Role of CO_2 Storage in CCUS Business Models

Prepared for:
2019 Baltic Carbon Forum (BCF)

Session 5: Building a Business Case for CCUS

Presented by:
Vello A. Kuuskraa, President
Advanced Resources International, Inc.
Arlington, Virginia USA

Tallinn, Estonia
22-23 October

Advanced Resources International, Inc.

Advanced Resources International

Our history of services:

Since 1971*, we have added value to hundreds of oil and gas E&P projects in the U.S. and in over 30 countries, from Australia to Zimbabwe.

Our approach integrates geology and geophysics, petroleum engineering, and strategic and economic analysis.

We specialize in enhanced oil and gas recovery and the geological storage of CO_2.

*From 1971 – 1987, the company was called Lewin & Associates; from 1987 – 1991, the company was a subsidiary of ICF Consulting/Kaiser Engineers; since 1991, the company is stand alone and called Advanced Resources International, Inc.

Our clients include:

Key Management and Staff

Mr. Vello A. Kuuskraa
President

- 40 years of experience in oil and gas particularly in enhanced oil recovery.
- SPE Distinguished Lecturer on Integrating CO_2-EOR and CO_2 storage.
- Major oil background (Chevron)
- B.S., North Carolina State Univ; MBA, Wharton Graduate Business School.
- Member of two Advisory Boards to the U.S. Secretary of Energy -- National Petroleum Council and National Coal Council. Board Member of the University of Wyoming's School of Energy Resources.

Mr. George J. Koperna, Jr.
Vice President

- 20 years of experience in oil, gas and CO_2 sequestration.
- Specialties include enhanced oil recovery, advanced production analysis and CO_2 storage project design and implementation.
- Leader of ARI's reservoir simulation team.
- Convener of Working Group in ISO TC-265 on CO_2-EOR.
- B.S. and M.S., Petroleum and Natural Gas Engineering, West Virginia University.
- SPE International (SPEI), Board of Directors.

CCUS Business Models

Three CCUS business models are available to electricity companies and other industrial entities:

- **Integrated Business Model.** "Doing it all by yourself."
- **Third Party Business Model.** "Let someone else do it."
- **Joint Venture Business Model.** "Let's do it together," particularly with a CO_2 EOR operator.

Look for Esposito, R., Kuuskraa, V., Rossman, C., and Corser, M., *Reconsidering CCUS in the Electricity Industry Under Section 45Q Tax Credits*, available from Greenhouse Gases: Science and Technology, Wiley Publications.

PetraNova: Joint Venture Business Model for CCUS

The PetraNova JV (NRG and JX) has installed post-combustion CO_2 capture on a 240 MW coal-fired unit at WA Parish power plant.

Approximately 75 MMcfd of captured CO_2 is transported and used for EOR at Hilcorp's West Ranch oil field with an oil production goal of 15,000 B/D.

Source: NRG, 2017

Advanced Resources International, Inc.

Assessing the Business Models

Identifying the most advantageous CCUS business model requires information on three key topics.

- **Cost of CO_2 Capture.** Examining cost reduction insights from installation of CO_2 capture at Sask Power's Boundary Dam and NRG's Parrish Station.
- **Cost of CO_2 Storage.** Recognizing that a high-quality storage complex located close to a power plant provides considerable value.
- **Value of CO_2 for EOR.** Incorporating key variables (e.g., price of oil, costs of transportation, quality of the EOR project, etc.) into the value proposition for CO_2 supplies.

SECARB's Anthropogenic Test Site R&D Project

Injection/Storage Site Geology

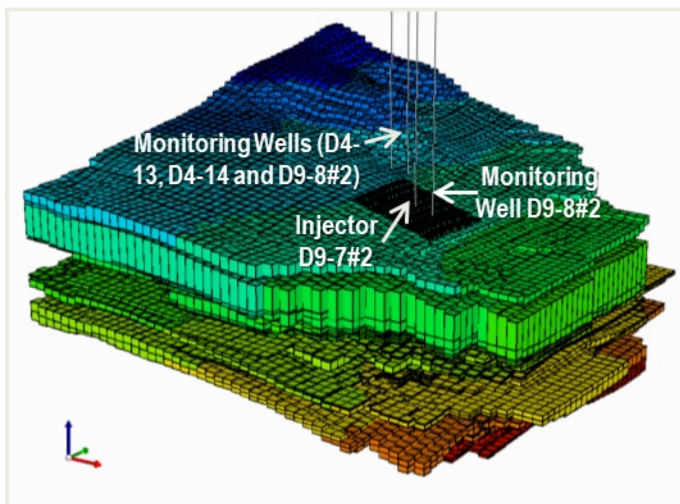
System	Series	Stratigraphic Unit	Major Sub Units	Potential Reservoirs and Confining Zones
Tertiary	Plio-Pliocene		Citronelle Formation	Freshwater Aquifer
	Miocene	Undifferentiated		Freshwater Aquifer
	Oligocene		Chickasawhay Fm.	Base of USDW
		Vicksburg Group	Bucatunna Clay	Local Confining Unit
	Eocene	Jackson Group		Minor Saline Reservoir
		Claiborne Group	Talahatta Fm.	Saline Reservoir
		Wilcox Group	Hatchetigbee Sand Bashi Marl Salt Mountain LS	Saline Reservoir
	Paleocene	Midway Group	Porters Creek Clay	Confining Unit
Cretaceous	Upper	Selma Group		Confining Unit
		Eutaw Formation		Minor Saline Reservoir
		Tuscaloosa Group	Upper Tusc.	Minor Saline Reservoir
			Mid. Tusc.: Marine Shale	Confining Unit
			Lower Tusc.: Pilot Sand Massive sand	Saline Reservoir
	Lower	Washita-Fredericksburg	Dantzler sand	Saline Reservoir
			Basal Shale	Primary Confining Unit
		Paluxy Formation	'Upper' 'Middle' 'Lower'	Injection Zone
		Mooringsport Formation		Confining Unit
		Ferry Lake Anhydrite		Confining Unit
		Donovan Sand	Rodessa Fm. Upper'	Oil Reservoir
			'Middle'	Minor Saline Reservoir
			'Lower'	Oil Reservoir

Advanced Resources was the lead technical and engineering contractor for SECARB's Anthropogenic Test Site R&D project, a U.S. DOE supported demonstration of the deployment of carbon capture, storage and monitoring technology.

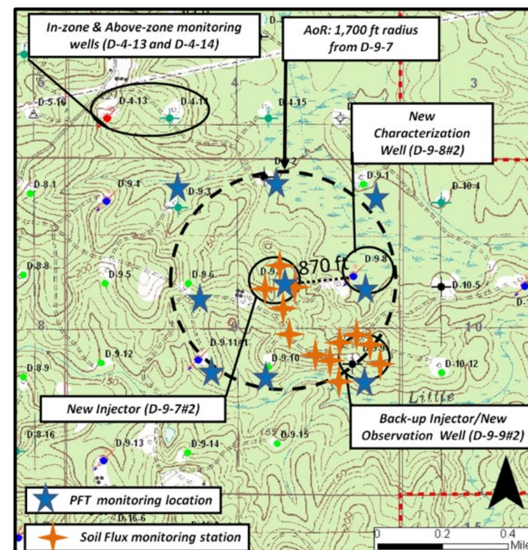
Permitting

- National Environmental Protection Act (NEPA)
- Alabama Historical Commission
- U.S. Fish and Wildlife
- U.S. Army Corps of Engineers
- Alabama Department of Environmental Management (ADEM)

Reservoir Modeling



CO_2 Monitoring, Verification and Accounting



Advanced Resources International, Inc. | U.S. Department of Energy | Southern States Energy Board | NETL | EPRI Electric Power Research Institute | Southern Company | SECARB Southeast Regional Carbon Sequestration Partnership | Denbury

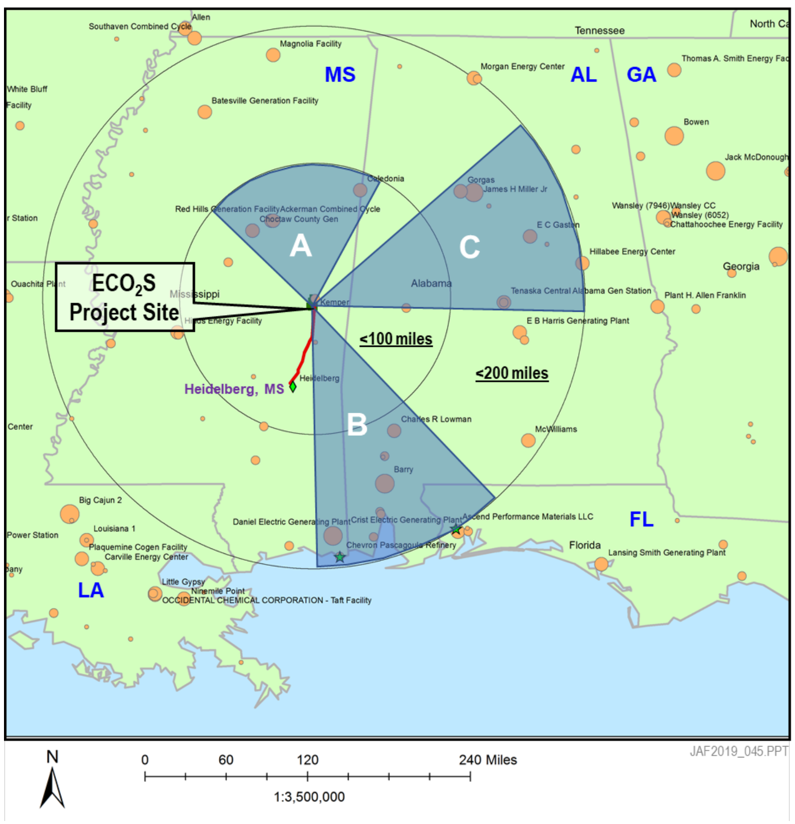
Project ECO$_2$S Storage Feasibility Study

- Southern Company and Mississippi Power are examining establishing a regional CO_2 storage center in Kemper County, east-central Mississippi.
- CO_2 injection into three deep saline formations - - the Paluxy, the Washita-Fredericksburg and the Massive/Danzler, and operating and monitoring this facility until post-injection site closure.
- Constructed in compliance with existing U.S. underground injection control (UIC) Class VI regs and EPA's MRV plan and reporting requirements.

Southern Company Mississippi Power Advanced Resources International, Inc.

Pipeline Corridors and Source of CO_2 Linked to the ECO$_2$S Project Site

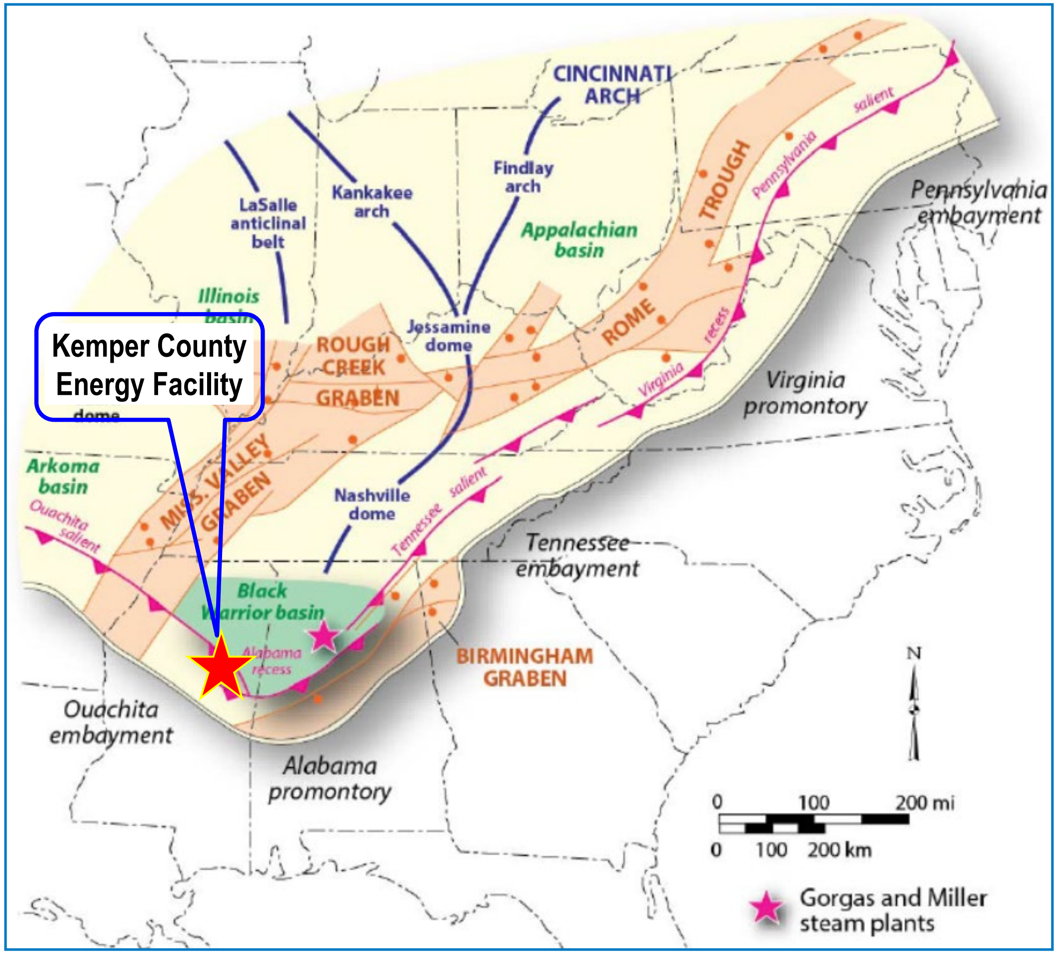
The three CO_2 pipeline corridors linked to the ECO$_2$S regional storage complex contain a series of large power and industrial facilities with 60 MMmt of annual CO_2 emissions.



- **Pipeline "Corridor A":** Three major facilities with annual CO_2 emissions of 6 million metric tons; 70-mile, 22-inch (diameter) CO_2 trunkline costing \$100 to \$200 MM, depending on terrain.
- **Pipeline "Corridor B":** Eleven major facilities with annual CO_2 emissions of 23 million metric tons; 150-mile, 24-inch (diameter) CO_2 trunkline costing \$500 MM, plus 200-mile, 28-inch (diameter) CO_2 trunkline costing \$800 MM.
- **Pipeline "Corridor C":** Numerous major facilities with annual CO_2 emissions of 31 million metric tons; 150-mile, 54-inch (diameter) CO_2 trunkline costing \$350 to \$750 MM, depending on terrain, plus a series of shorter distance, smaller volume laterals.

Advanced Resources International, Inc.

Kemper County, Mississippi Regional Structural Setting

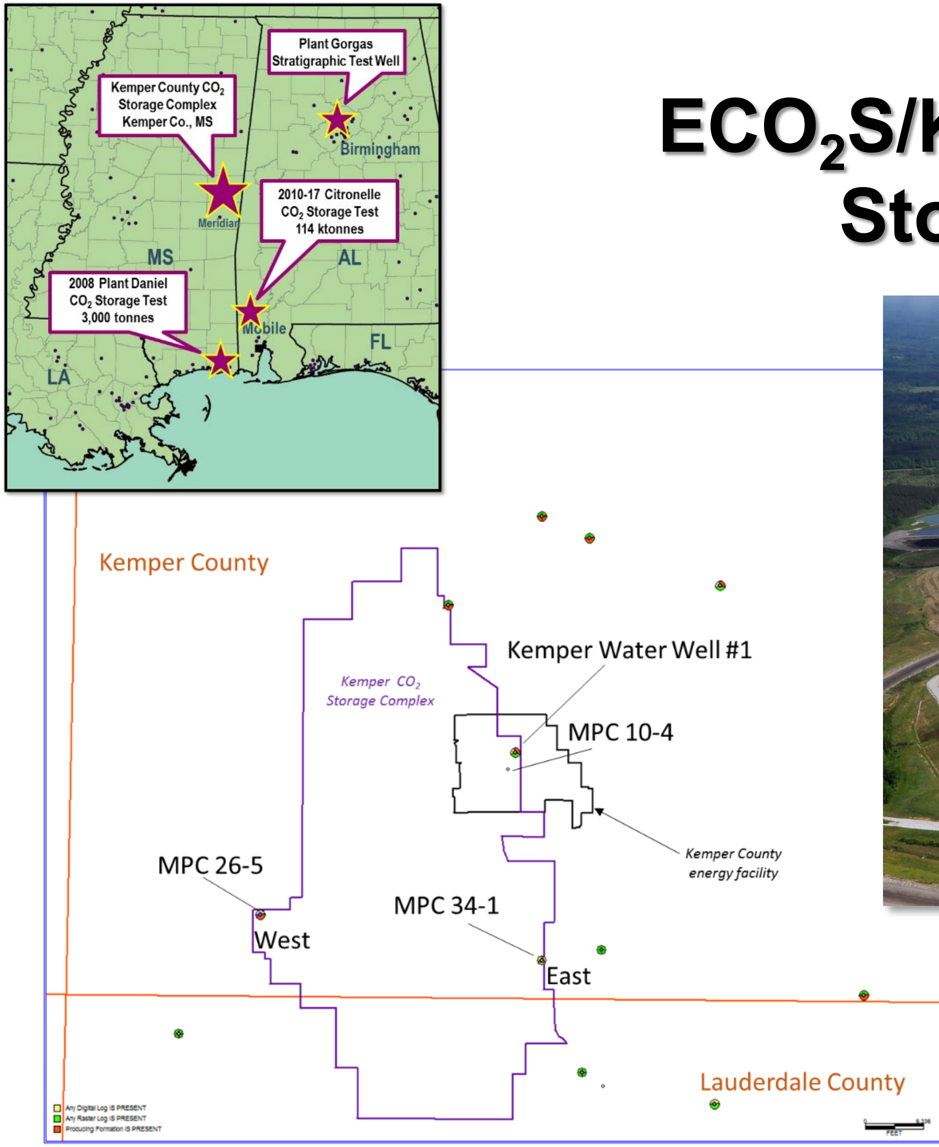


- Kemper Co., MS contains the southern portion of the Black Warrior Basin as well as the junction of the Ouachita Embayment and Appalachian Thrust Belt.
- The county is underlain by a thick section of Mesozoic sediments and a Paleozoic (Pennsylvanian, Mississippian and Devonian) section below a regional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

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

Advanced Resources International, Inc.

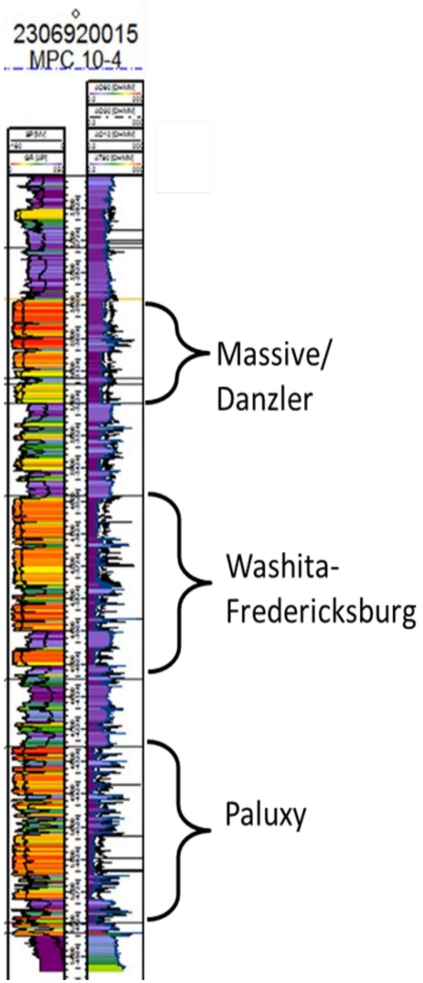
ECO$_2$S/Kemper County CO_2 Storage Complex



The project team has established a CO_2 storage area exceeding 30,000 acres near the Kemper County Energy Facility.

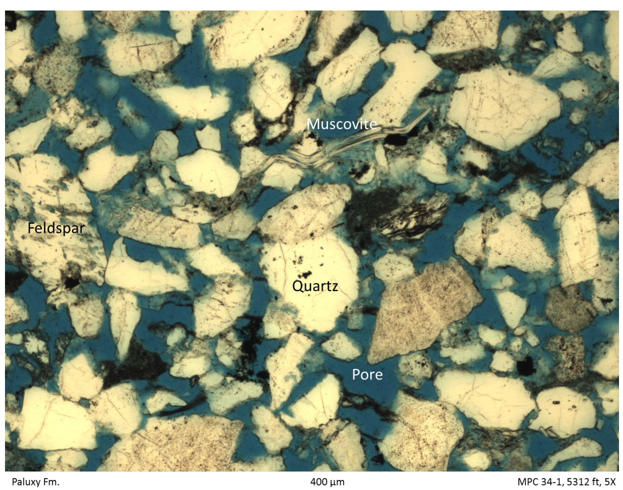
The goal of this project phase is to demonstrate that the subsurface at the ECO$_2$S/Kemper County CO_2 storage complex can <u>store commercial volumes of CO_2 safely and permanently</u> within the saline reservoir system.

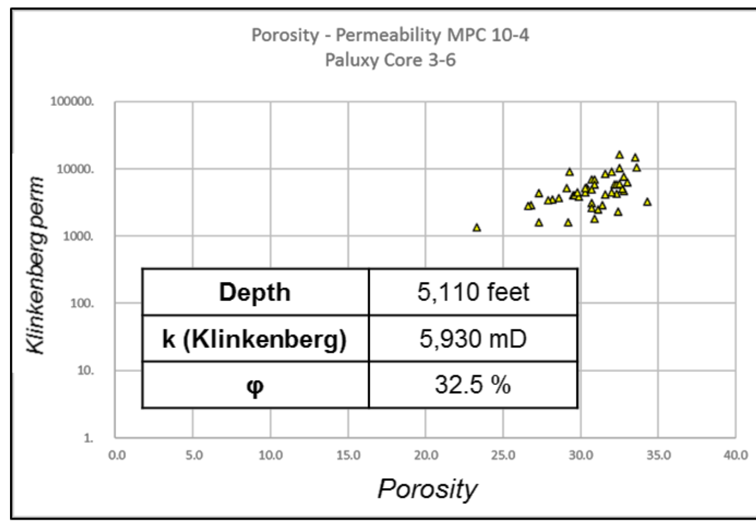
Project ECO$_2$S Storage Reservoirs



- Abundant stacked saline sandstone bodies in Paluxy, Wash-Fred, and lower Tuscaloosa at depths of 1,160m to 1,650m (3,800 ft to 5,000 ft).
- Over 375m (1,240 ft) of net sand, average porosity of 26 to 28% and Darcy-class permeability.
- At least 30,000 acres available for storage.

High-porosity sandstone in Paluxy Formation





Depth	5,110 feet
k (Klinkenberg)	5,930 mD
φ	32.5 %

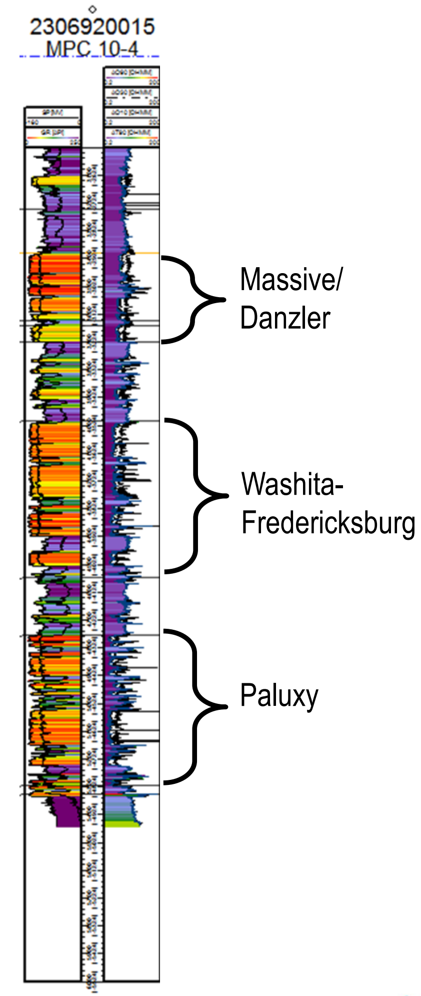
Advanced Resources International, Inc.

Storage Complex Capacity

Together the three storage zones provide nearly a gigatonne capacity CO_2 storage complex.

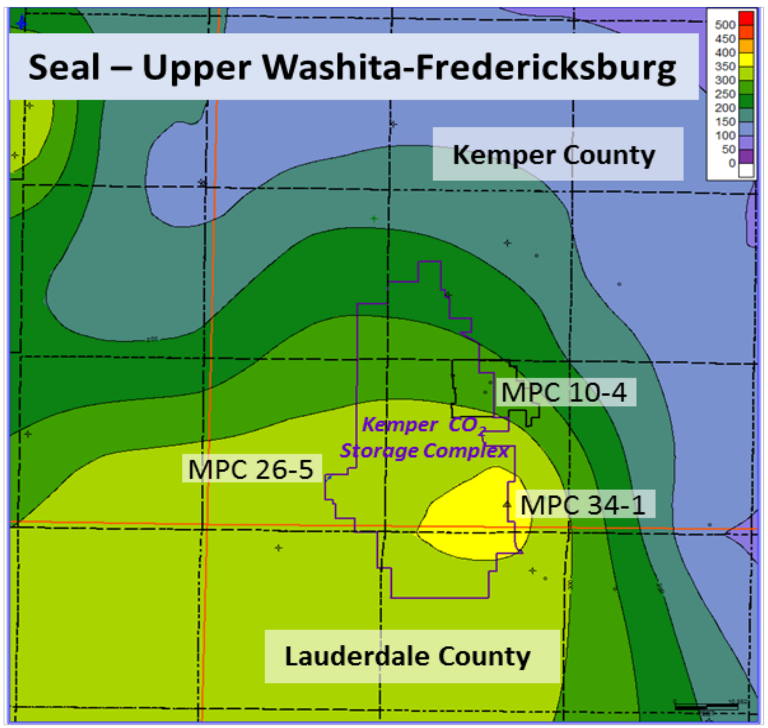
CO_2 Storage Reservoir	P_{10} Capacity (MMmt)	P_{50} Capacity (MMmt)	P_{90} Capacity (MMmt)
Massive/Dantzler	60	120	200
Wash.-Fred.	280	540	920
Paluxy	160	310	530
TOTAL	**510**	**970**	**1,660**

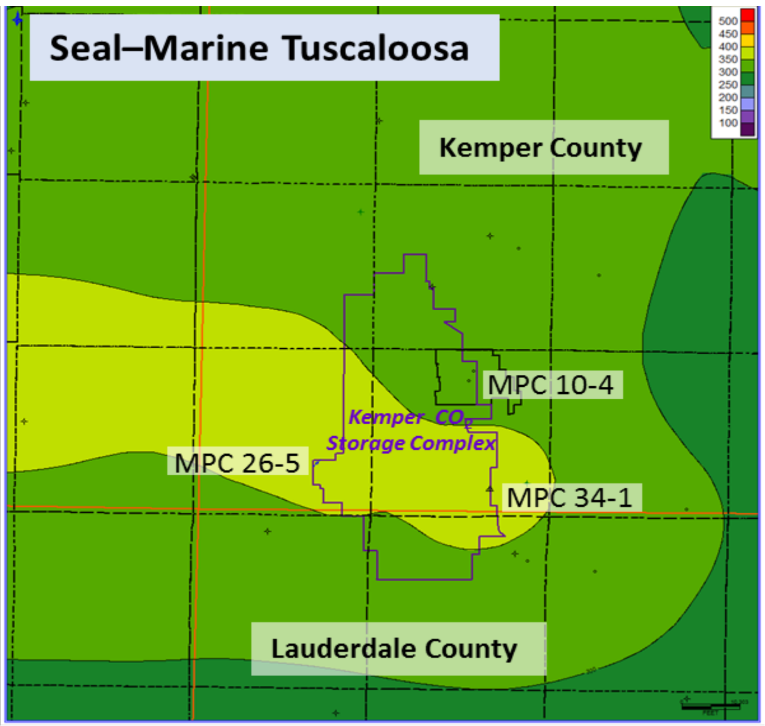
DOE methodology for site-specific saline storage efficiency calculation based on fluid displacement factors for clastic reservoirs where net pay, net thickness and net porosity are known of 7.4% (P_{10}), 14% (P_{50}) and 24% (P_{90}) (Goodman et al., 2011)



Project ECO$_2$S Confining Units (Seals)

The Upper Washita-Fredericksburg shale and Marine Tuscaloosa shale, each with thicknesses of 100 m to 150 m would serve as the primary confining zones for CO_2 storage at the ECO$_2$S regional CO_2 storage complex.





Advanced Resources International, Inc.

Project ECO_2S Storage Cost Study

Pre-feasibility level estimate for:

1. Site characterization storage facility design and permit application
2. Capital costs of establishing the CO_2 storage facility
3. Costs of operating and monitoring this facility for 20 to 30 years (60 to 90 million metric tonnes); and
4. Costs of 10 years of post-injection monitoring plus subsequent closure of the facility.

Southern Company Mississippi Power Advanced Resources International, Inc.

ECO_2S Site Characterization

- Drill three wells to gather drilling performance data, whole and sidewall core, logs
- Openhole Logs
  - Triple combo (caliper, array induction, gamma ray, density porosity, neutron porosity, spontaneous potential, photoelectric)
  - Combined magnetic resonance (CMR)
  - Formation micro imager (FMI)
  - Dipole sonic (mechanical properties)
  - Rotary sidewall cores
- Whole core of reservoir and seal intervals
- Evaluation of commercially available 2D seismic

Capital Costs of CO_2 Storage

As part of the U.S. DOE/NETL and Mississippi Power Phase II CarbonSAFE Project, Advanced Resources International (ARI) prepared cost estimates for establishing a large-scale CO_2 storage complex in Southeastern U.S.

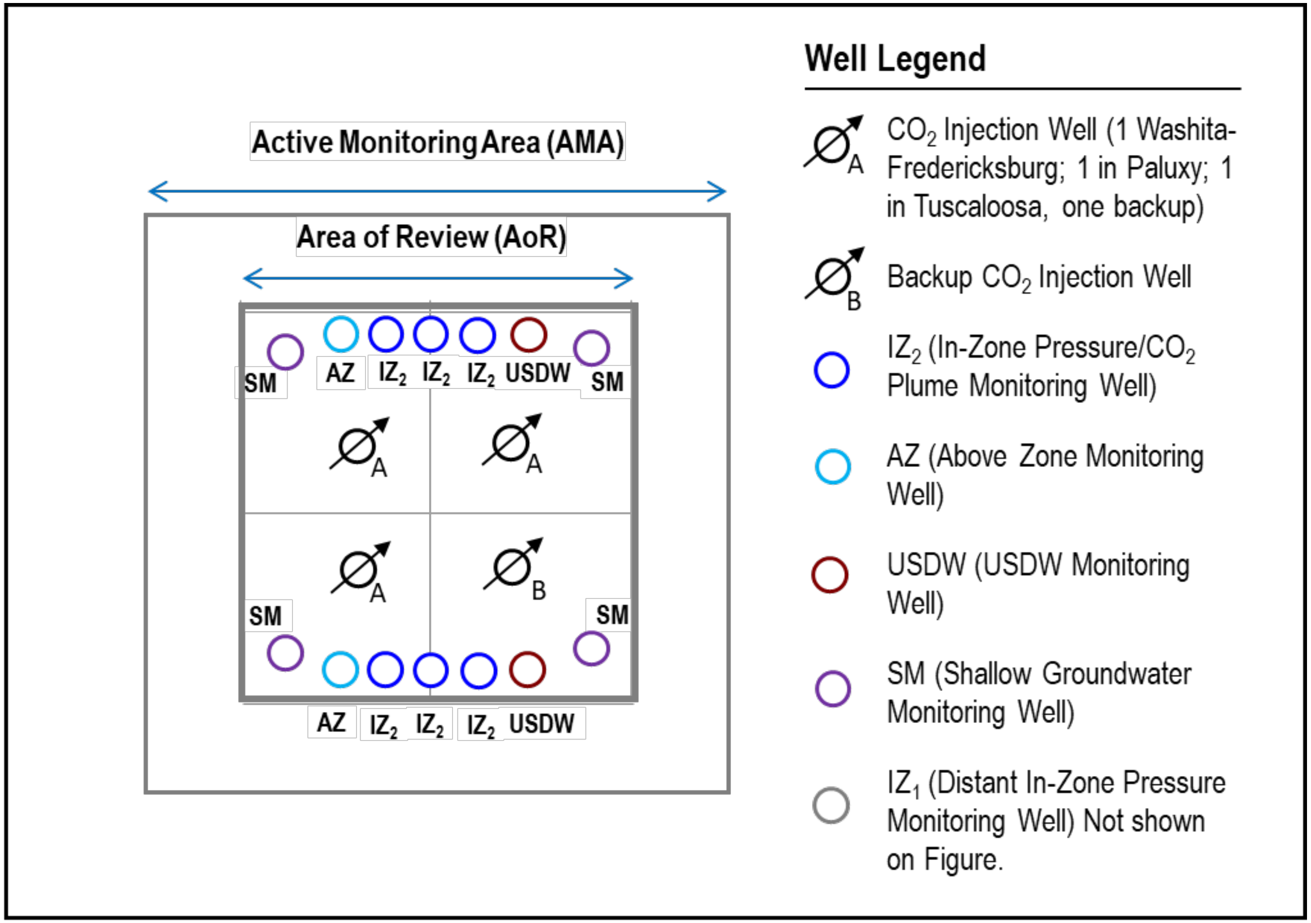
The example CO_2 storage facility is located near a power plant capturing 3 million metric tons of CO_2 per year using post-combustion capture technology.

The captured CO_2 is compressed and transported by pipeline to the CO_2 storage site located adjacent to the EGU and injected into deep saline formations.

The CO_2 storage facility is constructed and operated in full compliance with Class VI regulations.

Establishing the Storage Facility

The CO_2 storage complex contains a series of CO_2 injection and monitoring wells.



JAF2018_053.PPT

Capital Costs for Establishing Storage Site

		Total Cost (millions)
A. Site Design		
1. Site Characterization and Modeling ▪ Drill Characterization Wells ▪ Purchase and Interpret 2-D Seismic ▪ Build Geologic Model ▪ Conduct Reservoir/Geophysical Modeling		$8.4
2. Class VI Permit Application		$0.6
3. MRV Plan for Subpart RR		$0.1
4. Financial Bonds		$0.2
5. Site Preparation (included in well costs)		-
6. Acquisition of Pore Space Rights (assumed available)		-
	Sub-Total	**$9.3**
B. Site Installation		
1. CO2 Injection Wells		$14.3
2. Monitoring Wells		$20.0
3. Seismic/Microseismic		$2.1
4. Transportation		$7.4
5. Other Costs/Contingency		$7.4
	Sub-Total	**$51.2**
C. Total		**$60.5**

JAF2019_009.XLS

The capital costs for characterizing and installing the CO_2 storage complex at this high quality storage complex are $60 MM.

Less geologically favorable, smaller and more distant CO_2 storage complexes can have capital costs several times higher.

Advanced Resources International, Inc.

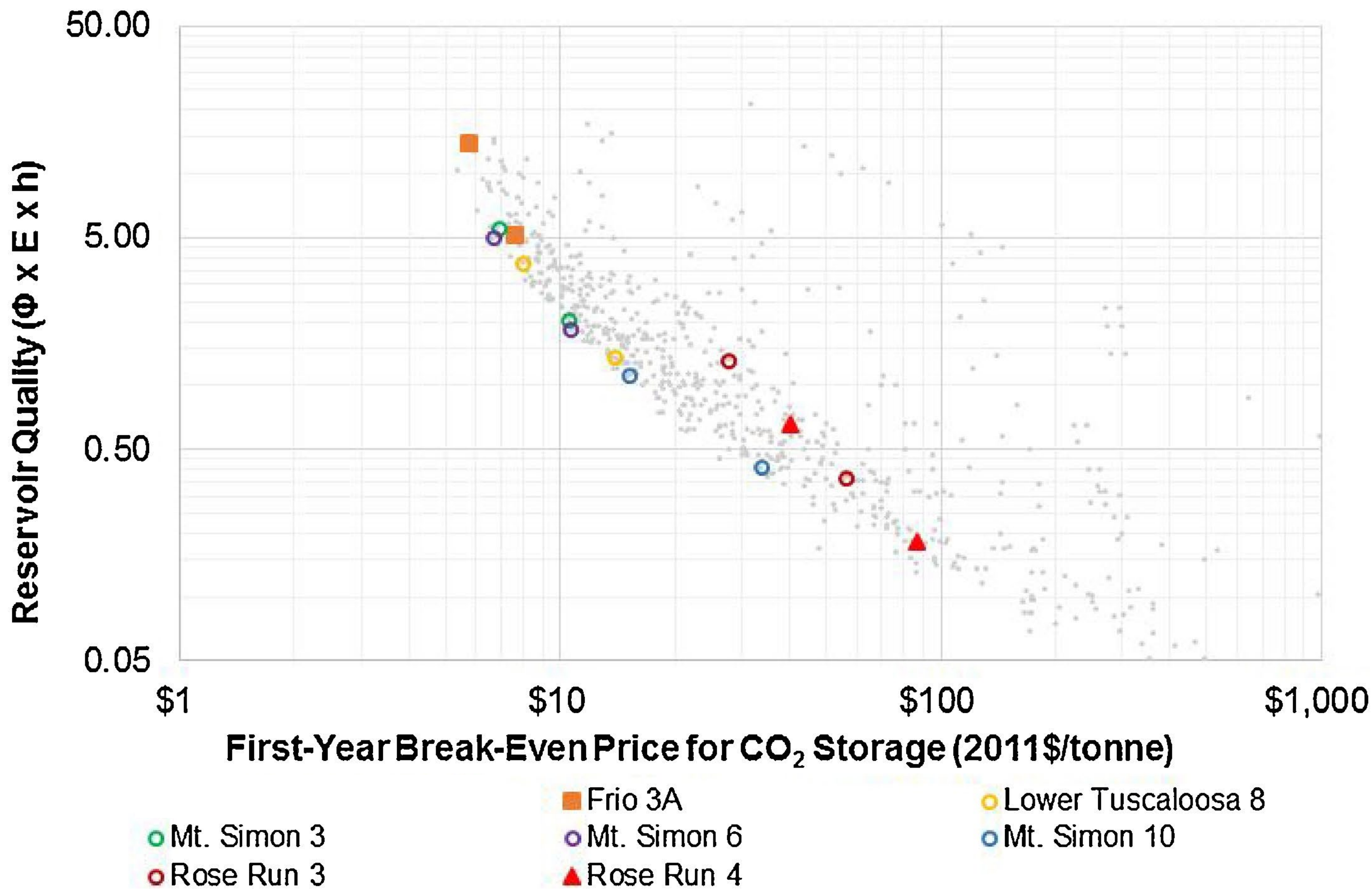
Storage Costs are Proportional to Volume and Reservoir Quality

	Large Volume Facility	Small Volume Facility
1. CO2 Injection Volumes		
▪ Annual (MMmt/yr)	3.0	1.0
▪ Daily (MMcf/d)	~150	~50
2. CO2 Storage (MMmt)		
▪ Cumulative 20 to 30 Yrs	60 to 90	20 to 30
3. Storage Costs ($MM)		
A. Site Characterization, Design and Permit	$9	$9
B. Site Installation and Transportation	$51	$35
C. Operating and Monitoring (20 to 30 Yrs)	$40 to $60	$30 to $45
D. Post Injection (10 Yrs)	$15	$10
Total	$115 to $135	$63 to $99
4. Storage Costs ($/metric tons)	**$1.50 to $1.90**	**$3.30 to $4.20**

JAF2018_037.XLS

Advanced Resources International, Inc.

Variability of Saline Aquifer Storage Costs



From Grant et al., IJGGC, Volume 72, May 2018, Pages 175-191

NATIONAL ENERGY TECHNOLOGY LABORATORY

Office Locations
Washington, DC
4501 Fairfax Drive, Suite 910
Arlington, VA 22203
Phone: (703) 528-8420

Knoxville, TN
1210 Kenesaw Ave.
Suite 1210A
Knoxville, TN 37919-7736