Commercial Scale CO_2 Injection and Optimization of Storage Capacity in the Southeastern United States

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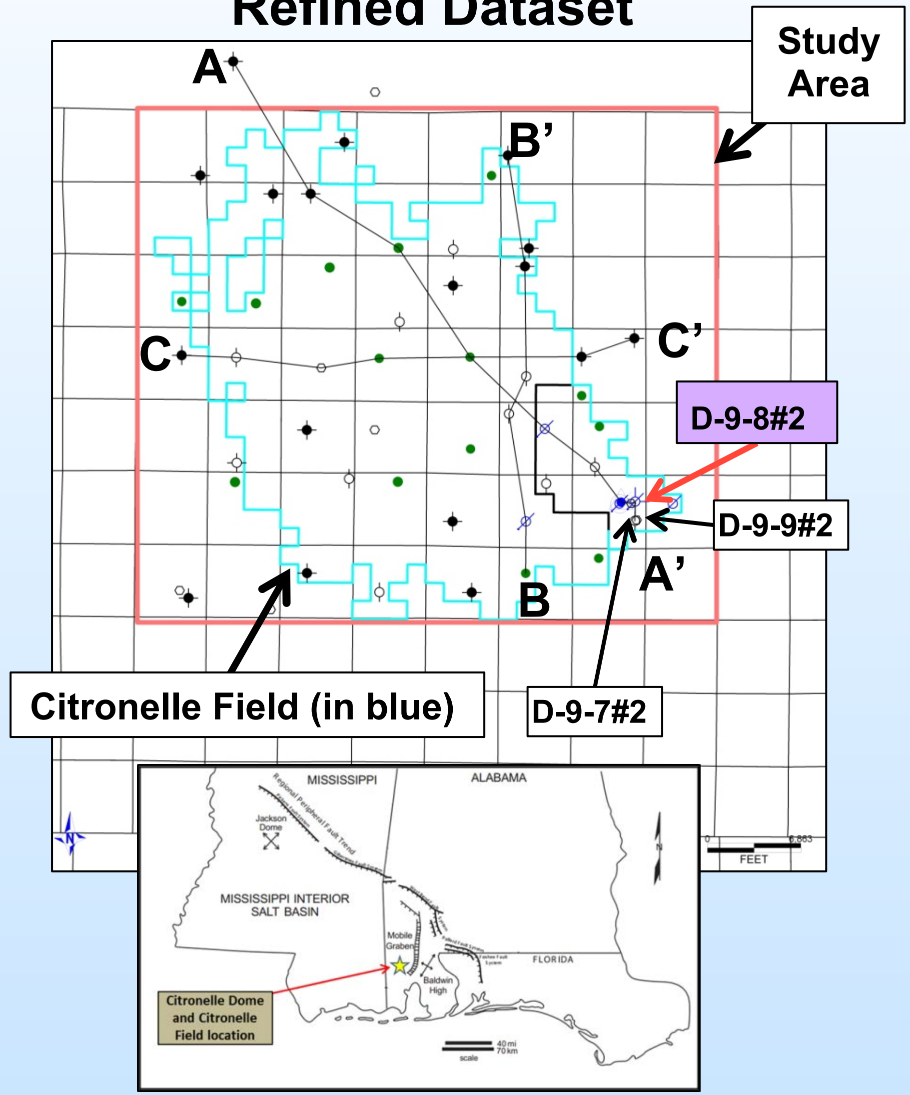
Project Objectives

- Optimize capacity and ensure storage containment in stacked Gulf Coast saline and oil bearing reservoirs
- Leverage modern and historical geologic characterization and injection performance data to develop detailed geologic models
- ***Overlay economic and risk management scenarios for each simulation case to determine the overall feasibility of commercial scale storage.***
- Conduct detailed cap rock core analysis testing
- Develop new storage efficiency factors based on these project results
- Develop reduced order models to approximate the ‘super computer’ results
- Summarize the results in a Best Practices Manual

Project Status: Study Area & Well Data Set

- The Citronelle Field is a 56 sq. mile study area with 400+ wells on 40-ac spacing.
- Geologic model characterizes injection zones and confining units from surface though the Donovan sandstones at depths >12,000 ft.
- D 9-8 #2 well in Citronelle Southeast Unit selected as Type Log for geologic correlations of injection zones & confining units.
- Multiple cross-sections constructed for geologic correlation of model layers.
- Digitized the SP & resistivity curves for 36 well logs. These data input to neural net software to estimate porosity.

Refined Dataset



Porosity and Permeability Extrapolated for Each Model Layer

- **Tertiary/ Quaternary** Model Layers (Midway-Surface):
  - Predicted porosity from neural net not successful due poor log data quality/ missing data.
  - A single porosity and permeability value applied for each model layer over the entire study area.
- **Cretaceous** Model Layers (Donovan to Selma):
  - Good prediction of porosity from neural net correlation.
  - Apply geostatistics to interpolate predicted porosity.
  - Apply porosity-permeability transforms from core data to extrapolate reservoir permeability from predicted porosity.

Formation	# Model Layers	Perm Transform
Alluvium	1	500,000 mD
Citronelle	1	17,500 mD
Miocene	1	34,600 mD
Chickasawhay	1	1,100 mD
Vicksburg	1	0.032 mD
Jackson	1	0.032 mD
Claiborne	3	0.032 to 386 mD
Wilcox	5	3.09E-5 to 660 mD
Midway	5	3.24E-6 to 1,680 mD
Selma	20	$K = 0.0033(e^{(0.1735*\phi)})$
Eutaw	20	$\text{Log } k = (0.13*\phi)-1.56$
Upper Tuscaloosa	50	$\text{Log } k = (0.18*\phi)-2.92$
Tuscaloosa Marine Shale	10	$k = (6E-19)*(\phi^{12.52})$
Lower Tuscaloosa	30	$k = (2E-14)*(\phi^{12.176})$
Washita	60	$k = (1E-9)*(\phi^{8.257})$
Fredericksburg	60	$k = (1E-9)*(\phi^{8.257})$
KWF Confining	5	1.21E-4 mD
Upper Paluxy	60	$k = (4E-10)*(\phi^{9.0365})$
Lower Paluxy	20	$K = 0.0004(e^{(0.6242*\phi)})$
Mooringsport	5	$K = 0.0033(e^{(0.1735*\phi)})$
Ferry Lake Anhydrite	1	5.5E-05 mD
Donovan	40	$K = 0.002(e^{(0.4873*\phi)})$

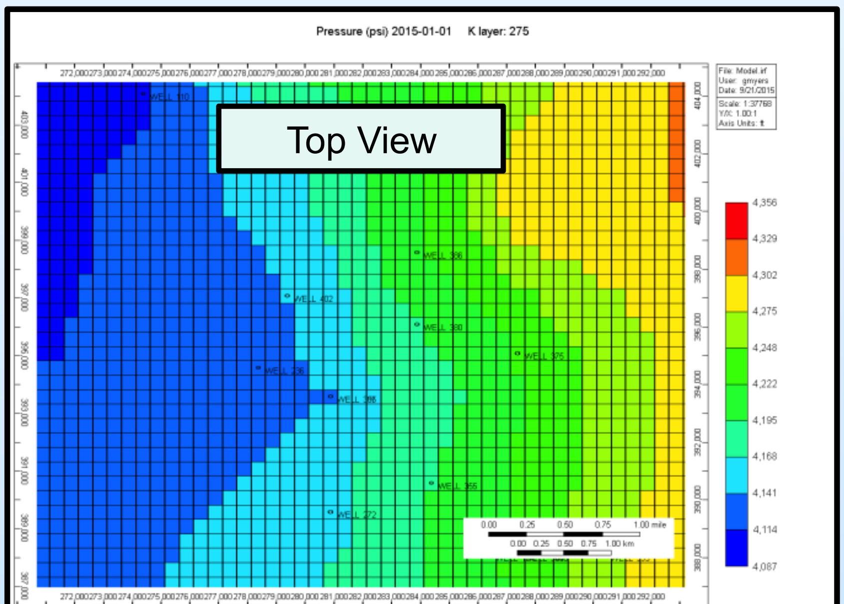
Model Parameters

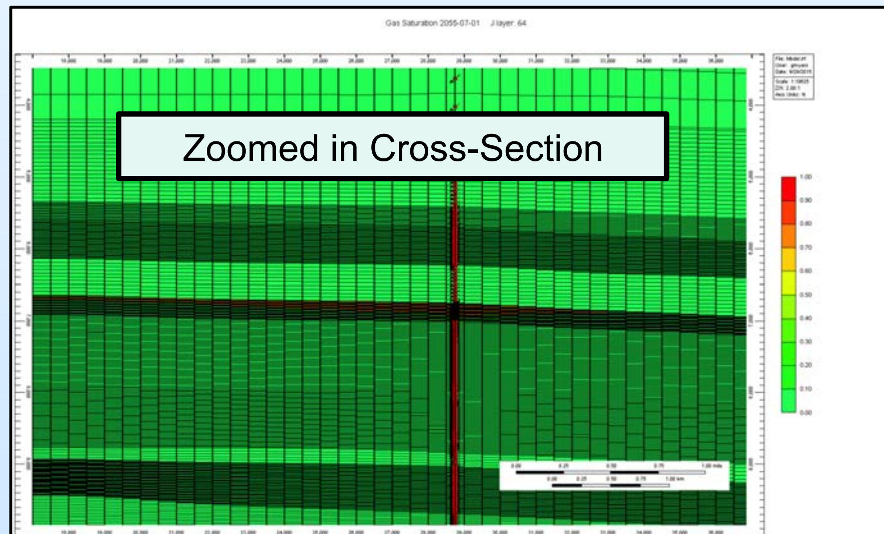
Model area consists of a volume of 1.9E+13 ft^3

- *(56 square miles x 12,000 vertical feet)*

The model is comprised of a total of 4.8 million cells:

- 120 Cells in the X direction, 100 Cells in the Y direction, and - 400 Cells in the Z direction
- all grid blocks are 500 feet by 500 feet





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Economic Evaluation Approach

- Evaluate saline CO_2 storage costs under UAB injection simulation results:
  - Reservoir (depths)
  - Injected volume (40 yrs)
  - Farthest plume movement at the end of CO_2 injection (plus ½ mile for active monitoring radius)
- Cost assumptions based on ARI CO_2 storage cost model* for Class VI and RR compliant storage (“stringent case”)
  - 40 yr injection project, 50 yr post injection site care

*See Godec et al. (2016), GHGT-13. “Potential issues and costs associated with verifying CO_2 storage during and after CO_2-EOR”

UAB Model Outputs

- Injection, independently into one of the five target reservoirs
- Injection of up to 40 MMscf/d CO_2 over a period of 40 years (pressure cutoff)

Formation	CO_2 Injection Volume *†, ft^3	Farthest Movement of CO_2 Plume*, ft	Layer No.
Upper Paluxy	5.84×10^{11}	4,910	275
Fredericksburg	5.14×10^{11}	4,140	254
Washita	5.84×10^{11}	5,510	156
Lower Tuscaloosa	5.84×10^{11}	13,530	125
Wilcox	9.28×10^{9}	4,010	9

* After 40 years of CO_2 injection.
† At surface conditions.

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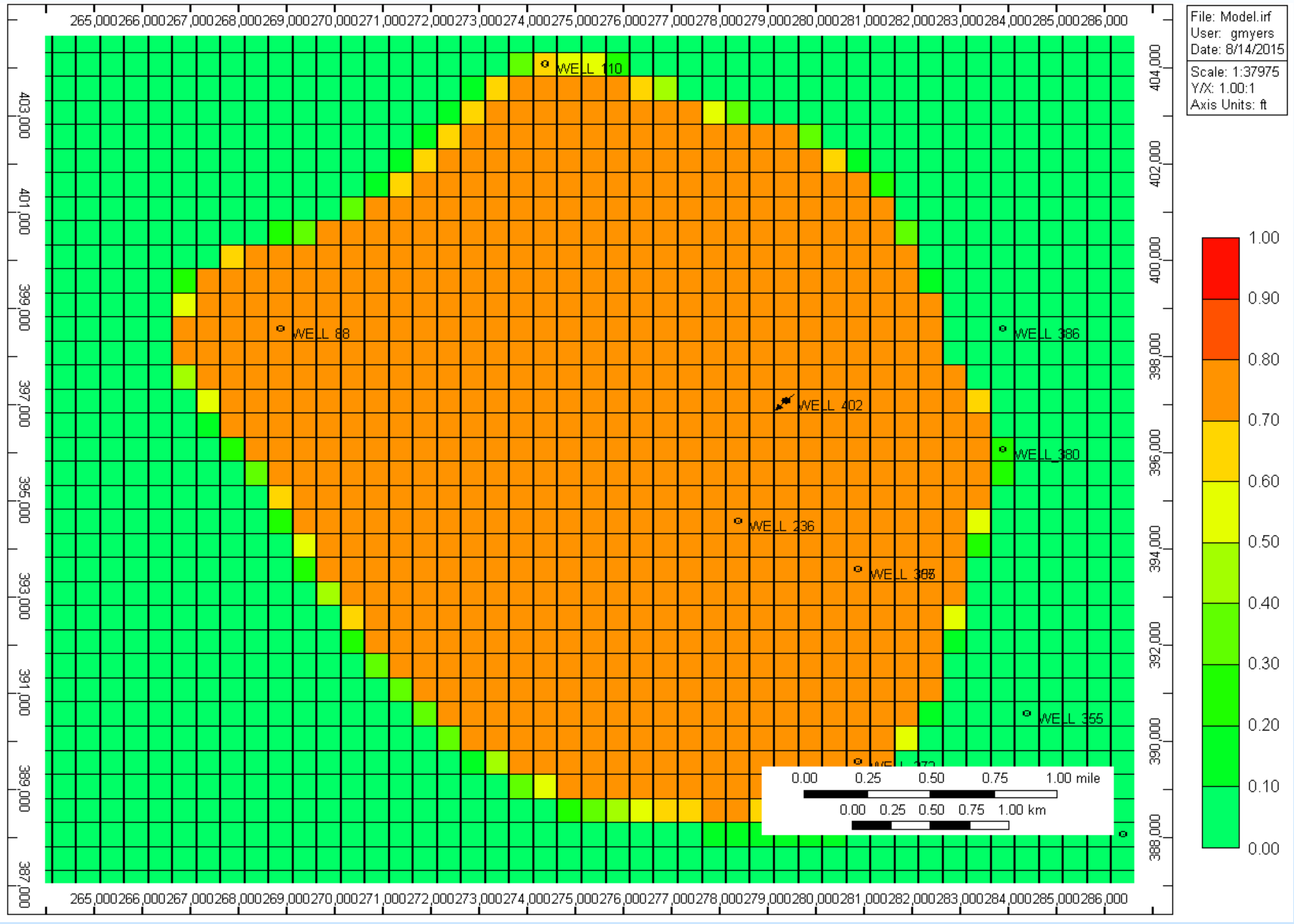
Lower Tuscaloosa Gas Saturation



Economic Model Inputs

Formation	Depth (ft)	Daily injection (metric tonnes)	max monitoring area (add half mile to plume, acre)	Total storage (40 years), MMtonnes	tonnes per max monitoring area acre
Wilcox	5,000	34	3,189	0.5	154
Lower Tuscaloosa	7,000	2,116	18,857	30.9	1,639
Washita	7,500	2,116	4,790	30.9	6,450
Fredericksburg	8,500	1,863	3,315	27.2	8,203
Upper Paluxy	9,500	2,116	4,111	30.9	7,516

Economic Model Assumptions (Washita Reservoir Case)

Upfront costs (one time) $13 MM

- Site char and permitting $2.4 MM
- Baseline MVA (3D seismic, microseismic, tilt, logging, groundwater) $3.5 MM
- New Class VI well $4.3 MM
- Convert 5 oilfield wells to monitoring $1.3MM
- Install injection monitoring $0.4MM
- Plug some existing wells (8 wells) $0.8MM

Economic Model Assumptions (Washita Reservoir Case)

Operating costs (annual) $1.5 MM

- Regulatory $160k
- Monitoring (3D seismic, microseismic, tilt, logging, groundwater) $1.1 MM
- Surface Equip and Well O&M $230k
- MIT $12k (annualized 5 yr MIT)
- Injection pressure/rates/corrosion monitoring, composition $100k

Economic Model Assumptions (Washita Reservoir Case)

<u>Post Injection Site Care (annual) $600k</u>

- Regulatory $40k
- Monitoring (3D seismic, microseismic, tilt, logging, groundwater) $400k
- Surface Equip, inejction and monitoring wells O&M $84k

Economic Model Assumptions (Washita Reservoir Case)

Site Closure (one time) $700k

- Injection well PA $140k
- Monitoring wells (5 wells) PA $460k
- Groundwater wells PA $25k
- Reporting $42k

Results
Cost Per Tonne Stored

Formation	Total storage (40 years), MMtonnes	Monitoring Area, acres	Upfront Costs ($$/tonne)	Operating Costs ($$/tonne)	PISC and Closure ($$/tonne)	**Total Costs ($$/tonne)**
Lower Tuscaloosa	30.9	18,857	$0.55	$3.10	$1.74	**$5.39**
Washita	30.9	4,790	$0.41	$1.93	$1.01	**$3.36**
Fredericksburg	27.2	3,315	$0.45	$2.05	$1.06	**$3.57**
Upper Paluxy	30.9	4,111	$0.40	$1.87	$0.98	**$3.26**

Results
CO_2 Storage Rate of Return

What if we were paid $5.00 per tonne at the field custody transfer station to store CO_2 (delivered at pipeline P/T; does not include capture and transportation)?

Formation	Total storage (40 years), MMtonnes	Monitoring Area, acres	**IRR at $5.00 CO_2**
Lower Tuscaloosa	30.9	18,857	**3%**
Washita	30.9	4,790	**17%**
Fredericksburg	27.2	3,315	**14%**
Upper Paluxy	30.9	4,111	**18%**

Caveats !

Potential costs I have not considered in my model:

- Plugging costs for existing oilfield wells during injection
- Reservoir pressure control (i.e., water withdrawal for plume management, injectivity/capacity enhancement)
- Bonding
- Pore space rights
- Land use permits
- Taxes
- Mitigation
- Regulatory evolution over 40 (or 90) years(!)

Concluding Thoughts

- Caveats in prior slide notwithstanding, CO_2 storage in the Citronelle dome appears to be economically viable at a *modest* storage credit (realized at the field)
- Stacked injection into multiple zones could be used to minimize the CO_2 monitoring area
- EOR may offset some field costs