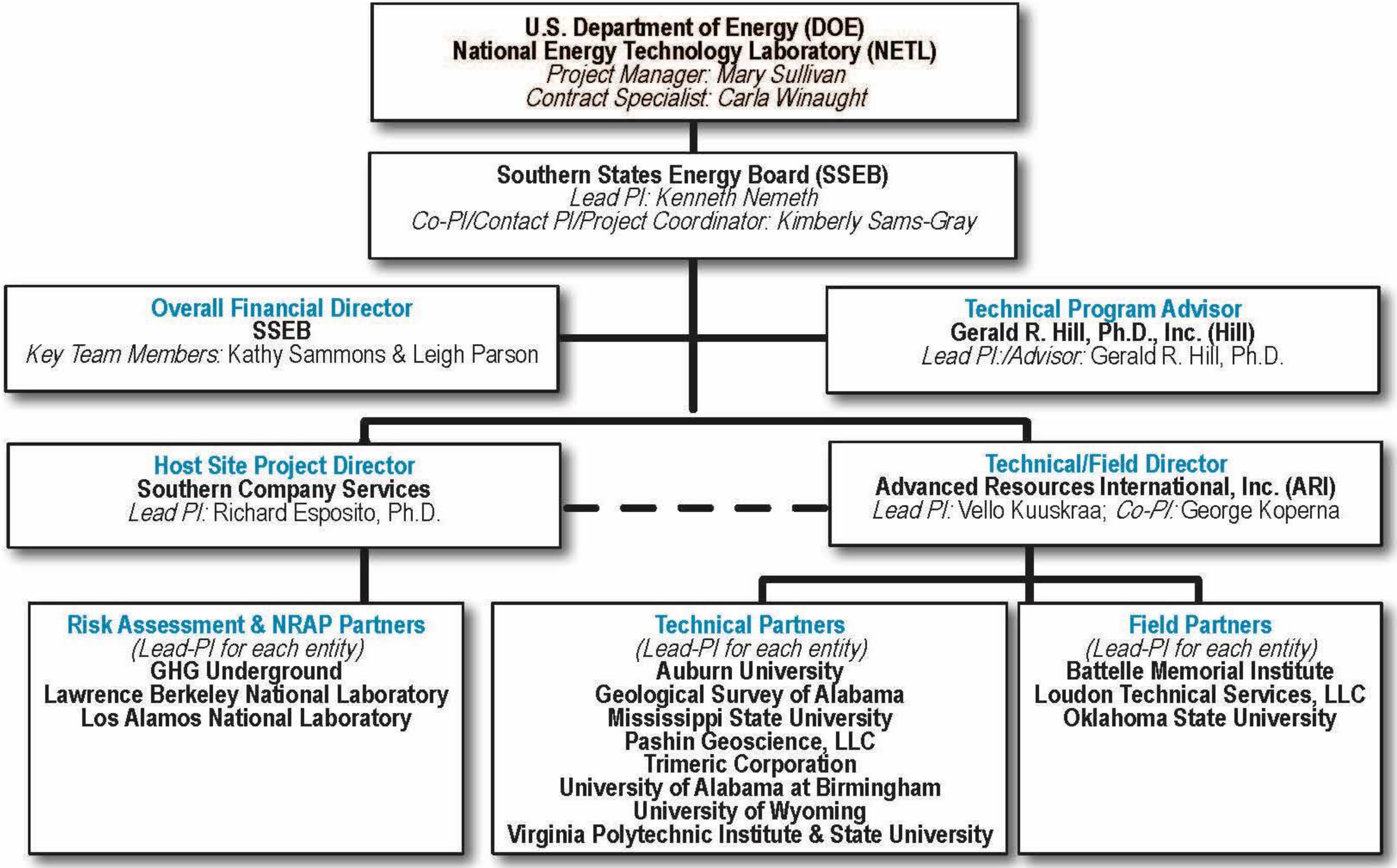
Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 13-16, 2018

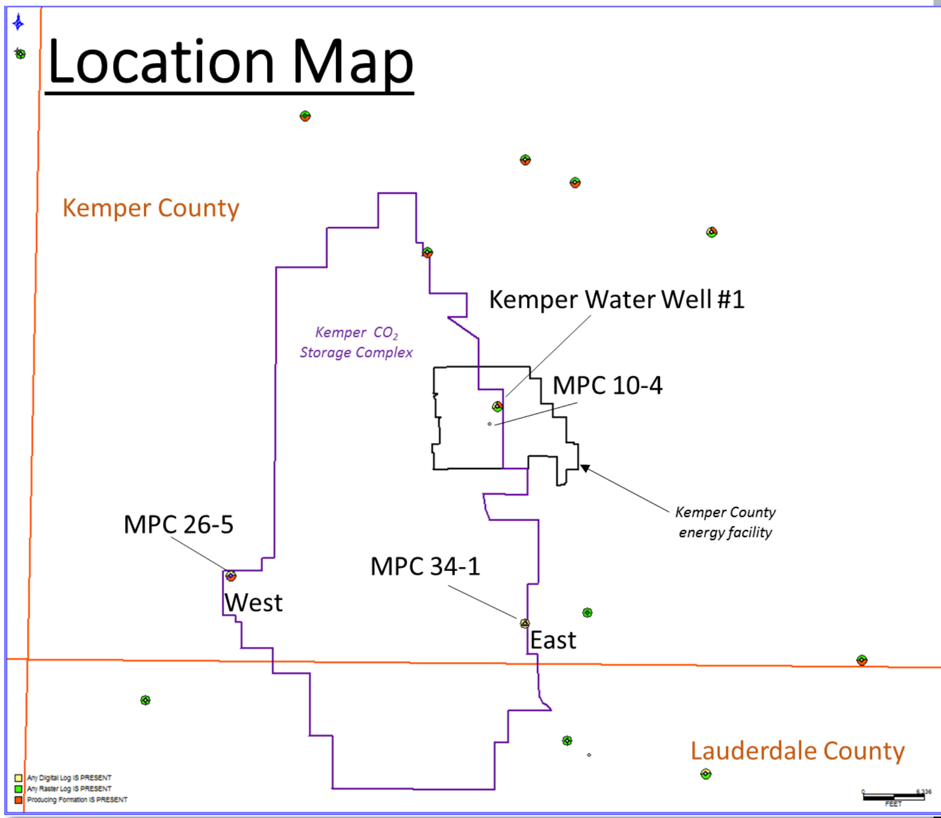
Acknowledgements

The Project Team led by Southern States Energy Board, Mississippi Power Company and Southern Company Services, with technical support from Advanced Resources Inc. and a host of key subcontractors, acknowledge the valuable support provided by the U.S. DOE National Energy Technology Laboratory on this Phase 2 CarbonSAFE field project.

Project ECO$_2$S Organization Chart



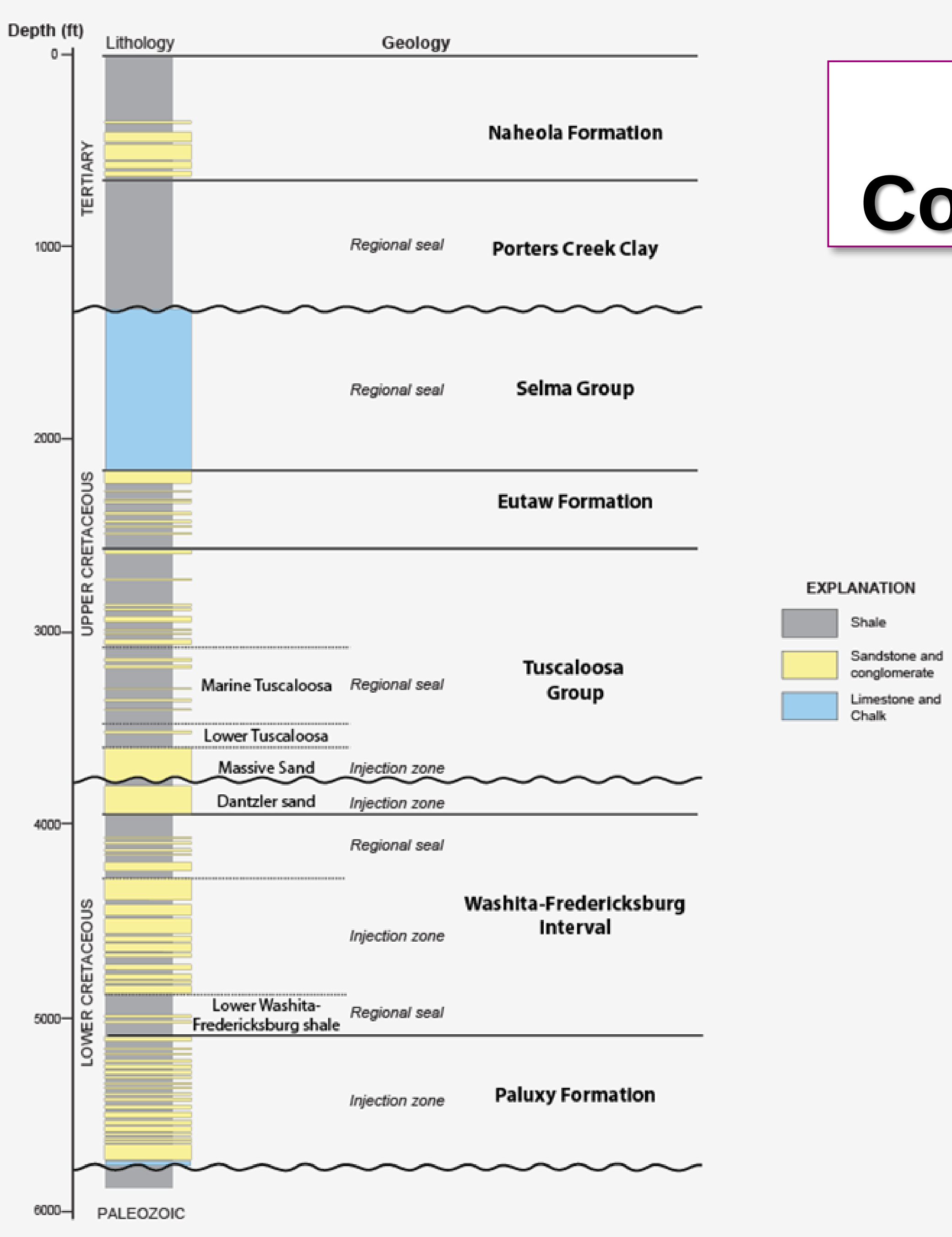
Why Kemper?



The goal is to demonstrate that the subsurface at Kemper CO_2 can <u>safely and permanently store commercial volumes of CO_2</u>

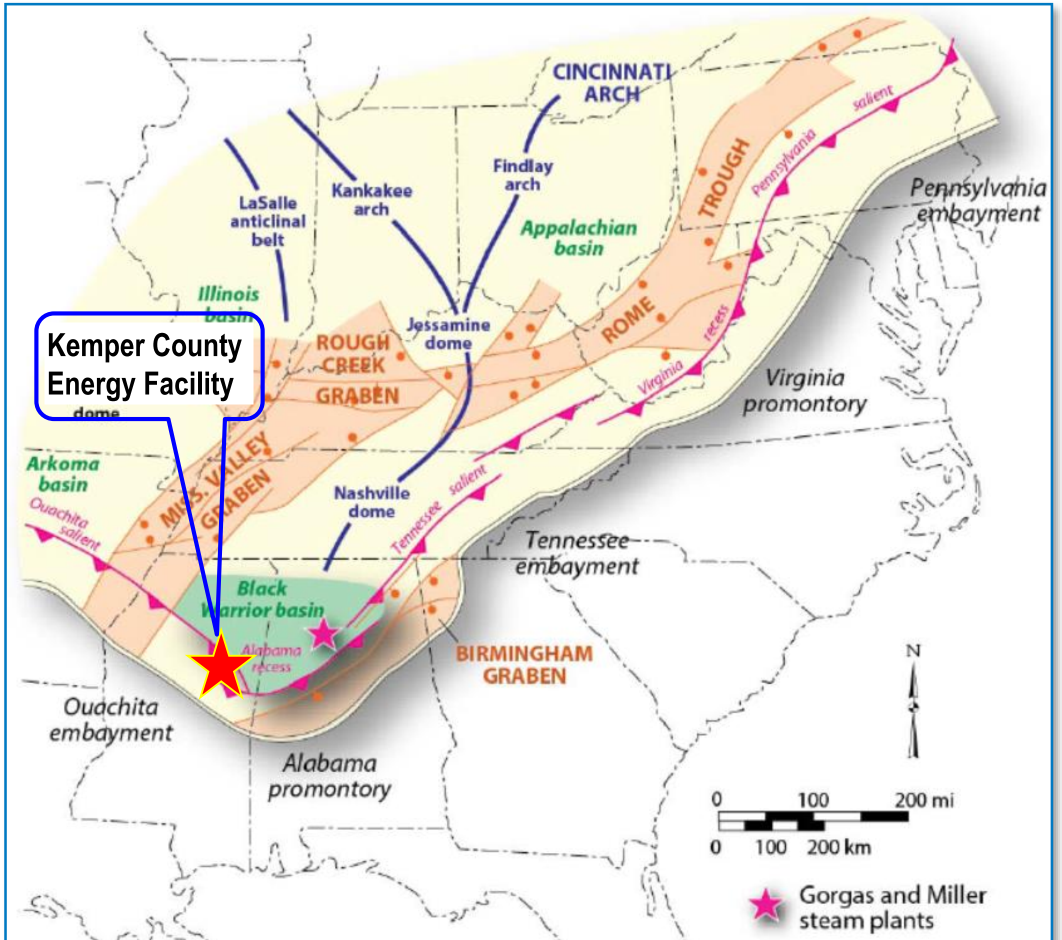
The project team has established an area of interest exceeding 30,000 acres near the Kemper County energy facility

Kemper Storage Complex Stratigraphy



- **Storage zones**
  - Lower Tuscaloosa Grp (‘Massive’ sand)
  - Washita-Fredericksburg interval
  - Paluxy Formation
- **Confinement**
  - Tuscaloosa marine shale
  - Shale interval at <u>top</u> of the Washita-Fredericksburg
  - Shale interval at <u>base</u> of Washita-Fredericksburg
  - Shallower seals in the Selma and Midway Groups

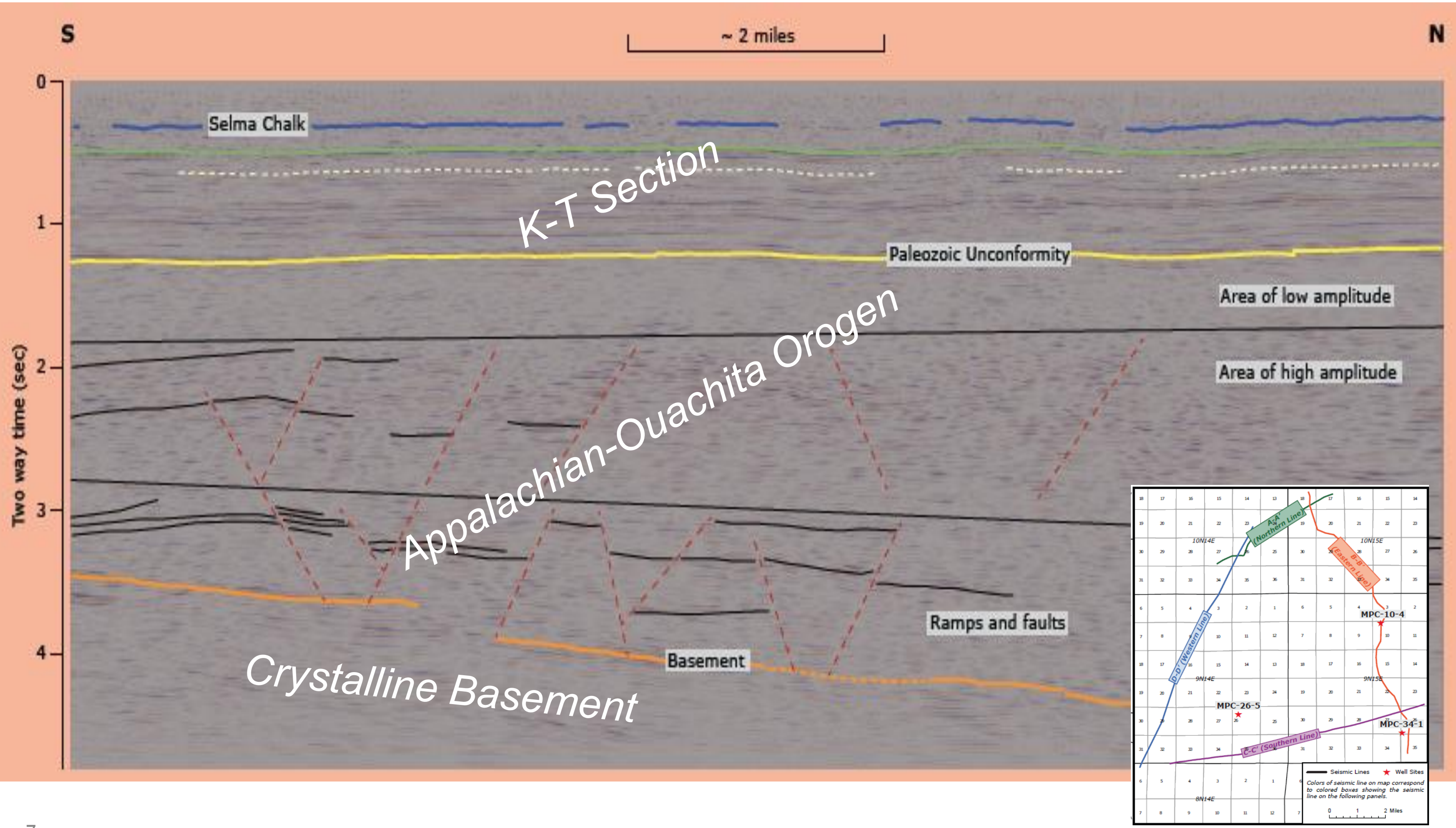
Kemper County, Mississippi Regional Structural Setting



Source: Clark, P.E., Pashin, J., and six others, 2013, Site Characterization for CO2 Storage from Coal-fired Power Facilities in the Black Warrior Basin of Alabama, Figure 1, Modified from Thomas, 1988

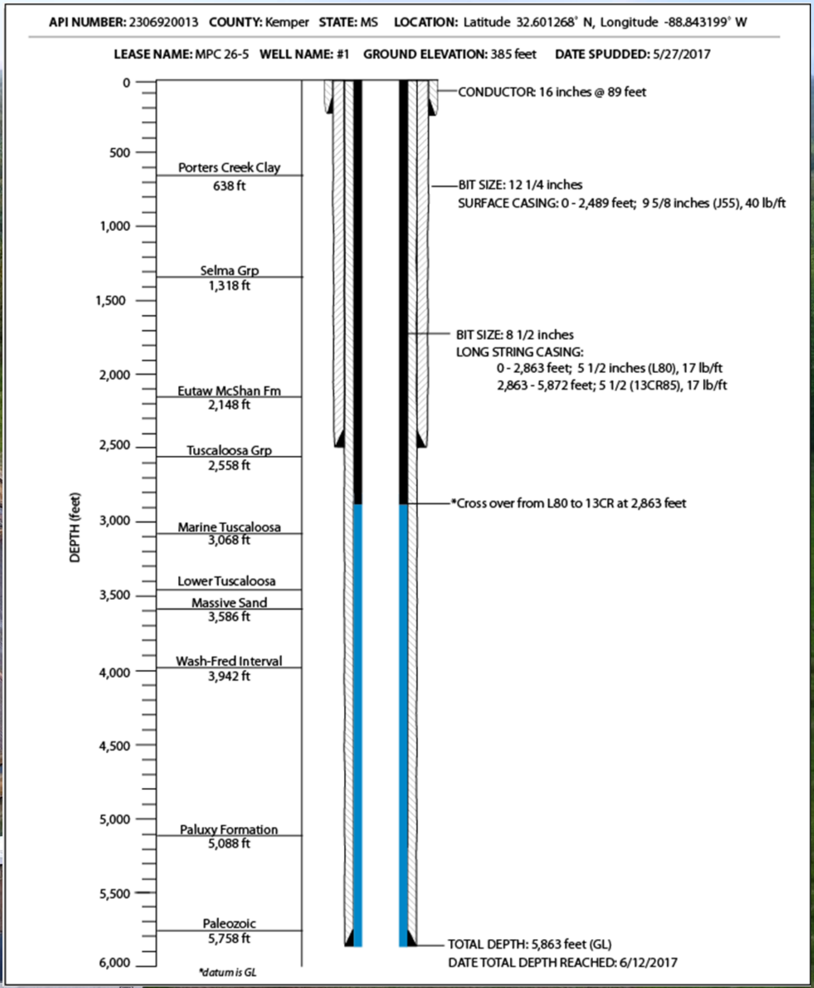
- Kemper Co., MS contains the southern portion of the Black Warrior Basin as well as the junction of the Ouachita Embayment and Appalachian Thrust Belt.
- The county is underlain by a thick section of Mesozoic sediments and a Paleozoic (Pennsylvanian, Mississippian and Devonian) section below a regional unconformity.
- The Cretaceous sediments thicken and deepen to the southwest.

Seismic Reflection Data Interpretation to Support Project ECO_2S



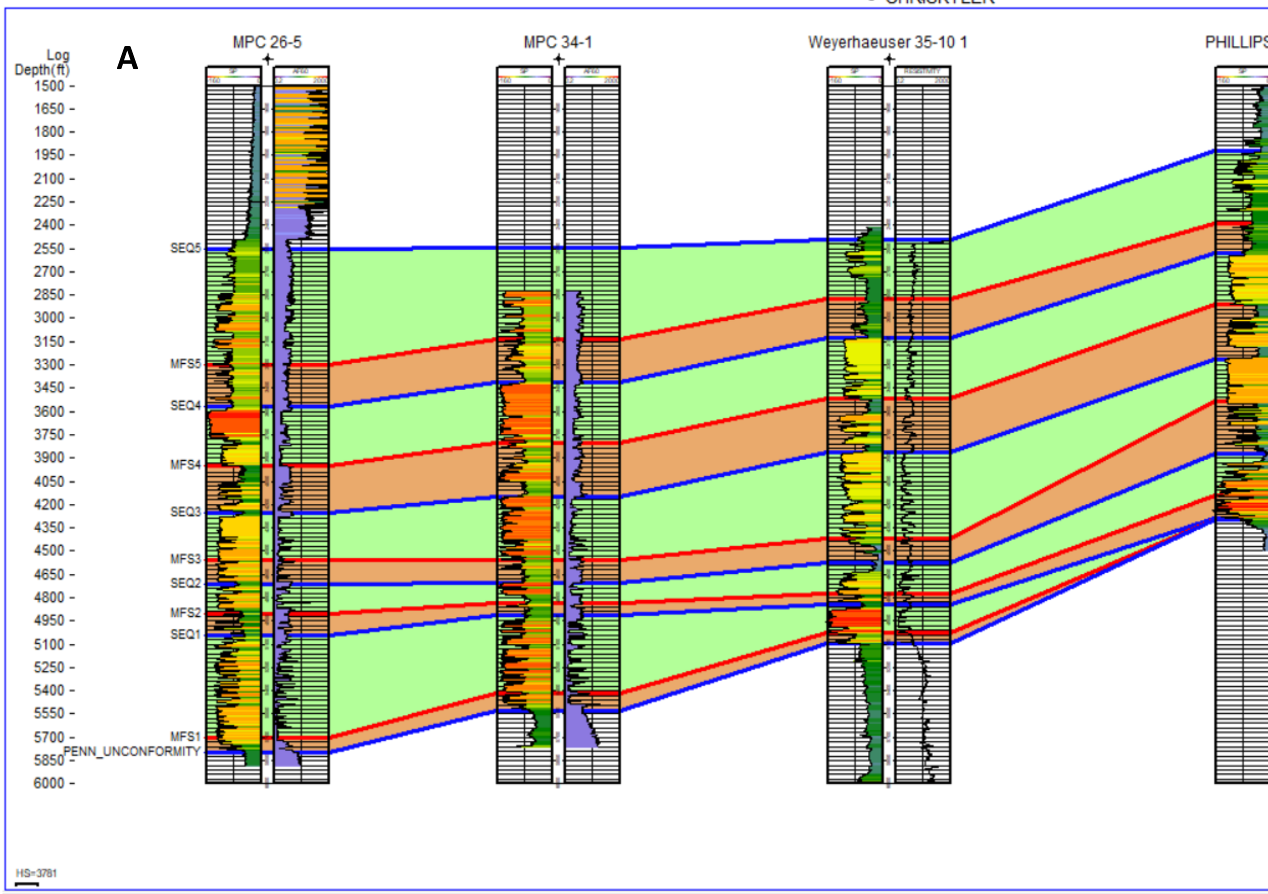
ECO$_2$S Well Drilling

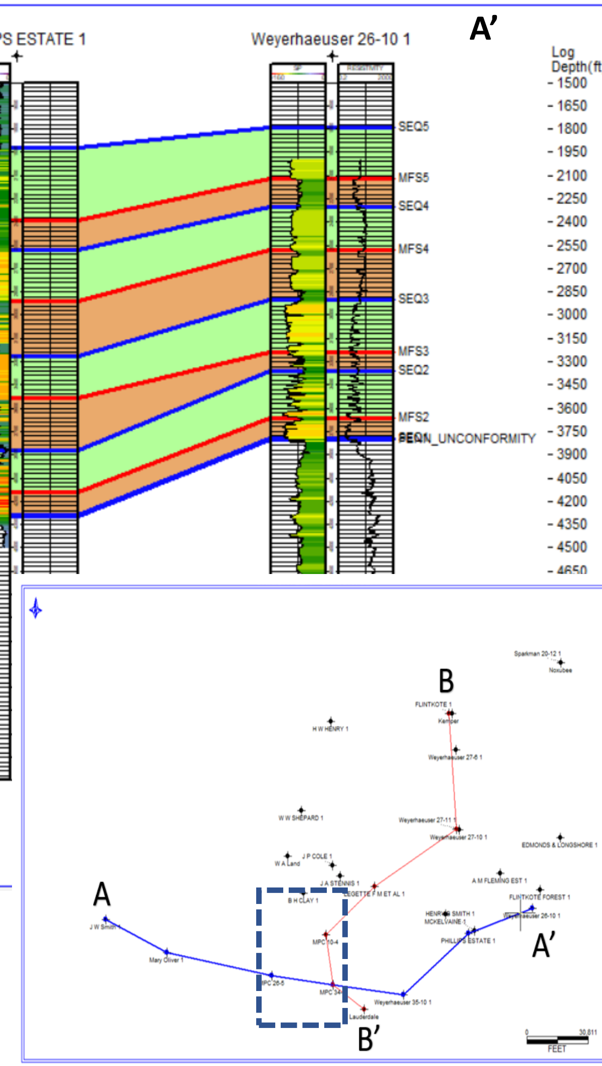
- **MPC 26-5, spud in May 2017**
  - ➢ **17 days from spud to TD including two core points**
- **MPC 34-1, spud in June 2017**
  - ➢ **14 days from spud to TD including two core points**
- **MPC 10-4 , spud in August 2017**
  - ➢ **14 days from spud to TD including two core points**
- **MPC 34-1 cement remediation and well test in April 2018**



Sequence Stratigraphy of Cretaceous Cycles in the Southern Margin of a Paleozoic Foreland Basin, Black Warrior Basin, Mississippi: A Potential Reservoir for Geologic Carbon Storage

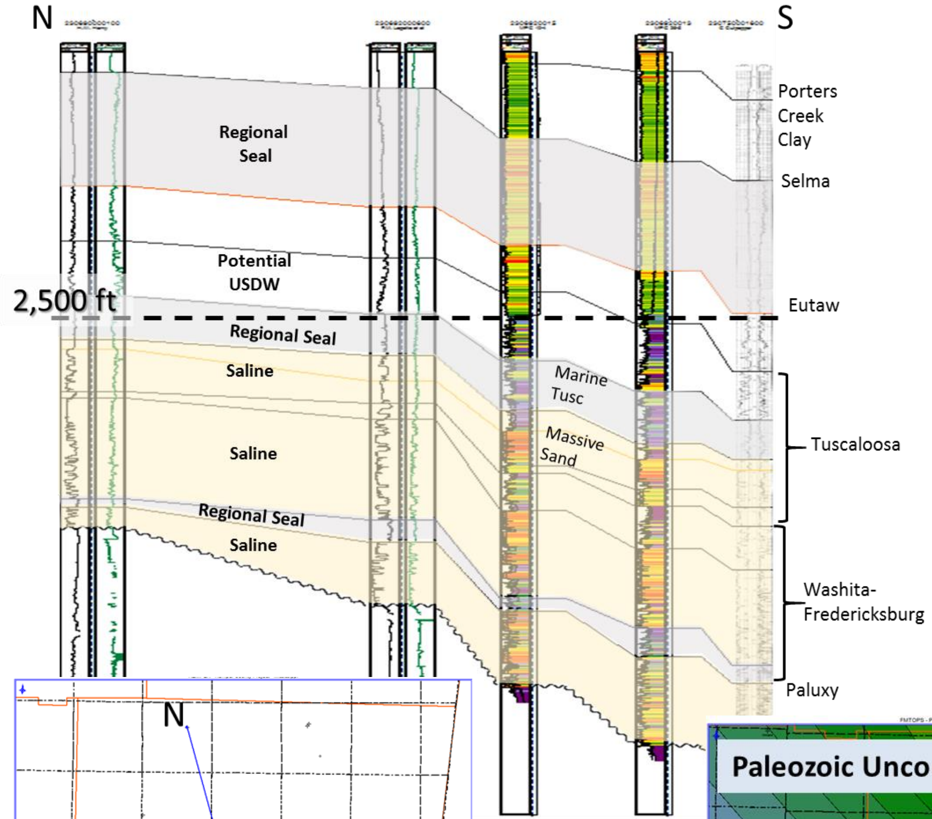
Chronostratigraphic Cross Section

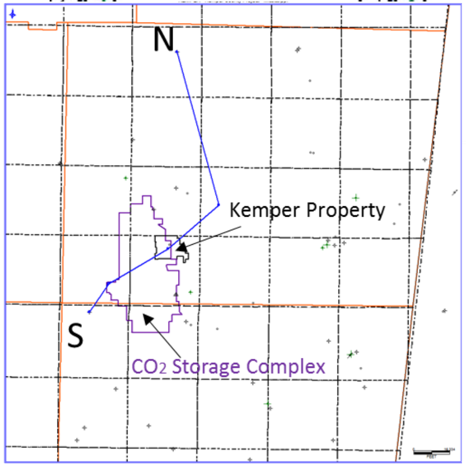




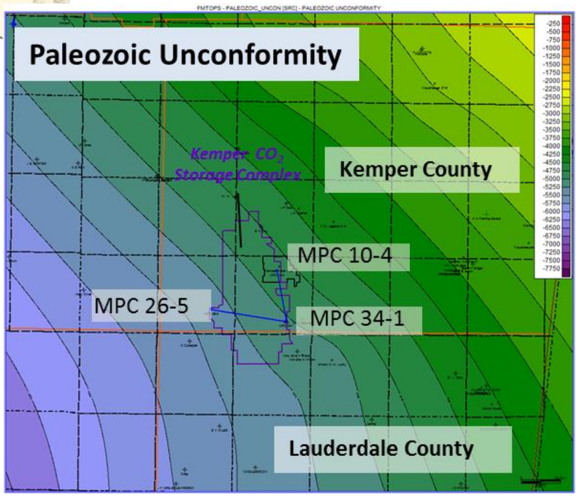
Sequence stratigraphic model supports the lithostratigraphic conclusion that the reservoir and seal units are regionally continuous.

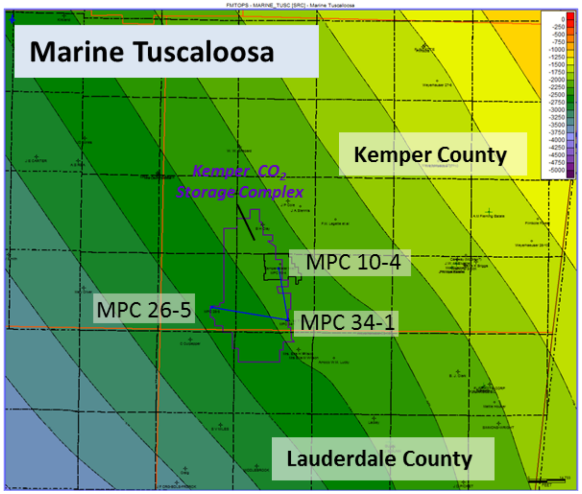
Geologic Structure From Logs





- Predictable Cretaceous-Tertiary structure
- Formations dip (deepen) to the southwest
- Marine Tuscaloosa dips 50 ft/mile
- Sub-Mesozoic unconformity dips 80 ft/mile





Core Acquisition

- Learn all about drilling/preserving poorly consolidated core!
- Constrain model porosity and permeability
- Reservoir and seal petrophysical and petrographic characterization
- Core floods (whole core, micro-fluidics, computer generated)

face discharge, low invasion core bit with a tapered face

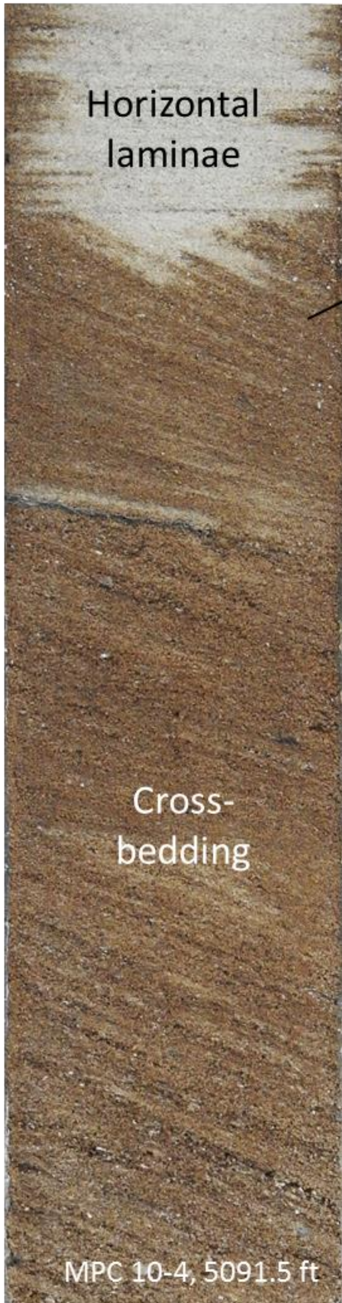
MPC 26-5 Lower Tuscaloosa massive – very poorly indurated sandstone, well caked

MPC 10-4 Epoxy injection for core preservation

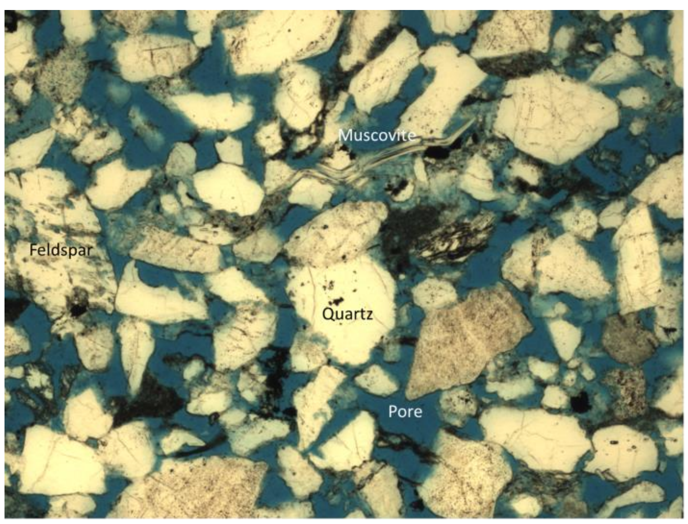
Reservoir

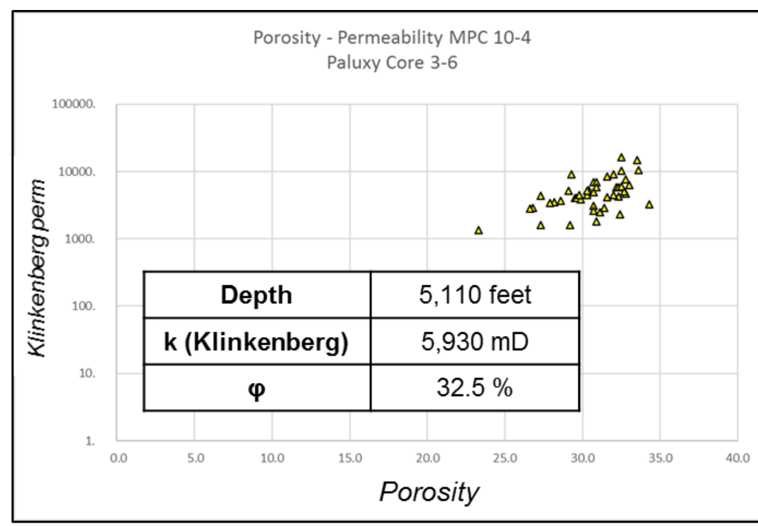
- Abundant stacked saline sandstone bodies in Paluxy, Wash-Fred, and lower Tuscaloosa.
- Over 1,100 ft net sand. Logs and core show sandstone average porosity of 30%(!!)
- Routine core analysis indicates all sandstone water-saturated
- Darcy-class permeability common (up to 16 D!!!)

Paluxy sandstone

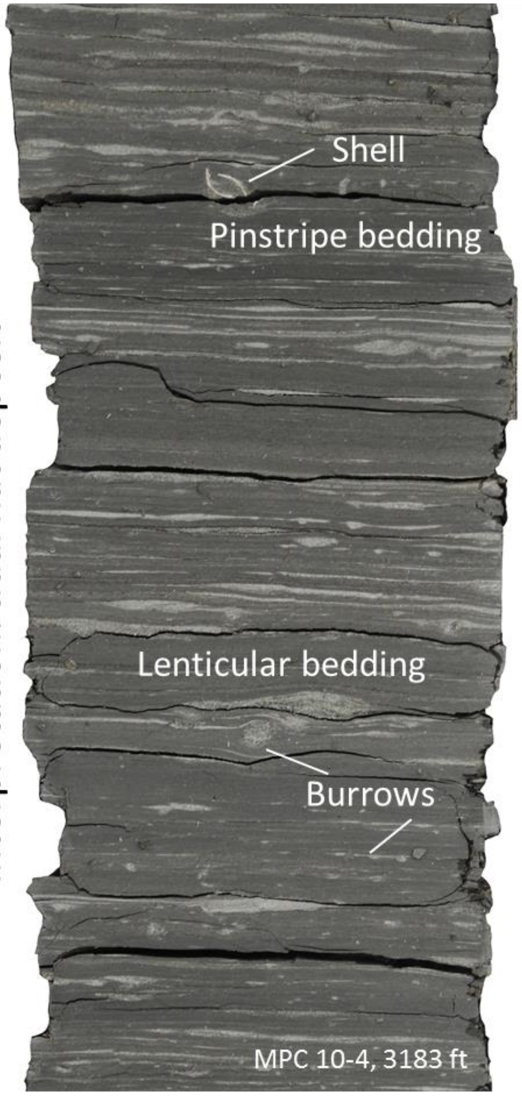


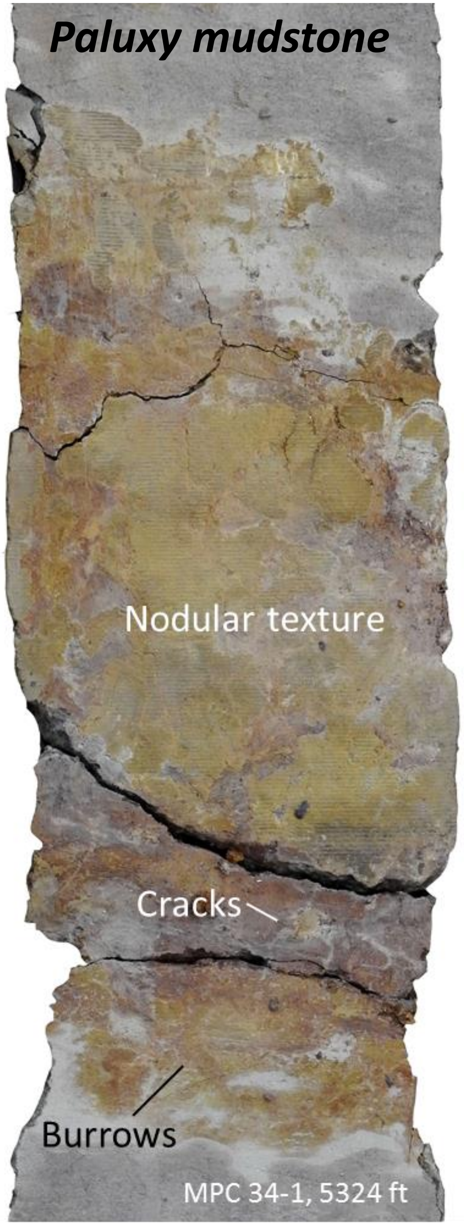
High-porosity sandstone in Paluxy Formation





Caprock Studies



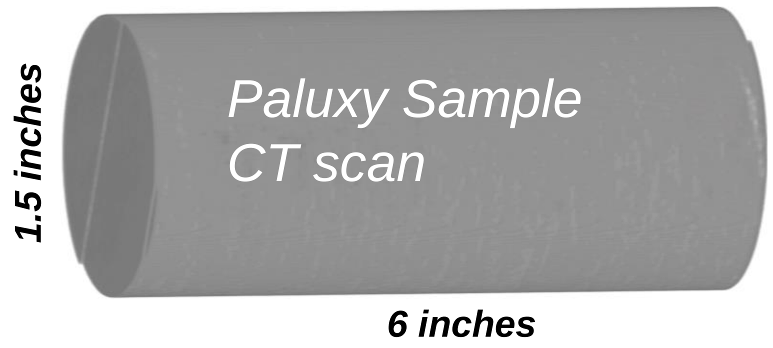


- Environments of deposition
- Mineralogy
- Minimum capillary displacement pressure
- Permeability response to pore and confining pressure
- high fraction of smectititic clay and kaolinite
- Geomechanically, the shale is soft and pliable and thus very difficult to fracture
- *Pressure decay permeametry indicates nanodarcy perm in moist shale*

Univ. Wyoming's High Bay Research Facility

Macro- and Micro-Scale Flow Experiments

- Investigate CO_2 capillary trapping in reservoirs
- Study end-point relative perms for a supercritical CO_2 /brine system
- Study draining-imbibition relative perm curves for a supercritical CO_2 /brine system
- Microfluidics model to test saturation and sweep efficiencies



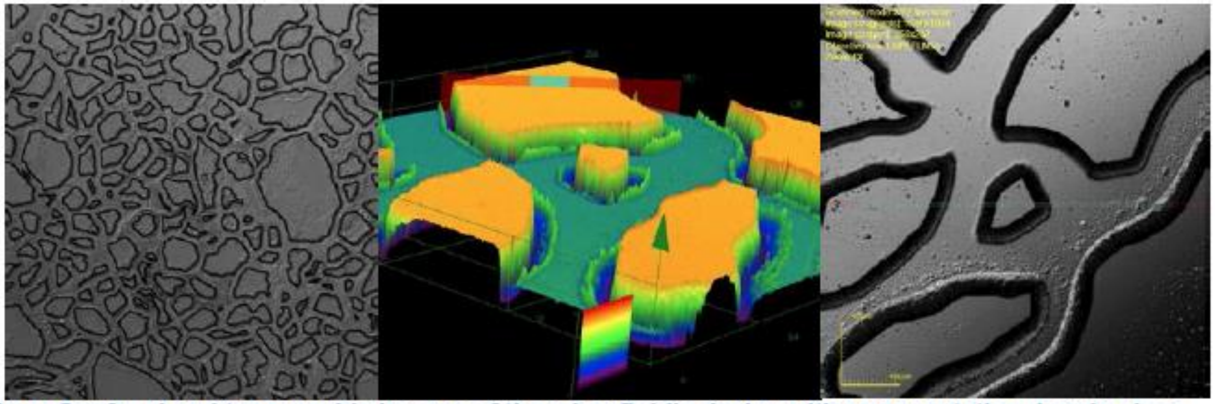
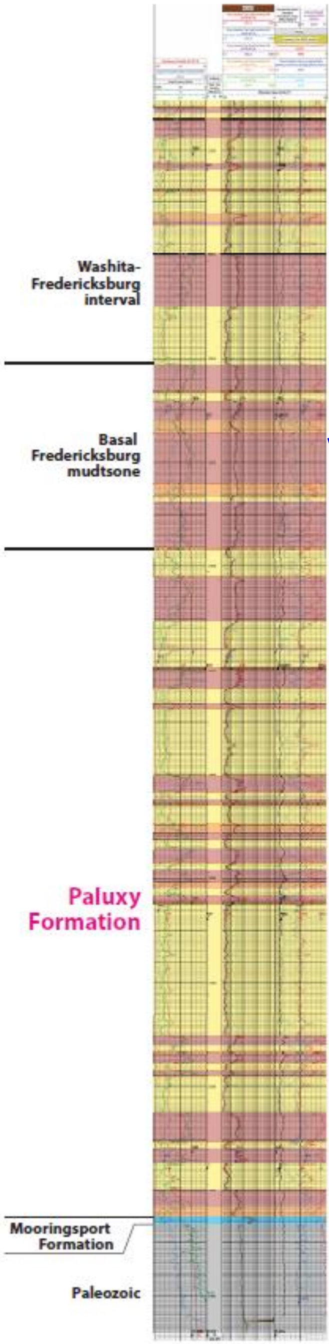


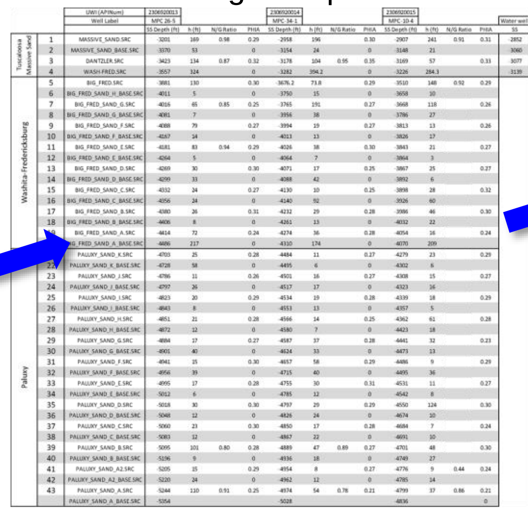
Figure 4a-c: Confocal and topographic images of the microfluidic device with representational grain sizes, distribution, porosity and pore throat distribution.

PIRI TECHNOLOGIES, LLC

Reservoir Simulation

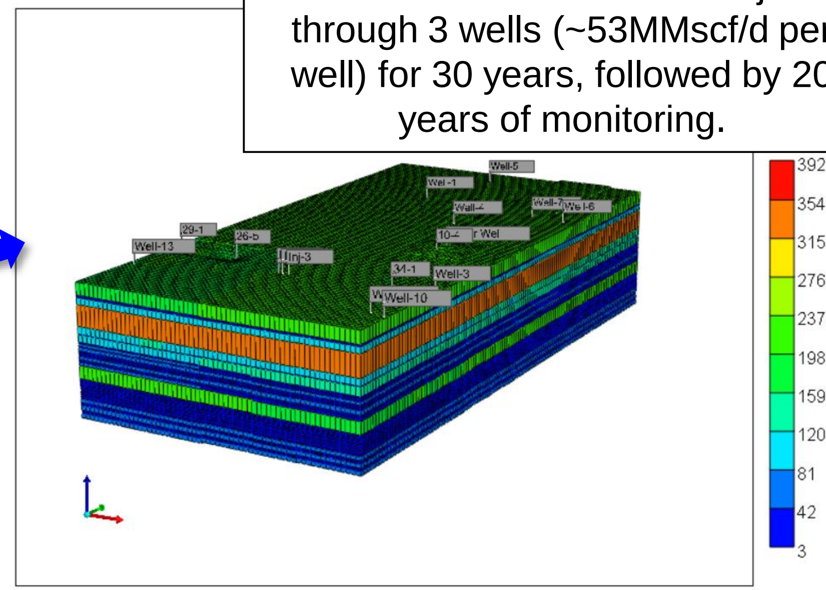


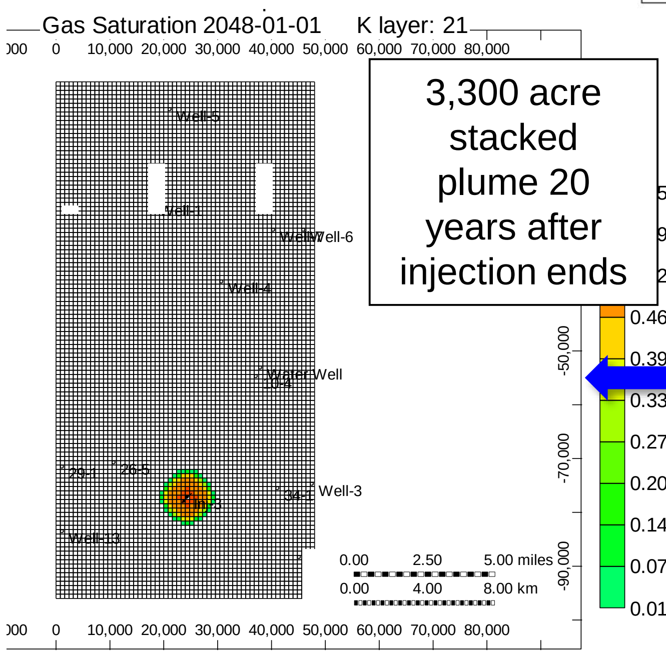
Geologic Properties



Geocellular Model

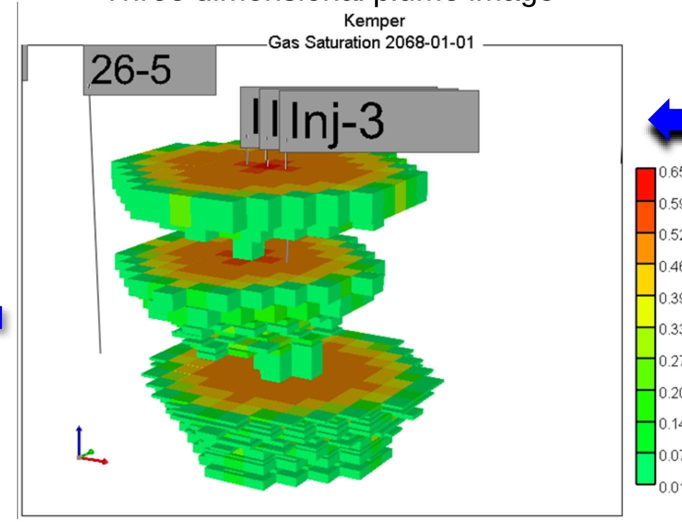
3 MM metric tons of CO_2 is injected through 3 wells (~53MMscf/d per well) for 30 years, followed by 20 years of monitoring.





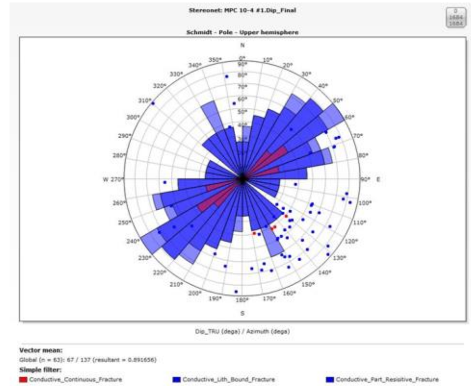
3,300 acre stacked plume 20 years after injection ends

Three dimensional plume image

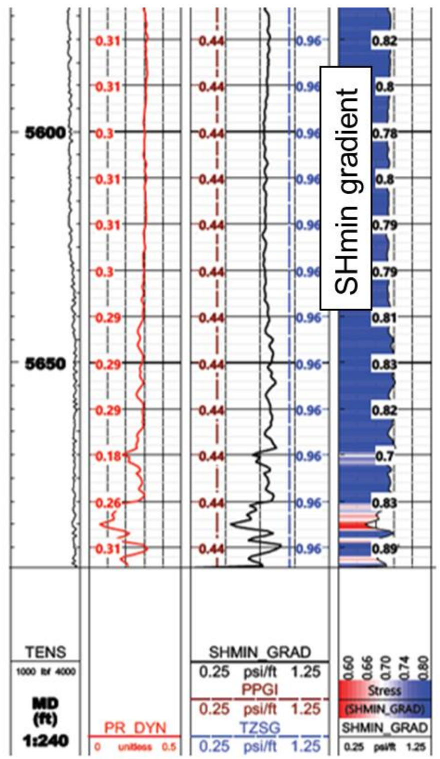


Thermo-Hydro-Mechanical (THM) Modeling

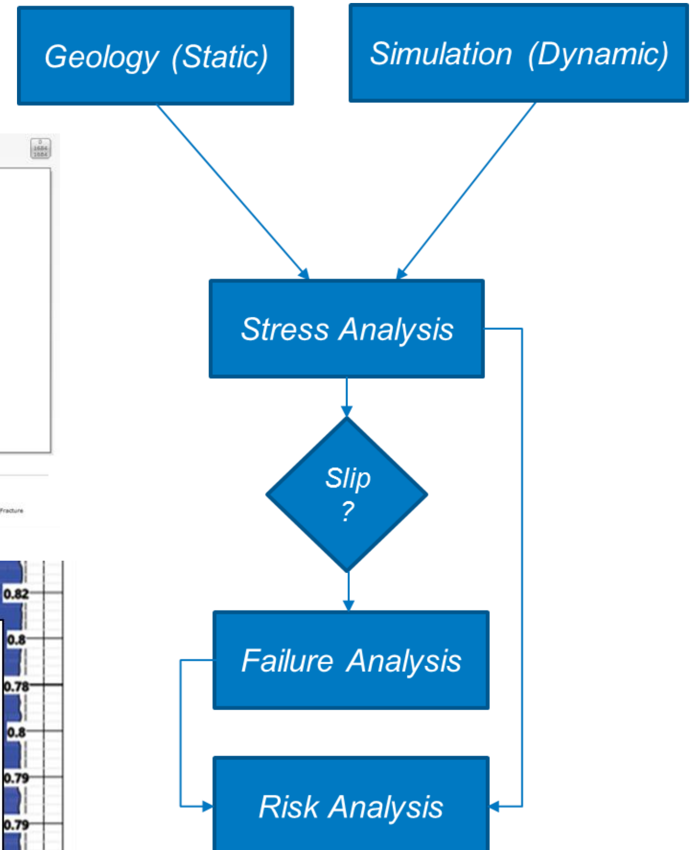
- **Stress Analysis**
  – Under what conditions will failure occur?
  – Test many scenarios – Monte Carlo Analysis
- **Reservoir Simulation**
  – Provides pore pressure / plume extent as a function of time
- **Dynamic failure analysis**
  – If joint slip / fault reactivation occurs, will it be felt?
  – Microseismic response is probably acceptable; large magnitude seismic is unlikely



MPC 10-4 conductive fracture stereonet



MPC 34-1 Geomechanical Properties Interp.

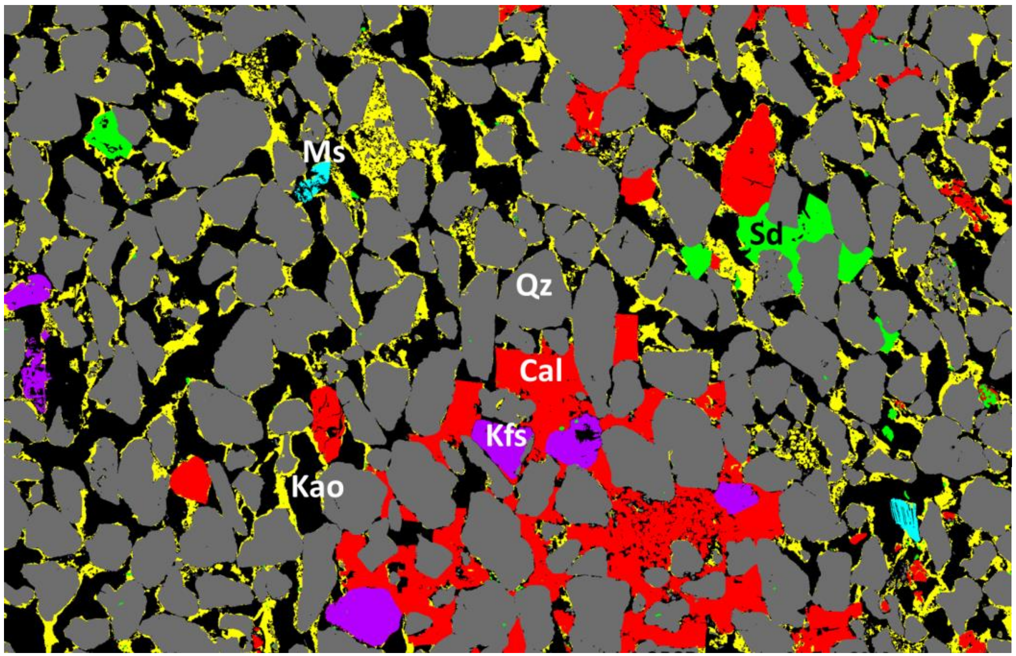


BERKELEY LAB

VIRGINIA TECH

CO_2-brine-mineral reactions in the Paluxy Formation

CO_2-brine-mineral reactions in the Paluxy formation



Porosity: 0.2732
Reactive mineral: 19.23 v%

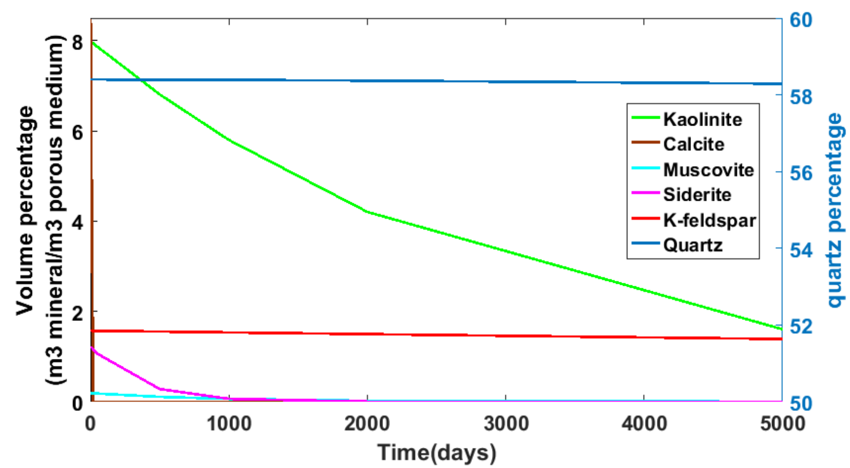
Assume all reactive minerals dissolve:
Porosity increases: 0.27 to 0.36
Permeability increases: ~2.3×10^{-12} m^2 to ~5.1×10^{-12} m^2

Mineral abundance and accessibility

Mineral distribution from SEM analyses and mineral reaction rates at 33 °C.

Mineral	Volume percentage (%)	Accessible percentage (%)	Log K ($mol \cdot m^2 \cdot s^{-1}$)
Quartz[3]	74.57	34.92	-12.03
K-feldspar[2]	2.01	1.65	-11.66
Kaolinite[7]	10.14	51.07	-12.50
Calcite[1]	11.47	10.01	-3.901
Muscovite[9]	0.24	1.00	-12.194
Siderite[8]	1.57	1.34	-9.97

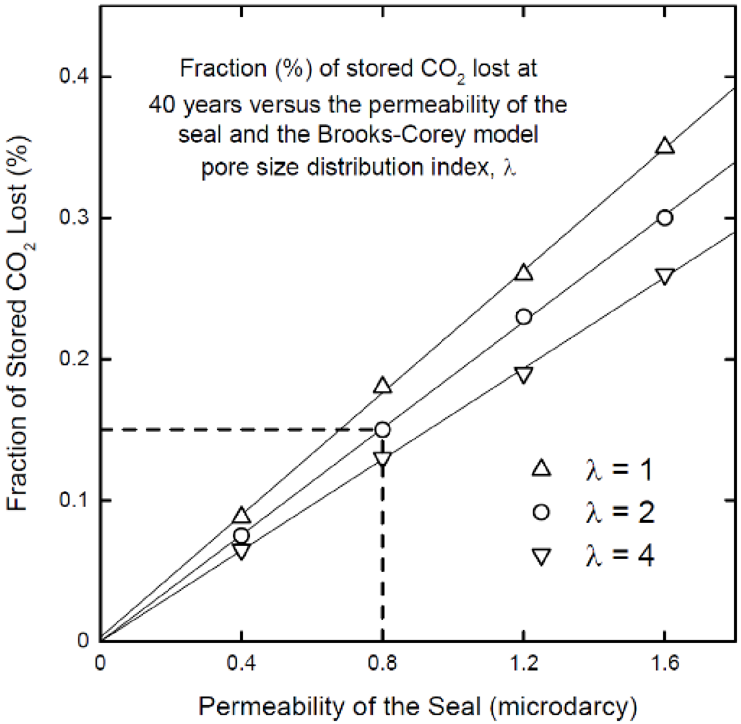
Simulated evolution of mineralogy



Testing NRAP Tools

Seal Leakage

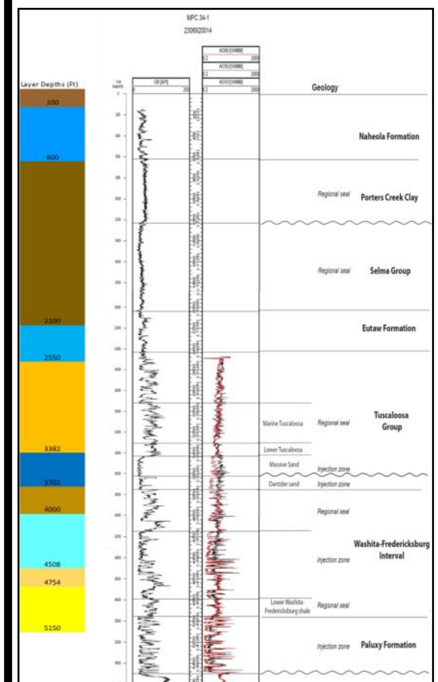
NSealR Tool

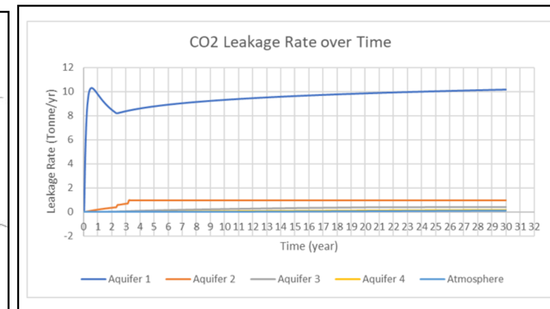


Thickness of seals limits vertical migration and leakage

Wellbore Leakage

WLAT Multi-Segmented Wellbore





Cement Perm. (md)	Total CO_2 Leakage (tonne)	% leakage of total CO_2 injection
0.01	4	0.0001%
1	420	0.015%
10	4,530	0.16%

Multiple shale intervals and thief zones mitigate CO_2 migration along a leaky cement annulus

Project ECO_2S Risk Assessment

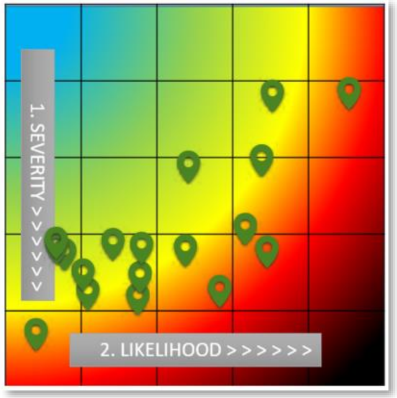
What's at risk? PROJECT VALUES

Overarching Objective	**Store commercial volumes of CO_2 safely, permanently, and economically within a regionally significant saline reservoir system**
Specific Goals & Objectives	Drill, core, and log 3 new wells
	Refine knowledge of reservoir properties
	Build geological numerical model
	Model CO_2 injection to identify physical risks
	Develop site-specific monitoring plans
	Identify contractual and regulatory pathways toward development
	Comprehensively identify and manage risks to project success
Preclusions & Avoidances	Injuries to staff or public
	Environmental damage
	Reputation damage
	Noncompliance and illegality
	Public anger, rejection, negative opinion about CCS

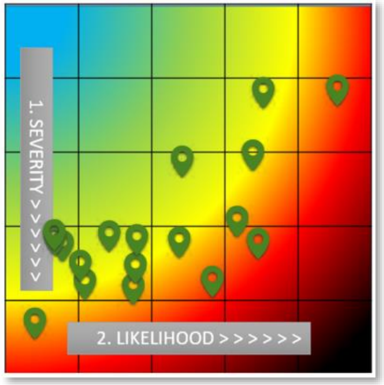
How to quantify? SEVERITY and LIKELIHOOD SCALES

LIKELIHOOD of Impact or Failure Occurring (L)				
1	**2**	**3**	**4**	**5**
Very Unlikely	**Unlikely**	**50/50**	**Likely**	**Very Likely**
In 50 ECO_2S-like commercial projects, might happen once.	Probably won't happen during this project. In ten such projects, once per decade.		Probably would occur during the pilot or commercial-scale ECO_2S Project. Once per several years.	Nearly sure to occur during the pilot or commercial-scale ECO_2S Project. Could happen yearly.

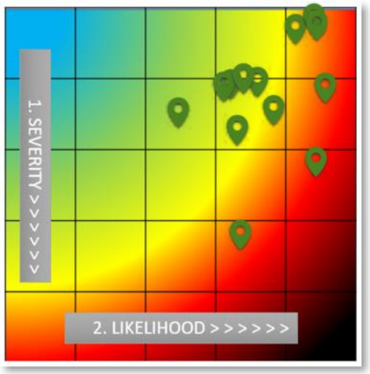
Sample scenarios evaluated "live" during workshop



Pore space rights are insufficient for the project



Insufficient CO_2 supply commitments to support regional storage hub



Plume geometry differs from baseline models

GHG Underground

102 ECO$_2$S Scenarios ranked by risk, sorted by topic group

G01	7.33
G03	6.62
G02	6.52
G15	6.49
G14	6.38
G09	6.32
G06	6.28
G12	6.00
G05	5.53
G04	5.16
G11	5.16
G13	4.90
G07	4.33
G10	4.31
G08	3.85

G: Geo-logy, -physics, -mechanics, -chemistry

M20	7.56
M11	7.13
M15	7.04
M19	6.65
M07	6.44
M02	6.38
M10	6.33
M12	6.04
M03	6.02
M14	5.96
M13	5.92
M06	5.83
M09	5.74
M17	5.67
M18	5.56
M08	5.45
M16	5.12
M05	4.25
M01	4.20
M04	3.95

M: Monitor-Model

O15	10.90
O14	8.88
O10	8.48
O21	8.16
O17	7.30
O01	7.21
O24	7.21
O13	7.03
O03	6.85
O23	6.34
O09	6.22
O08	6.21
O19	6.05
O16	5.77
O02	5.72
O18	5.62
O22	5.44
O07	5.31
O04	5.28
O20	5.07
O05	4.80
O06	4.56
O11	4.14
O12	3.64

O: Operations

P01	12.17
P09	12.16
P18	11.48
P13	10.10
P12	10.06
P04	9.92
P14	9.43
P15	9.43
P11	9.09
P07	8.17
P19	7.74
P03	7.16
P10	5.98
P06	5.86
P08	5.66
P16	5.53
P02	4.77
P05	4.16
P17	3.27

P: Project and Program Management

U03	11.13
U11	8.75
U16	8.30
U21	7.40
U18	7.28
U08	6.96
U13	6.92
U19	6.79
U15	6.65
U22	6.41
U06	6.33
U04	6.31
U17	6.14
U01	6.03
U02	5.93
U07	5.87
U09	5.79
U10	5.69
U05	5.57
U14	5.29
U20	4.97
U23	4.88
U12	4.29
U24	3.15

U: Publics

GHG Underground

Highest-risk ECO$_2$S Scenarios

Risk	Rank by Risk (all)	Risk Scenario
12.2	1	Changes in the operational status or commercial viability of CO_2 source plant prevent meeting project objectives.
12.2	2	Kemper energy facility does not become a source of CO_2.
11.5	3	Insufficient CO_2 supply commitments to support regional storage hub.
11.1	4	Changes in U.S. government personnel or policies result in removal of government support of the CarbonSAFE program.
10.9	5	Operational problems at CO_2 source plant prevent delivering the CO_2 needed to show commercial-scale geological storage.

GHG Underground

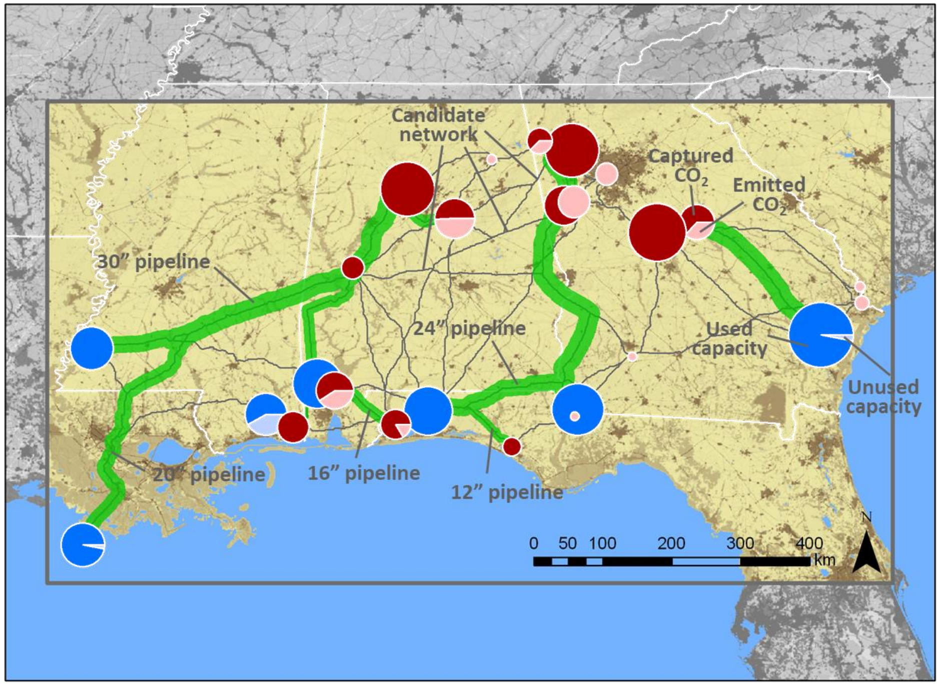
SimCCS: Integrated CCS Decision Making

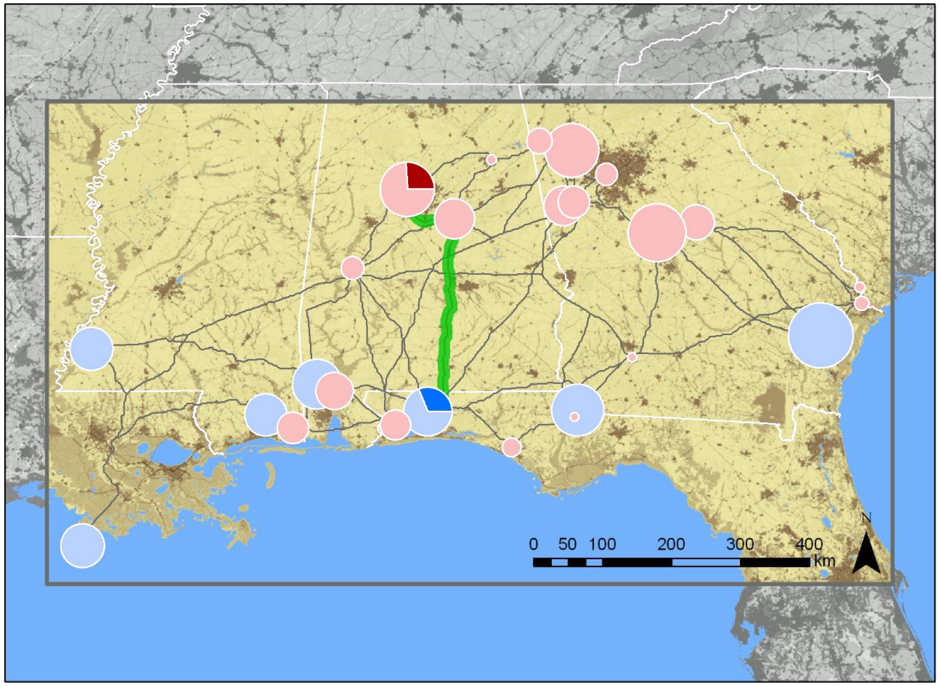
SimCCS (*Scalable infrastructure model for CCS*)

- Economic-engineering model for optimizing CCS infrastructure design.

SimCCS[2.0] †

- Ground-up redesign—enabled by CarbonSAFE—into a Java-based package with HPC.
- Open-source: can be utilized by any DOE project (and beyond).
- Preparing for 2019 R&D 100 Award entry, southeast CCS study part of package.





†Middleton *et al.* (2018). An open-source tool for optimizing CO_2 capture, transport, and storage infrastructure, *Environmental Modelling and Software*, In Review

Value of CarbonSAFE Program to The Kemper County Energy Facility

- Low-cost storage options occur beneath the energy facility
  - $2.00 - $4.00 per metric ton depending on the volume of CO_2 captured
- This drives the value proposition where existing infrastructure could be utilized for CO_2 capture, compression, transportation and storage
- Given the expanded 45Q tax credit for CO_2 storage, having geologic storage data and cost estimates drives ongoing:
  - Refining cost and performance data with technology vendors
  - Applying data to internal resource planning and modeling
  - Improving internal transportation, storage and monitoring cost information
- The project has reduced commercial-scale development risks associated with large storage capital expenses such as well drilling and injection facilities

Southern Company

Other Ongoing ECO_2S Work

- Risk treatment/mitigation strategies
- Monitoring strategies
- Technical outreach
- Commercialization plan
- Assess ECO_2S against ISO Geological Storage Standard (ISO /27914)

2018 AAPG Annual Meeting
ECO_2S Poster Session

Theme 8: Kemper, Mississippi CO_2 Sequestration Site (DEG)

Exhibit Hall | 9:00 a.m. - 2:00 p.m.
Co-Chairs: D. Riestenberg, G. Koperna

The Paluxy Formation in the East-Central Gulf of Mexico Basin: Geology of an Ultra-Giant Anthropogenic CO_2 Sink ...
J. C. Pashin, M. Achang, A. Chandra, A. Folaranmi, S. Martin, J. Meng, S. Urban, C. Wethington, D. E. Riestenberg, G. Koperna, M. Redden-McIntyre, D. J. Hills, R. Esposito

Advanced Reservoir and Seal Characterization at the Kemper Storage Site ...
J. F. McLaughlin, P. Walsh, E. Lowery, S. Saraji, M. Akbarabadi, M. Piri

Evaluation of Potential Geochemical Reactions and Changes in Hydrologic Properties at the Kemper County CO_2 Storage Complex ...
L. E. Beckingham, F. Qin, I. Anjikar, B. L. Kirkland, S. Cyphers

Investigation of Reactions Between Glauconite and Carbon Dioxide, With Implications for Carbon Sequestration ...
A. V. Nguyen, R. Gabitov, L. Beckingham, T. Hossein, F. Yu, B. Kirkland

Seismic Reflection Data Interpretation to Support Project ECO_2S, Kemper County, MS ...
D. J. Hills, J. W. Koster, J. C. Pashin

Lessons Learned From Recent CCS Well Construction Projects ...
A. Duguid, J. Kirksey*, G. Koperna, D. E. Riestenberg

Project ECO_2S: Commercial Scale Risk Management for CO_2 Storage ...
K. Hnottavange-Telleen, J. MacGregor, D. E. Riestenberg, D. J. Hills

Sequence Stratigraphy of Cretaceous Cycles in the Southern Margin of the Black Warrior Basin, Mississippi: A Potential Reservoir for Geologic Carbon Sequestration ...
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