Integrated Carbon Capture and Storage in the Louisiana Chemical Corridor

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National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration:
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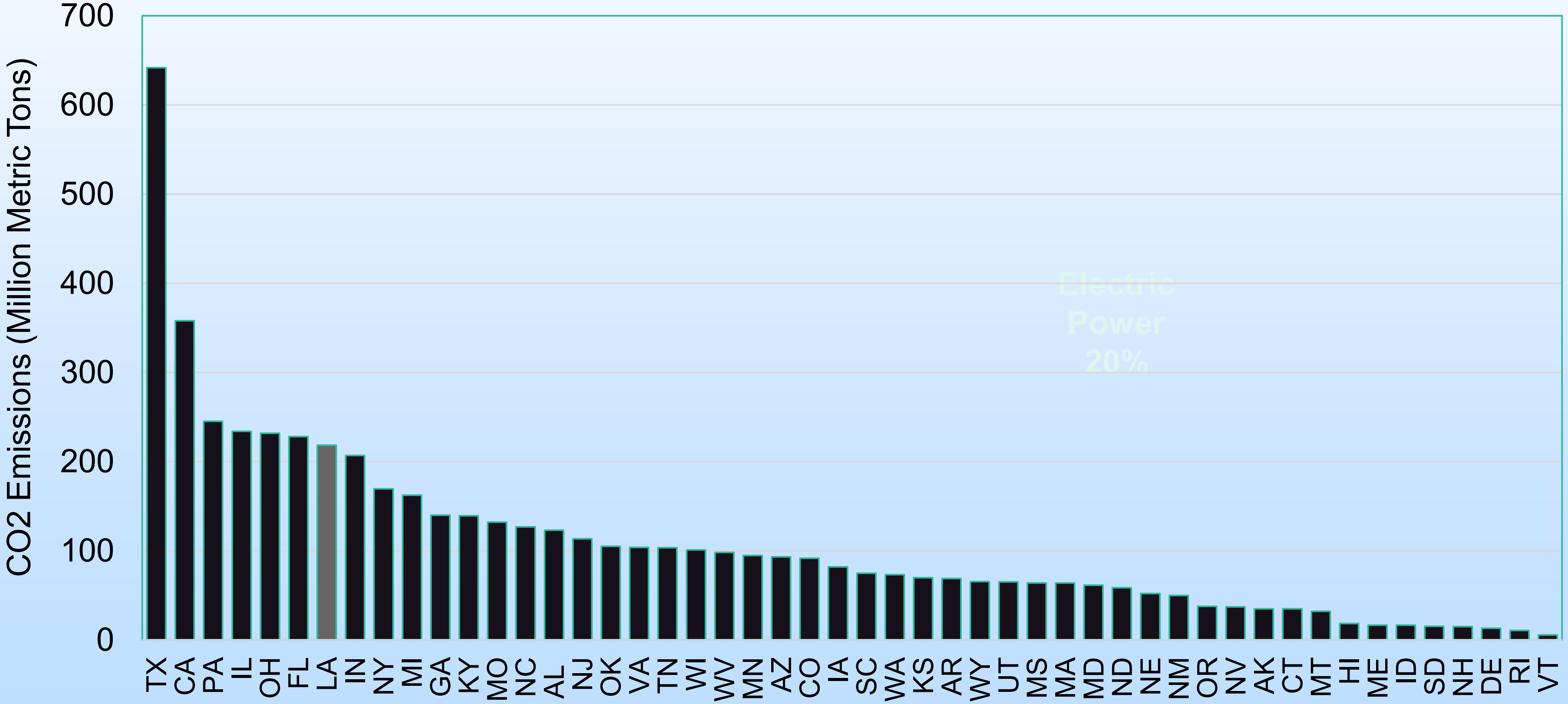
Presentation Outline

- CO_2 emissions in Louisiana
- Source-sink matching
- Selected fields' characterization
- Storage capacity estimation
- Dynamic capacity sensitivity
- Containment assessment
  - Wells
  - Faults
- Conclusions

Energy-Related Emissions by State, 2014

At just under 220 million tons of CO_2 emissions, Louisiana ranks seventh in the U.S.

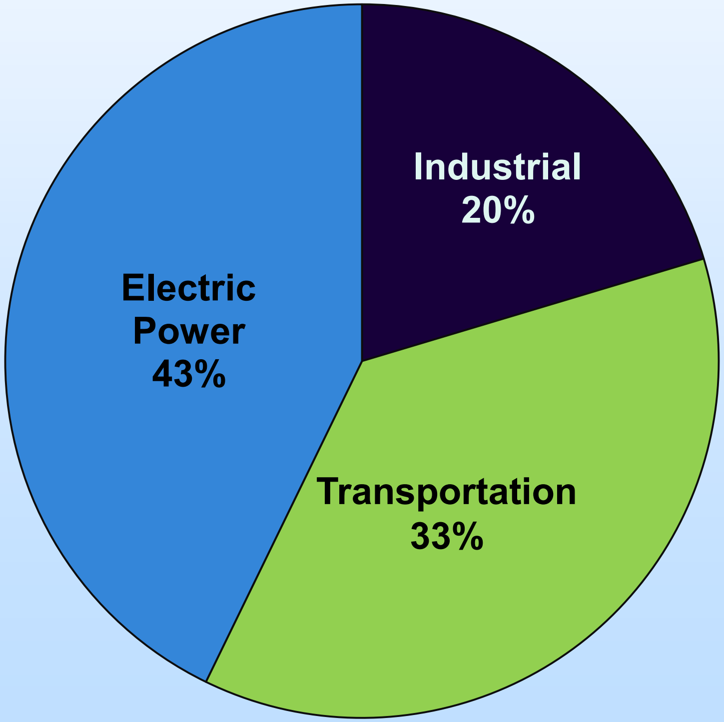


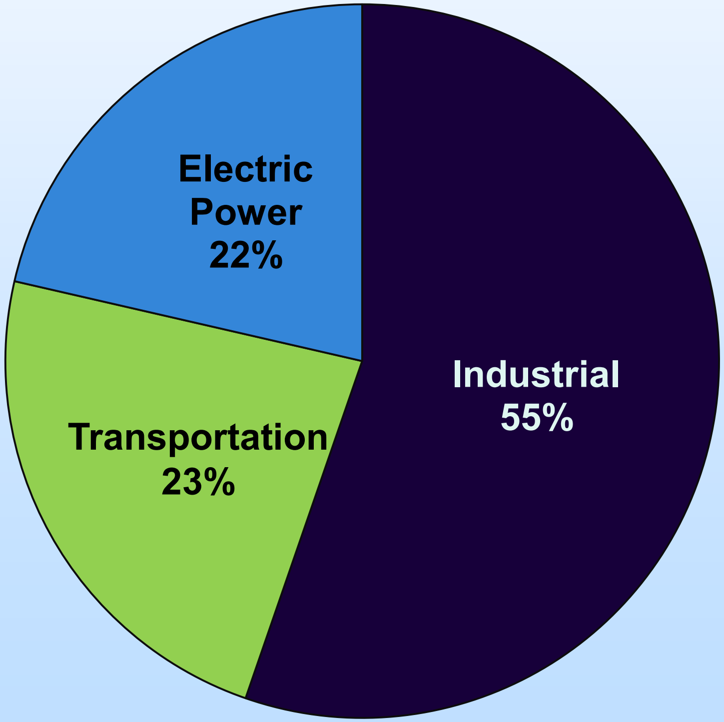
Source: Energy Information Administration, U.S. Department of Energy.

U.S. and Louisiana CO_2 Emissions per Sector

In the U.S., power generation comprises over 40 percent of overall national emissions.

In Louisiana, power generation comprises about 22 percent of overall state emissions. Louisiana's primary source of CO_2 emissions comes from industry.

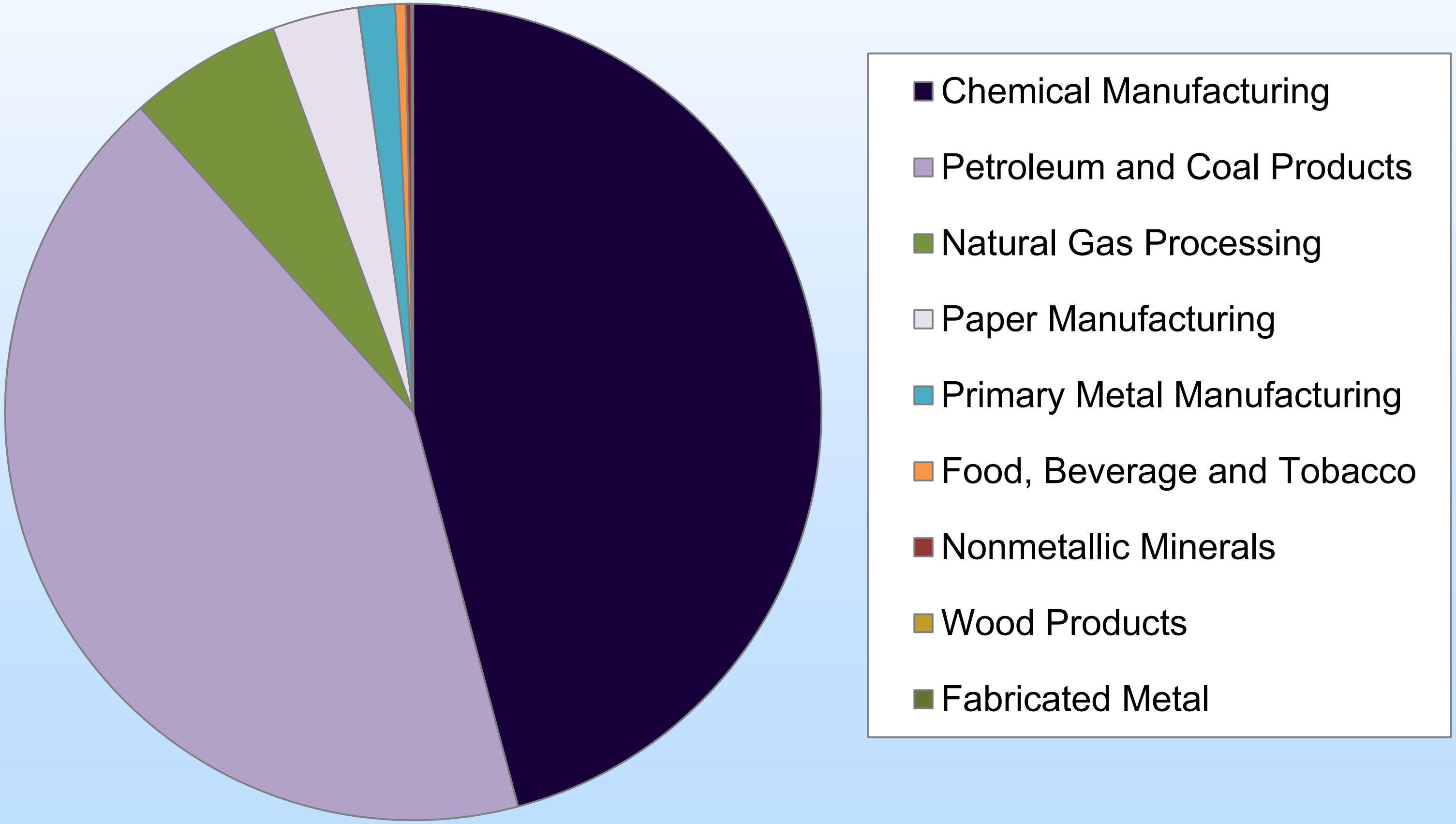




Source: Energy Information Administration, U.S. Department of Energy.

Industrial CO_2 emissions by category

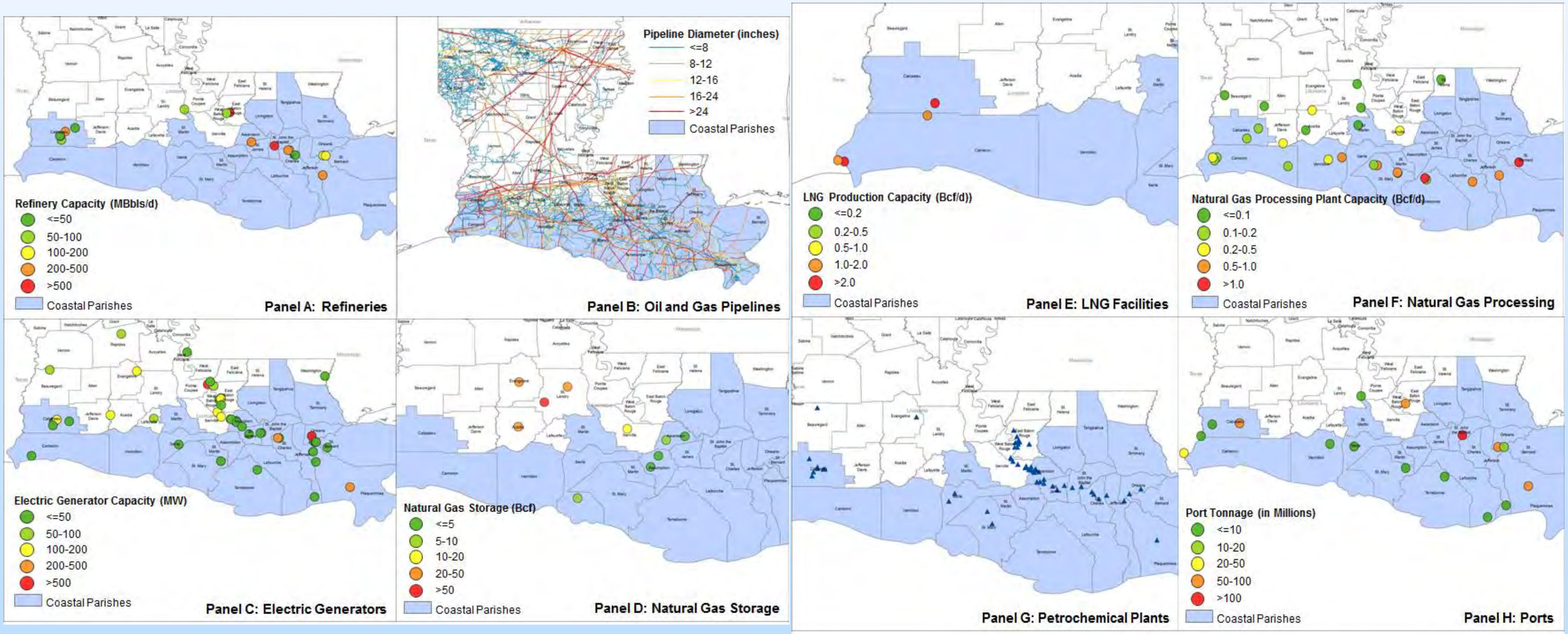
Most of the Louisiana industrial CO_2 emissions are concentrated in the chemical and refining sectors. Natural gas processing is a distant third.



Source: U.S. EPA Envirofacts.

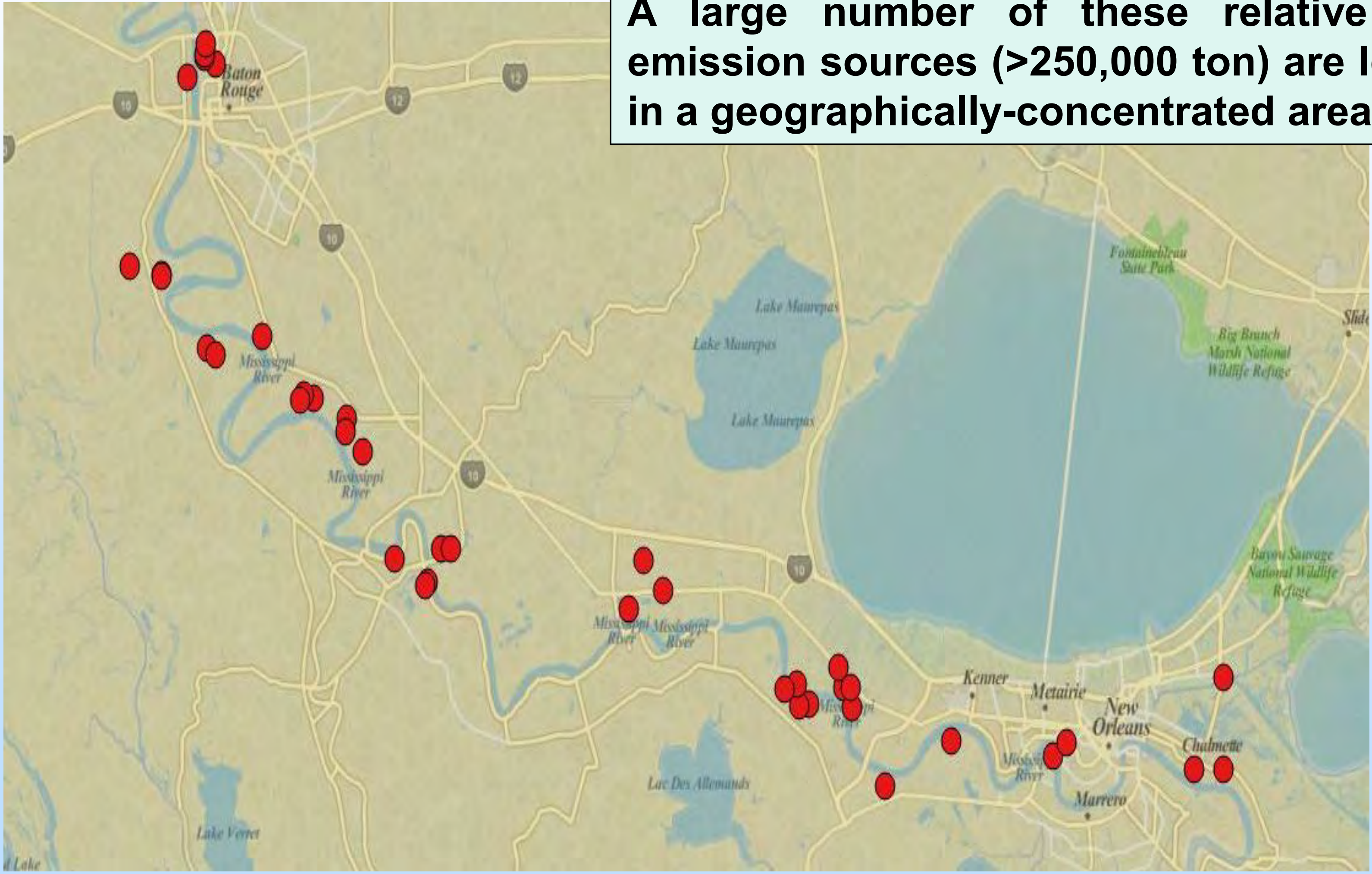
Louisiana's critical energy infrastructure

Refineries, certain petrochemical facilities, and gas processing facilities can serve as important carbon sources. The existing pipeline and storage infrastructure underscores opportunities for linking potential sources and sinks.



Industrial Sources (corridor)

A large number of these relative high-emission sources (>250,000 ton) are located in a geographically-concentrated area.

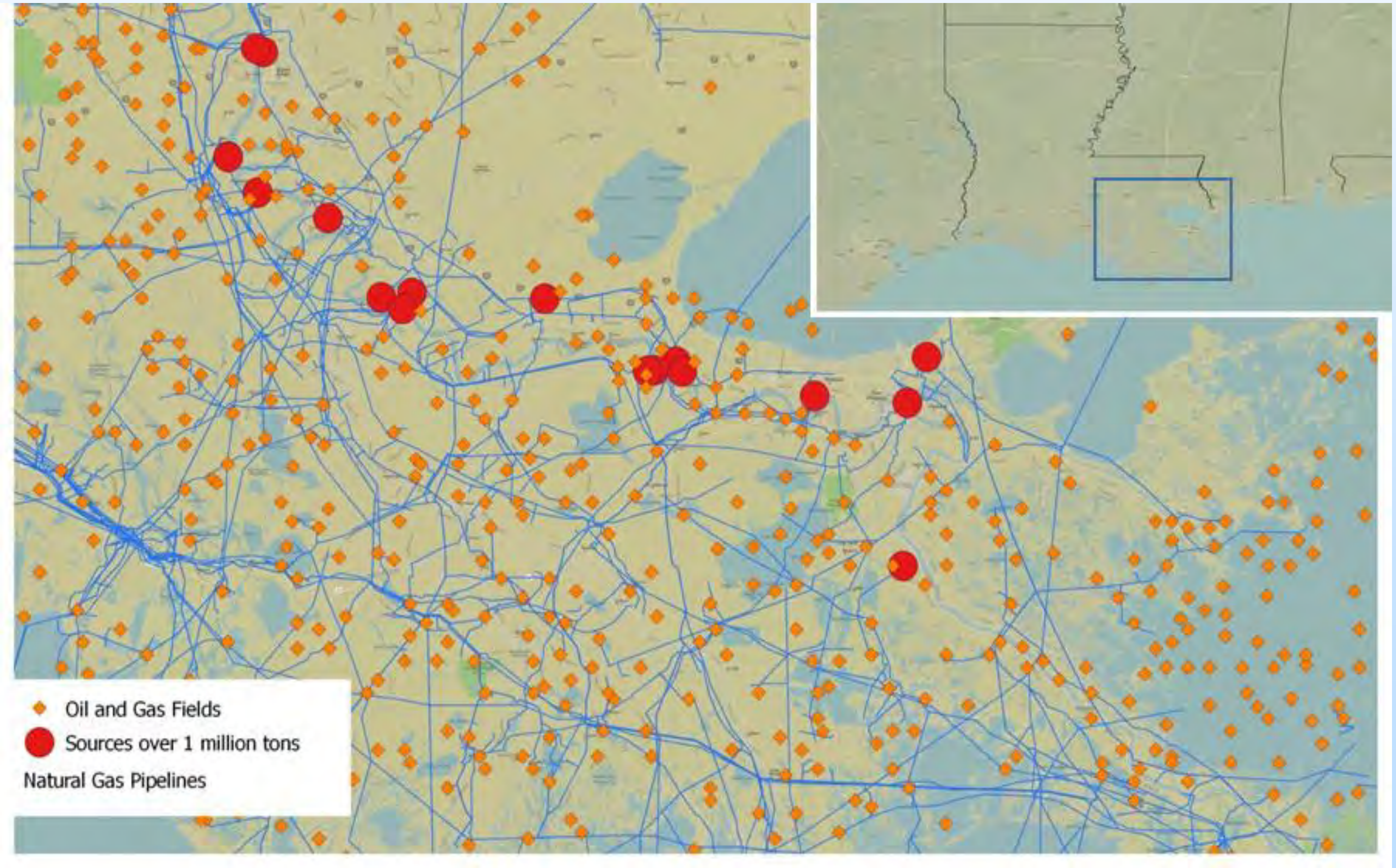


Top Industrial Sources (totals)

Facility	City	2014 CO_2 Emissions (mt)	CO_2 Purity	Facility Type	NAICS
Big Cajun 2	New Roads	10,624,054	Low	Power Plant	221112
Brame Energy Center	Lens	6,725,251	Low	Power Plant	221112
ExxonMobil Baton Rouge	Baton Rouge	6,245,428	Mostly Low	Refinery	324110
CF Industries Nitrogen	Donaldsonville	5,388,579	High	Petrochemical	325311
CITGO Lake Charles	Sulphur	4,766,415	Mostly Low	Refinery	324110
Marathon Petroleum Company	Garyville	3,930,022	Mostly Low	Refinery	324110
Norco Manufacturing Complex	Norco	3,527,991	Mostly Low	Refinery	324110
R S Nelson	Westlake	3,513,465	Low	Power Plant	221112
Dolet Hills Power Station	Mansfield	2,943,833	Low	Power Plant	221112
Saint Charles Operations - Dow	Taft	2,881,974	Mostly Low	Petrochemical	325199

Sink Site Selection

There are a number of oil and gas production reservoirs, some of which are depleted, that could be used as sources with considerable co-located transport infrastructure.

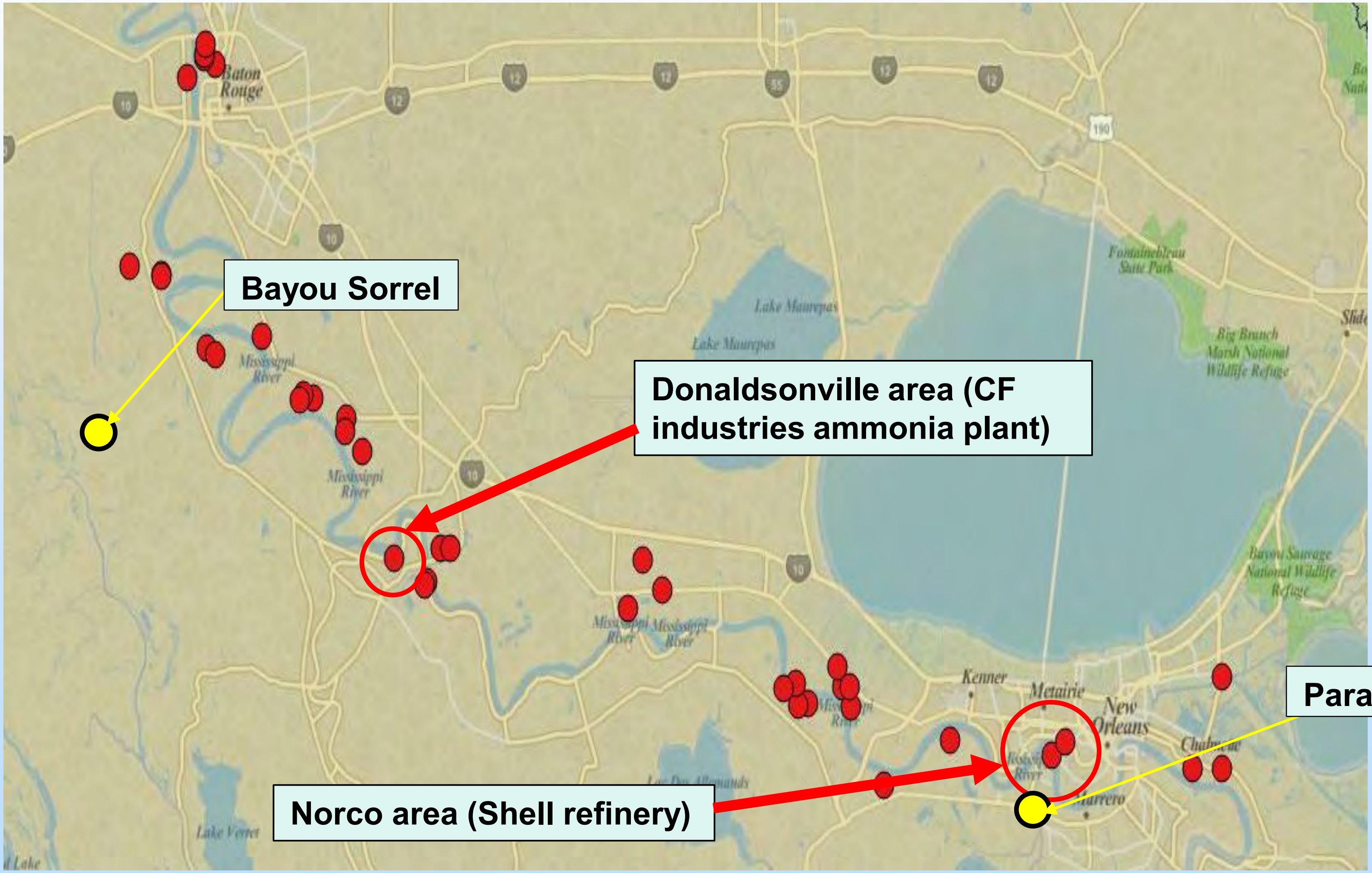


Sink Site Selection

- **Site selection criteria**:
  - Proximity to CO_2 sources
  - Potential for CO_2 containment
  - Potential for large storage capacity
- **Initial site screening by LGS (Louisiana Geological Survey)***
- **Site specific data collection from public source (SONRIS)**
  - Field production history (initial site potential)
  - Well data (active and abandoned)
  - Well logs (to estimate capacity)
  - Well history data: cement tops, plugged data etc (to estimate leakage risk)

Source: *Chacko John, Warren Schulingkamp, Bobby Jones, Brian Harder & Reed Bourgeois, (2011). “Potential for Carbon Dioxide Sequestration in Five Fields along the Mississippi River Industrial Corridor in Louisiana”, LGS, LSU.

Selected Depleted Oil Fields



Bayou Sorrel

Donaldsonville area (CF industries ammonia plant)

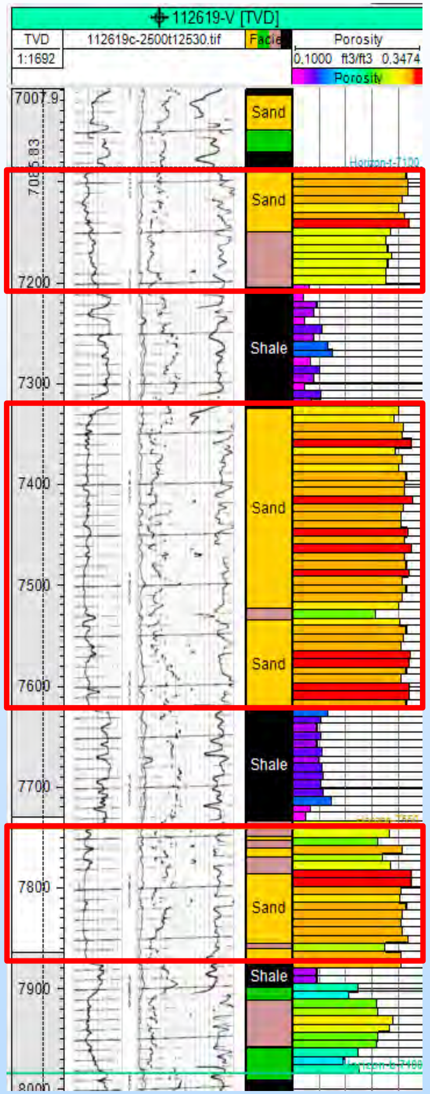
Paradis

Norco area (Shell refinery)

Common Field Features

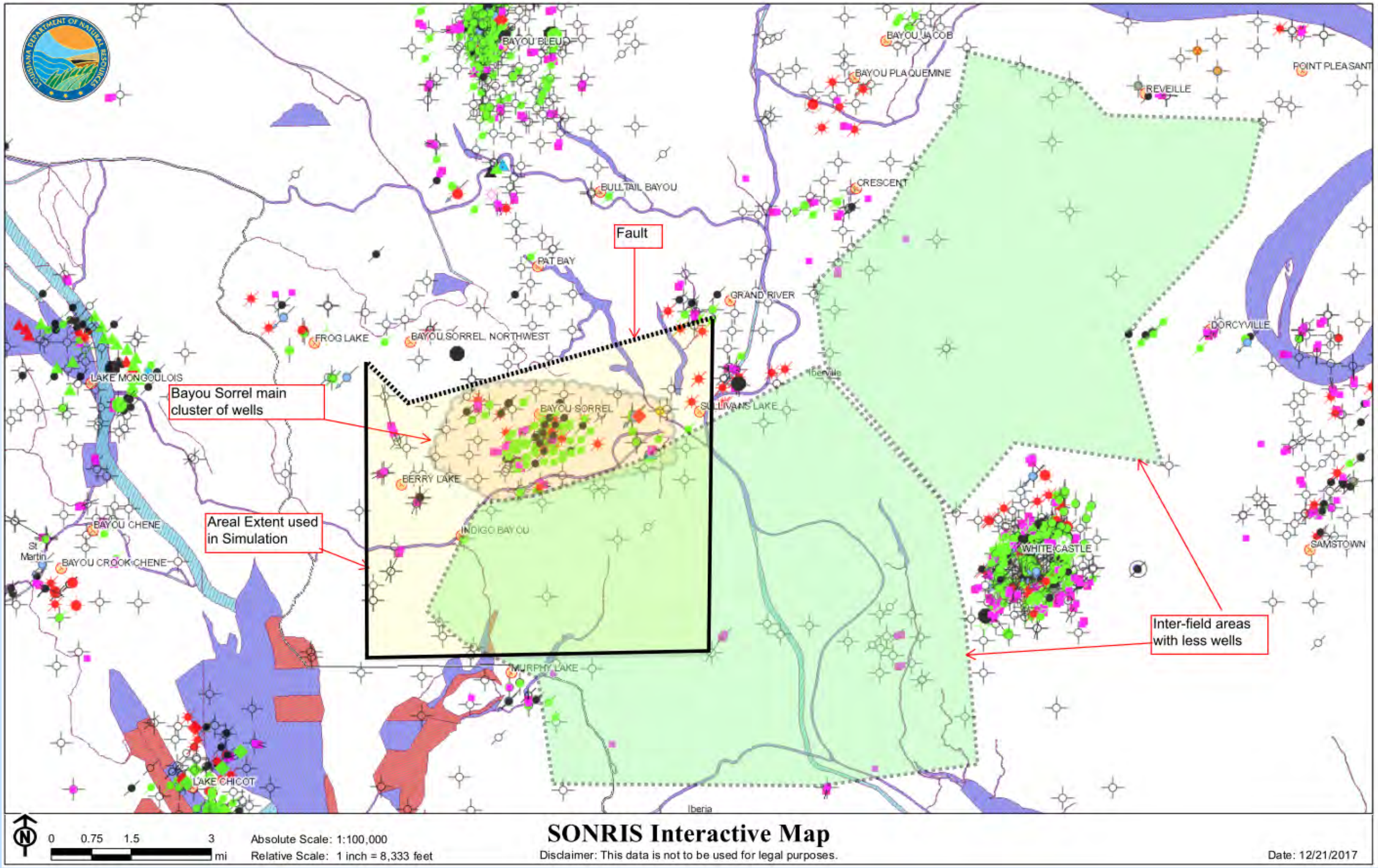
- Multiple storage zones with stacked sand systems
- Thick zones (up to several hundred ft.)
- High porosity and high permeability
- Normal hydrostatic pressure ~0.465 psi/ft

	Cum oil (MMSTB)	Cum gas (BSCF)	Total wells	Currently prod. wells*
Bayou Sorrel	44	190	176	3
Paradis	156	1350	411	16



* Current production intervals are deeper than 10,000 ft

Bayou Sorrel and Surrounding Areas


Fault

Bayou Sorrel main cluster of wells

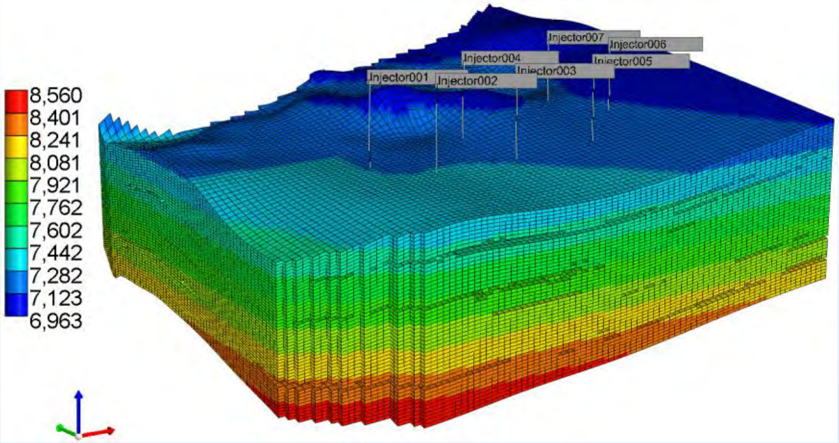
Areal Extent used in Simulation

Inter-field areas with less wells

Source: SONRIS

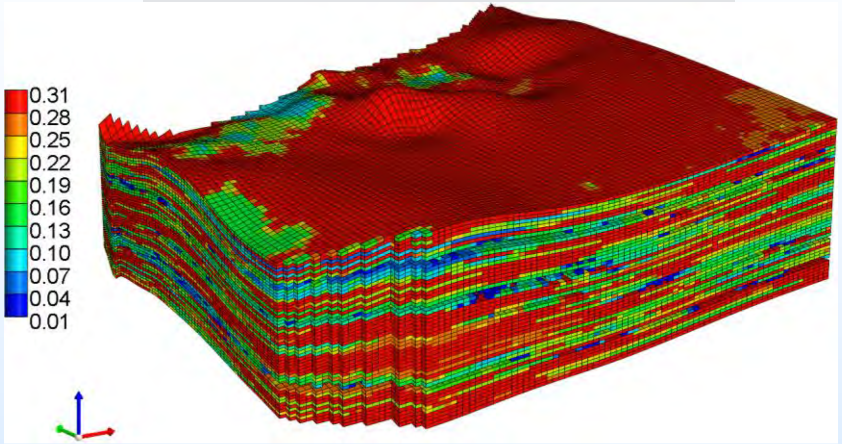
Bayou Sorrel Petrophysical Data

Zone Depth (ft)



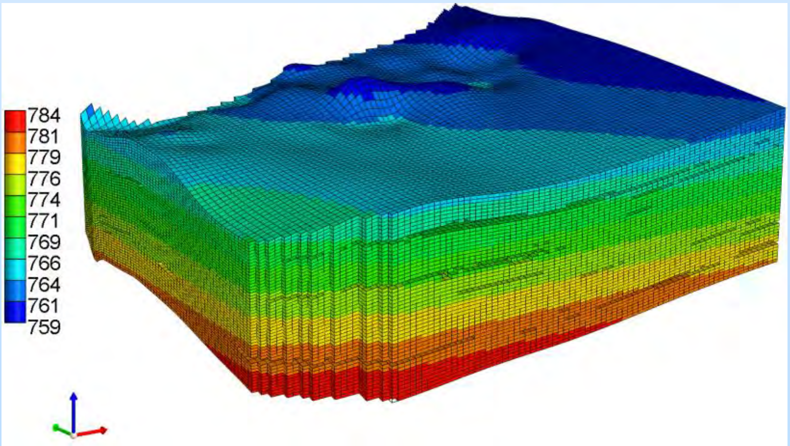
Average thickness = 998 ft

Porosity

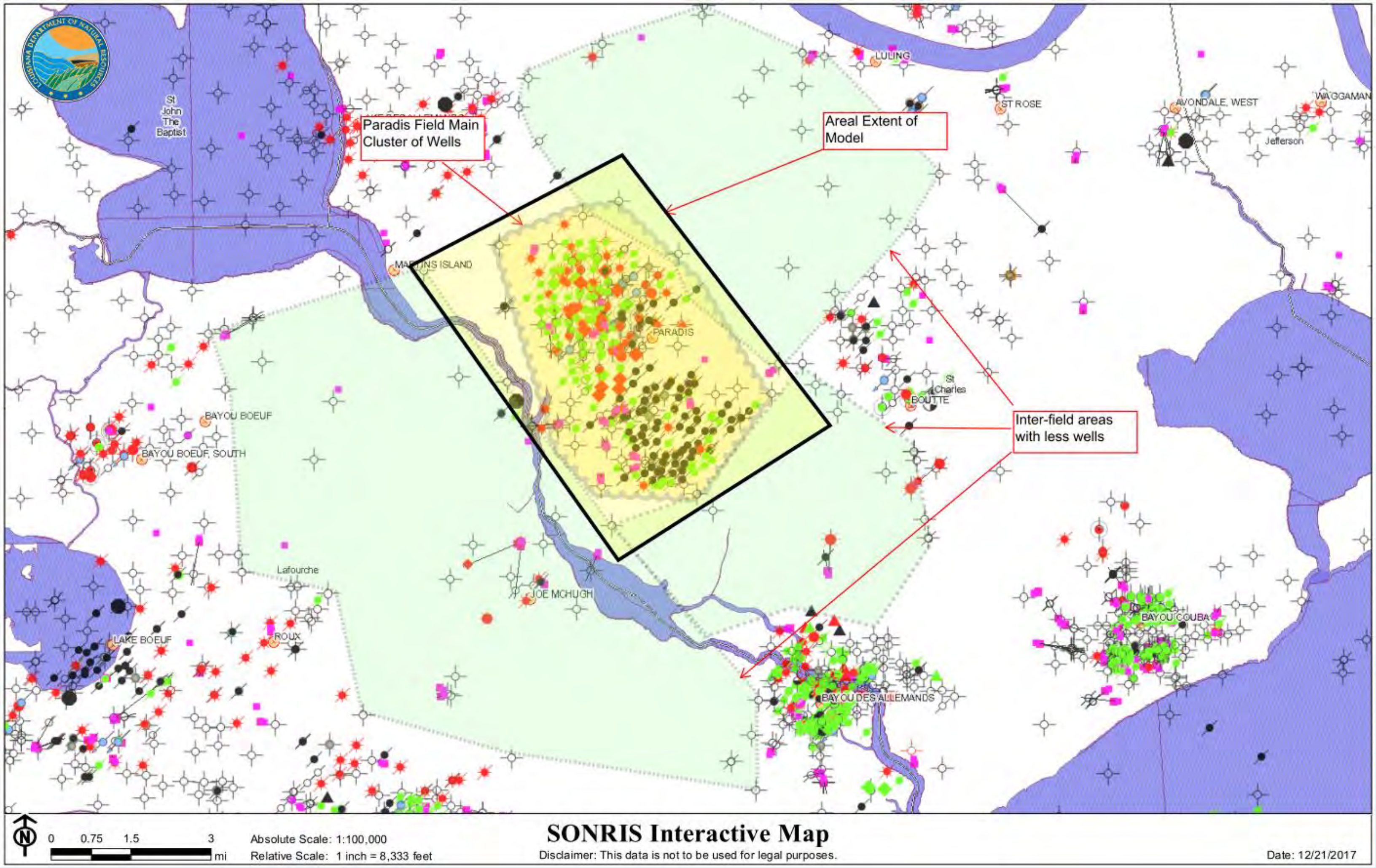


Average Porosity = 0.28

CO_2 Density (kg)



Paradis and Surrounding Areas



Paradis Field Main Cluster of Wells

Areal Extent of Model

Inter-field areas with less wells

Absolute Scale: 1:100,000
Relative Scale: 1 inch = 8,333 feet

SONRIS Interactive Map

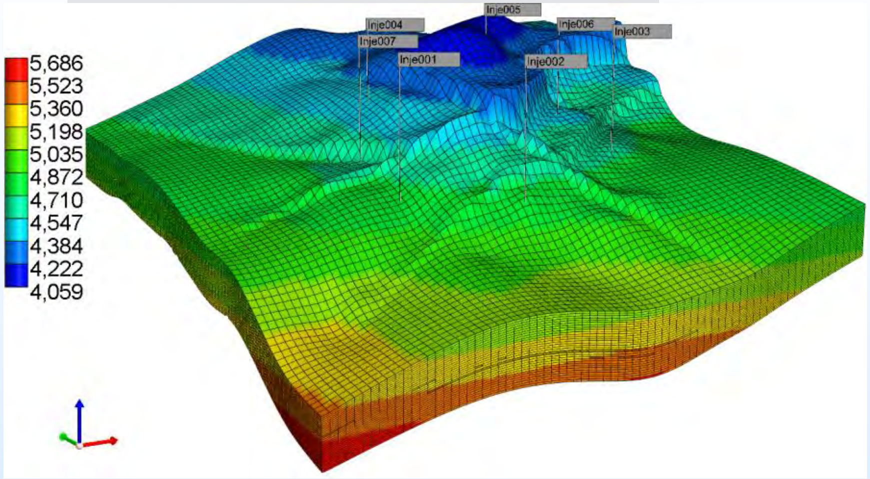
Disclaimer: This data is not to be used for legal purposes.

Date: 12/21/2017

Source: SONRIS

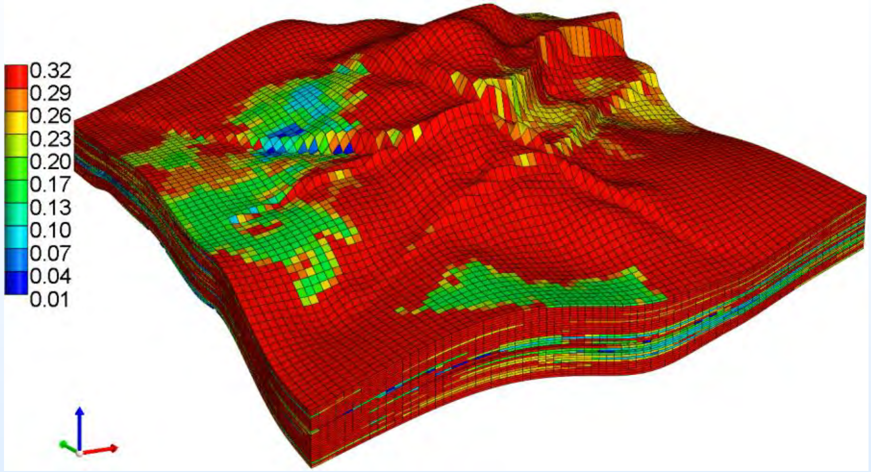
Paradis Petrophysical Data

Zone Depth (ft)



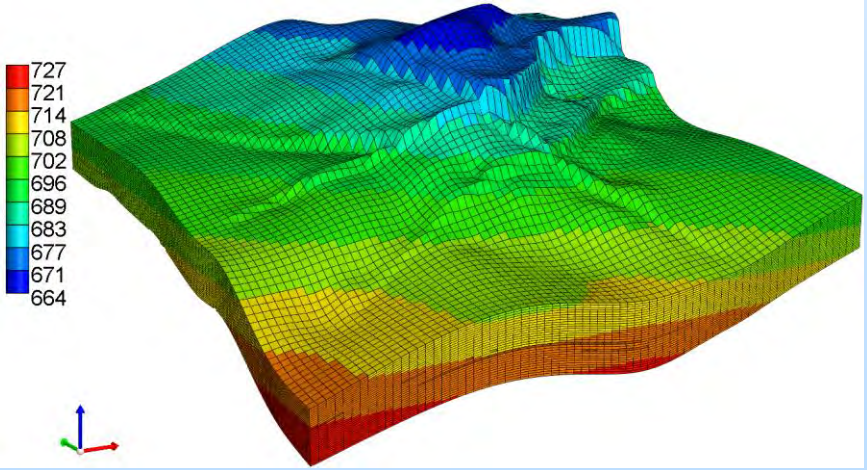
Average thickness = 350 ft

Porosity



Average Porosity = 0.3

CO_2 Density (kg)



Static and Dynamic Storage

Static Model	Bayou Sorrel	Paradis
Average depth to top of potential storage zone (ft)	7300	4300
Average thickness of potential storage zone (ft)	990	350
Average porosity of potential storage zone (fraction)	0.280	0.300
Average CO2 density (kg/m3)	771.1	714
Static storage efficiency (fraction)	0.020	0.020
Static storage capacity (Mt)	133.182	83.957
Static capacity per unit volume (Kg/m3)	4.318	4.284

Dynamic Model Parameters	Bayou Sorrel	Paradis	
		Transmissive Faults	Non-transmissive Faults
No. of wells	7	7	7
Dynamic Capacity (Mt)	129.59	124.093	71.189
Storage efficiency (fraction)	0.019	0.043	0.025
Dynamic capacity (Kg/m3)	4.20	9.29	5.33

Dynamic Storage Sensitivity

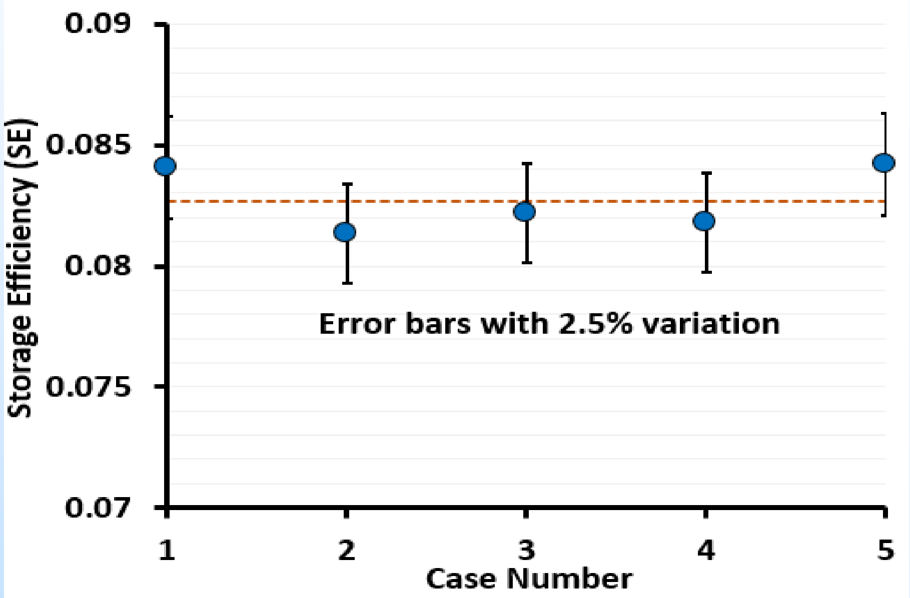
- Inspection analysis is used to derive basic dimensionless numbers/scaling parameters

$$N_\alpha = \frac{L}{H}\tan\alpha$$ Dip Angle Group

$$R_L = \frac{L}{H}\sqrt{\frac{k_z}{k_x}}$$ Effective Aspect Ratio

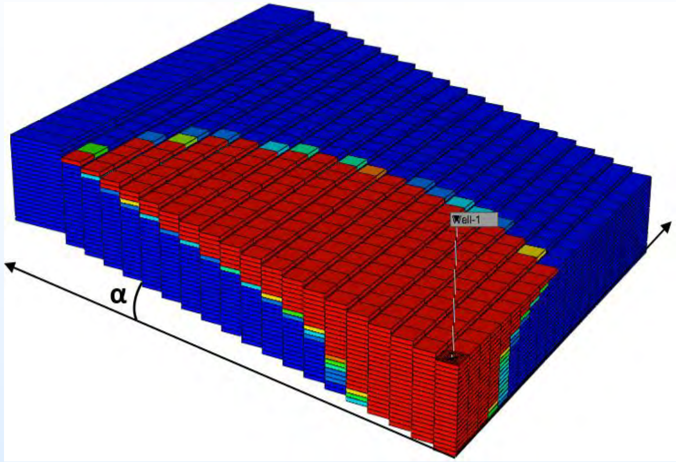
$$M = \frac{k_{rg}\mu_w}{k_{rw}\mu_g}$$ Mobility Ratio

S_{wi} Irreducible Water Saturation

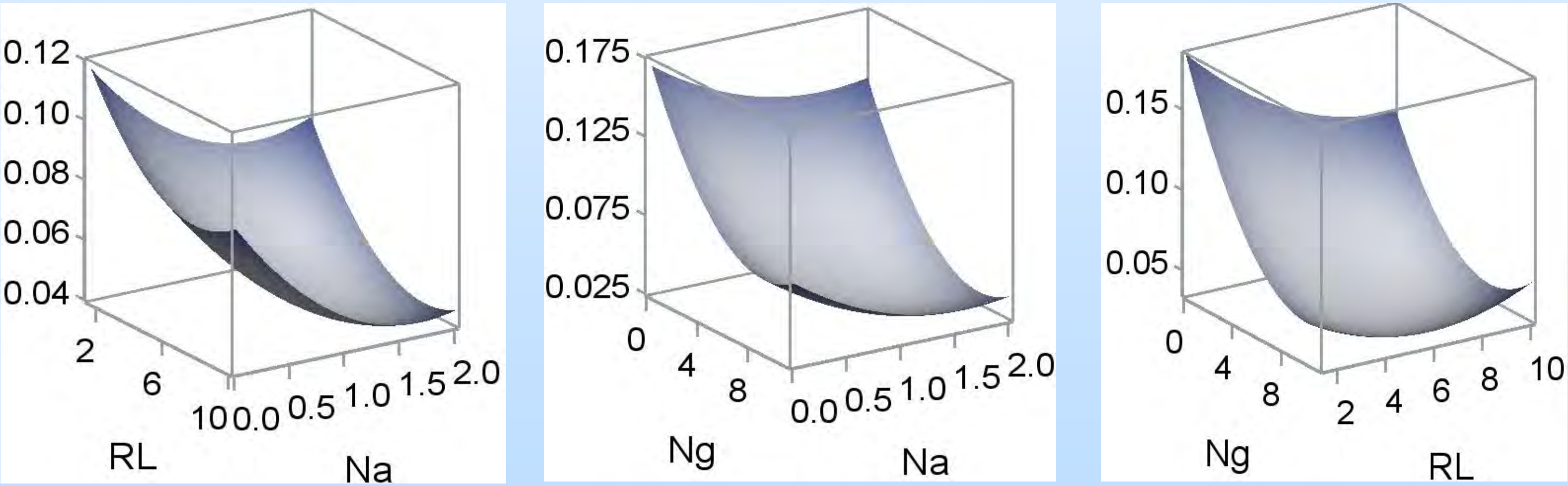


$$N_g = \frac{k_x k_{rg}\Delta\rho g H cos\alpha}{q_g\ \mu_g}\frac{2\pi r_w H}{L}$$ Gravity Number

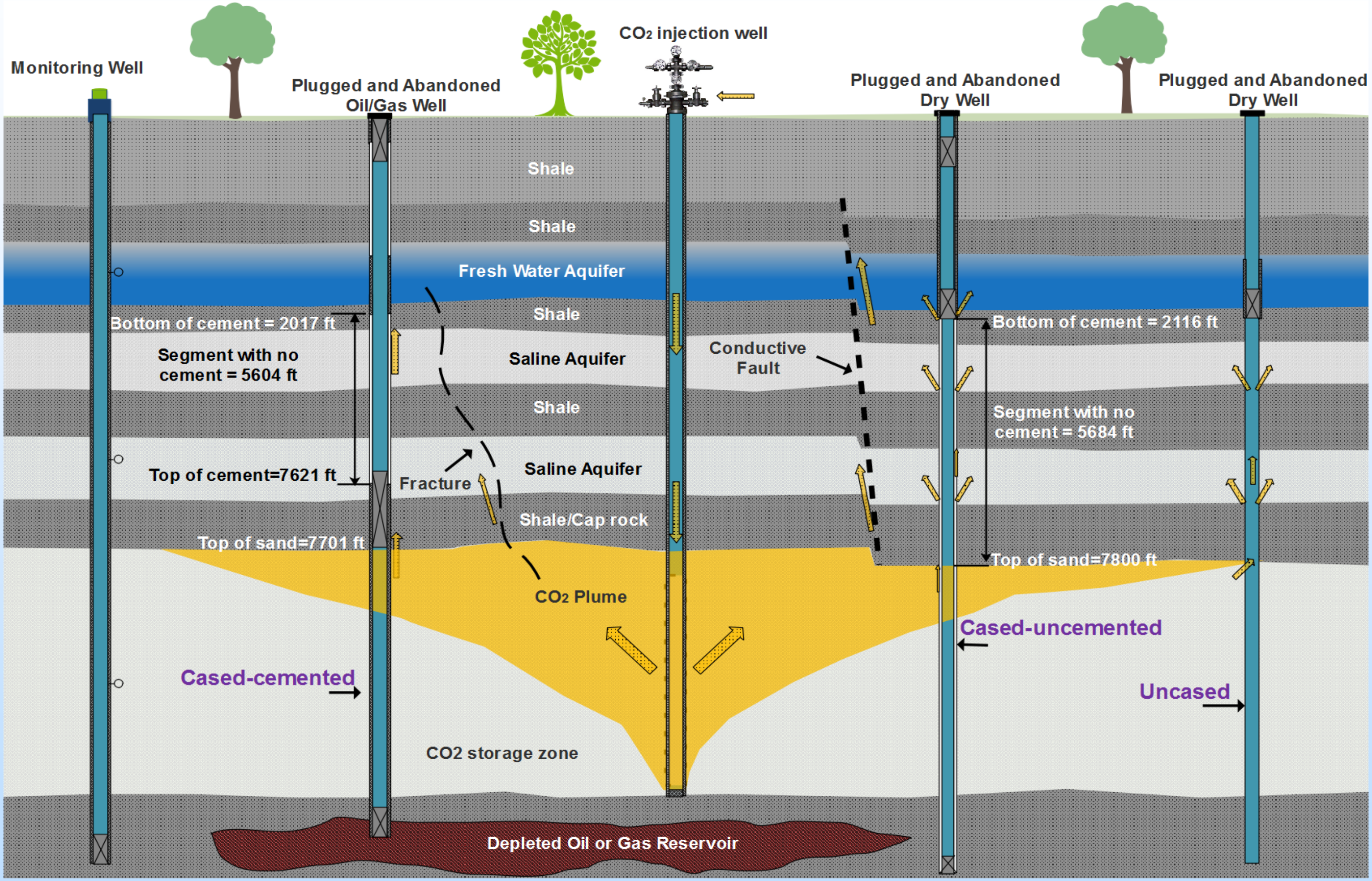
Dynamic Storage Sensitivity



Dimensionless Group	Min	Max
N_α	0.196	1.861
R_L	2.145	9.406
M	2.787	8.956
$N_g \times 10^{-3}$	0.034	100.225
S_{wi}	0.100	0.4



Wellbore CO_2 Leakage Risk



Wellbore CO_2 Leakage Risk

Based on following four parameters

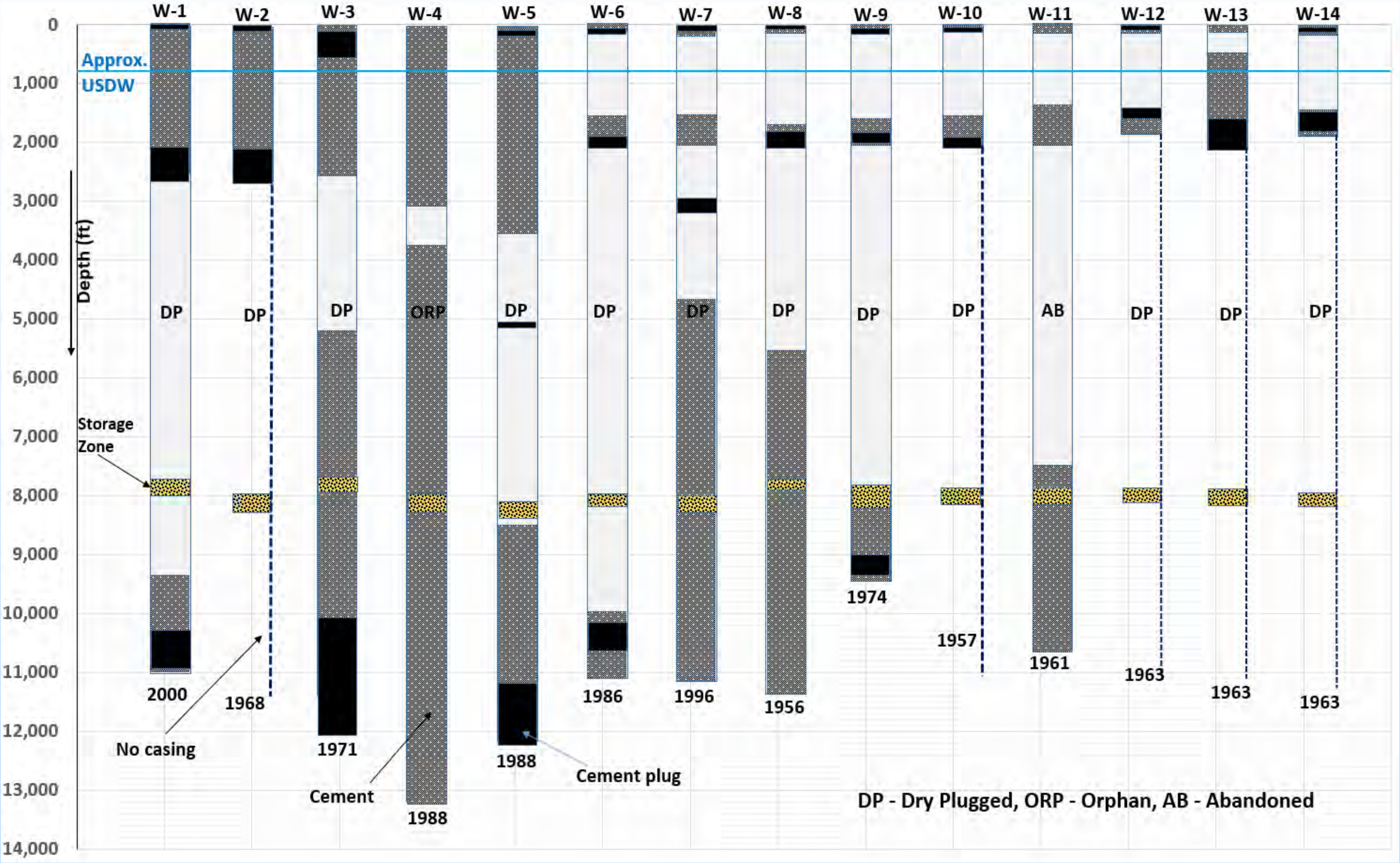
- Wellbore type (Cement Index)-*CI*
- Injector-Leaky well distance(Distance Index)-*DI*
- Overlaying buffer layers (segments) (Layer index)-*LI*
- Storage zone boundaries (Boundary Index)-*BI*

$$Wellbore\ Leakage\ Index\ (WLI) = CI \times DI \times LI \times BI$$

		Assumed ranges	
Variable category	Symbols	Min	Max
Wellbore type (cased-cemented, cased-uncemented, uncased)	cement index (CI)	0	1
Injector-leaky well distance	distance index (DI)	0	1
Buffer layers	Layer index (LI)	0	1
Boundary type (open, semi-closed, closed)	Boundary index (BI)	0	1

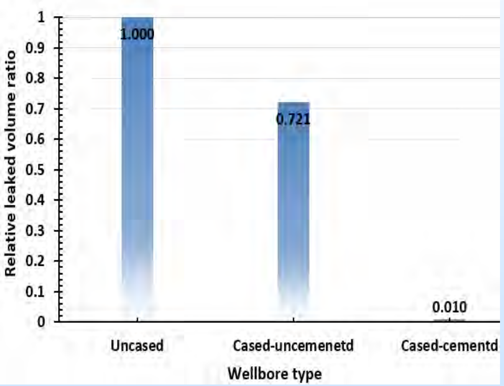
Well Tiers	WLI range	Remarks
1	<=0.03	Wells with minor leakage risk
2	0.03-0.05	Wells with moderate leakage risk
3	>0.05<0.1	Wells with high leakage risk
4	>0.1	Wells with severe leakage risk

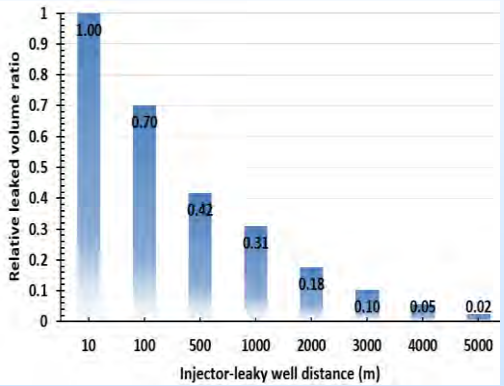
Wellbore CO_2 Leakage Risk (cont.)

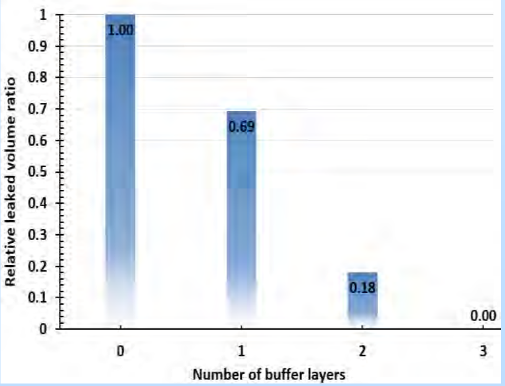


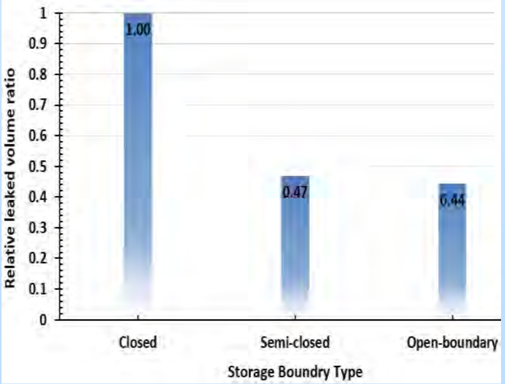
Wellbore CO_2 Leakage Risk (cont.)

- Two wellbore leakage models available in NRAP-WLA toolset are used to model (Multi segment wellbore model (MWM) and Cemented wellbore model (CWM)
- cumulative leakage volume over 30 years for injection rate of 2.64 Mt/y









Minimizing Well Leakage

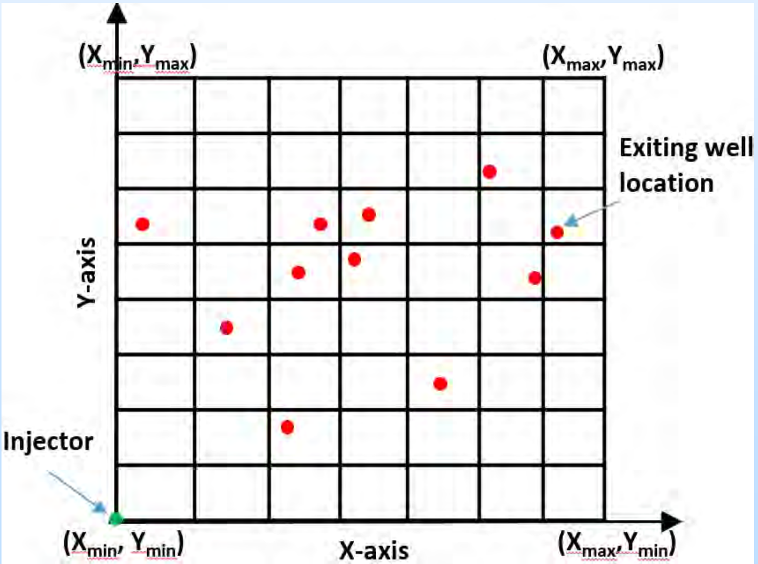
- For a particular well in a specific storage zone the indices SI, LI and BI are fixed, therefore Eq. (5) can be re-written as

$$WLI = (Constant) \times DI = \alpha \times DI \quad (6)$$

A site specific wellbore leakage index can be written as

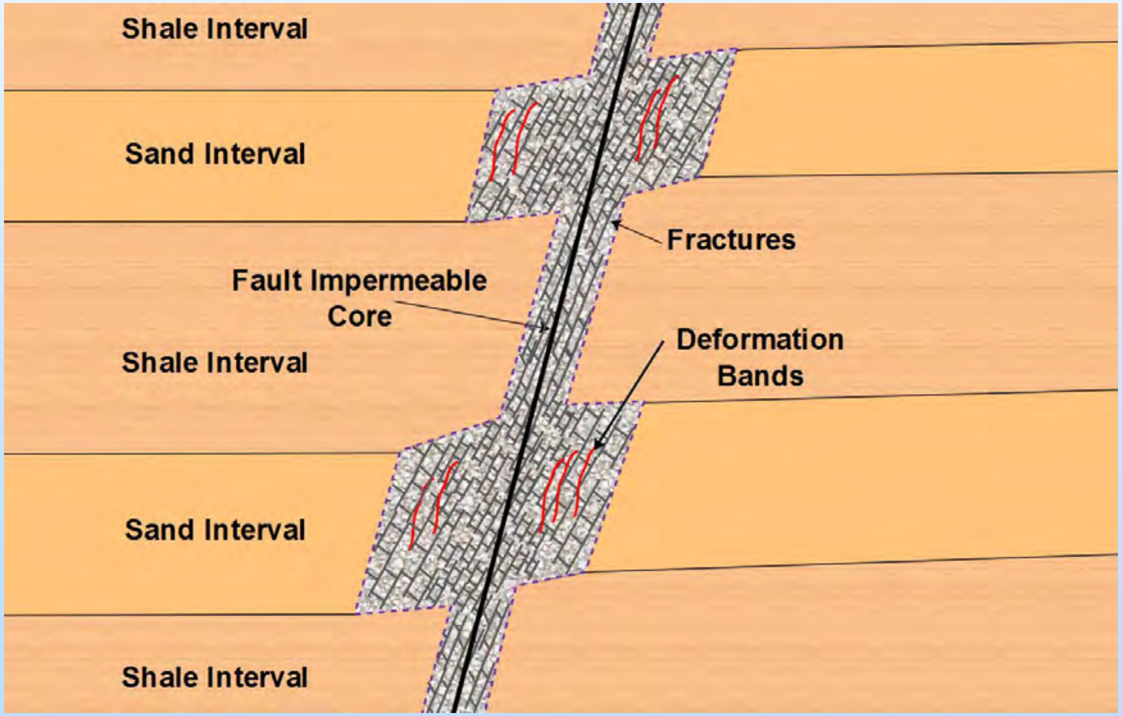
$$SWLI = \sum_{i=1}^{N} \alpha_i \times DI_i$$

$$min \sum_{i=1}^{N} \alpha_i DI_i$$

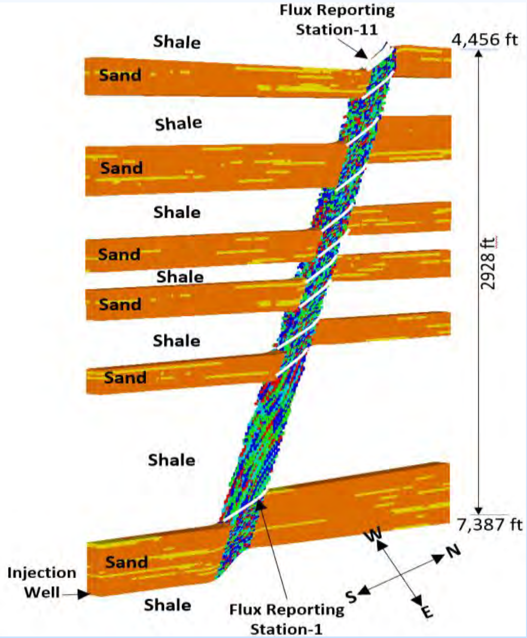


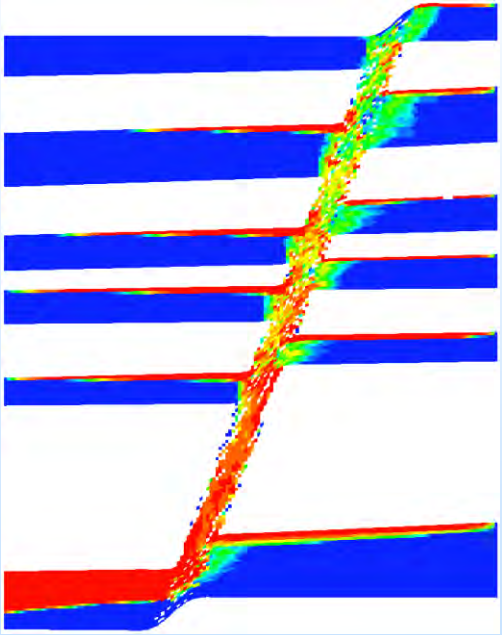
Fault Leakage Modeling

- Estimation of faults leakage potential is an essential component of CO_2 storage integrity analysis
- Fault heterogeneities and associated interplay between dissolution and capillary trapping mechanisms

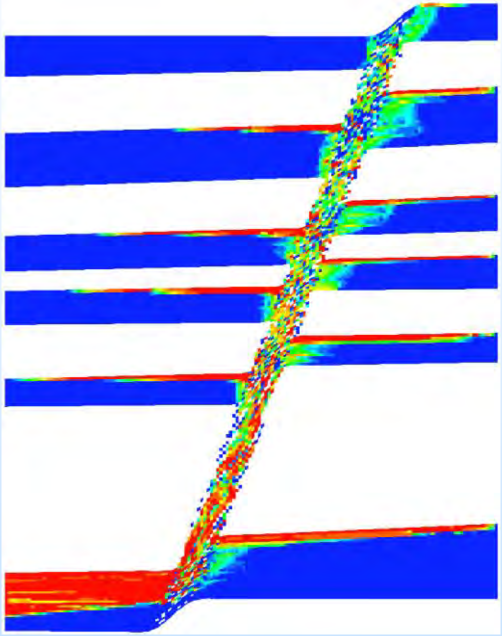


Fault Leakage Modeling



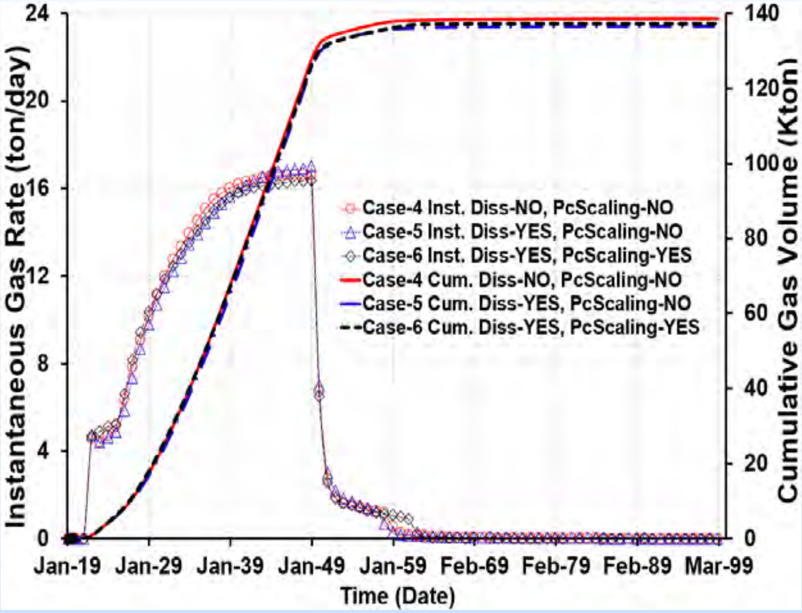


No diss/Pc trapping

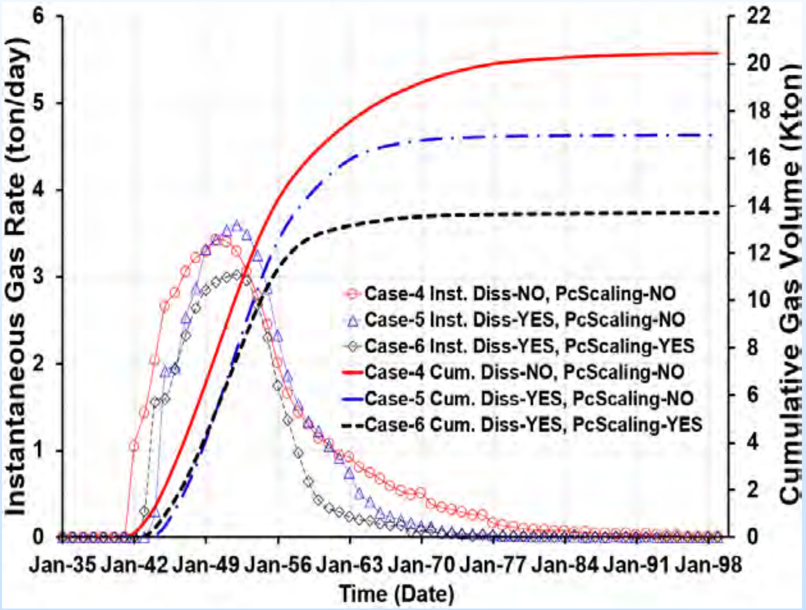


Diss-Pc trapping

Fault Leakage Modeling



(a) station-1



(b) station 10

Accomplishments to Date

- Site specific static and dynamic CO_2 storage capacity estimate obtained for selected interval in two fields;
- Dynamic storage sensitivity to petrophysical properties and operations conditions has been conducted. A correlation is being developed to estimate the dynamic storage efficiency;
- A wellbore leakage risk assessment criteria was developed to identify the wells having relatively higher leakage potential and to find optimal locations of injection wells;
- Fault leakage have been modeled considering fault structure heterogeneities while accounting for capillary and dissolution trapping mechanisms.

Lessons Learned

- Current well leakage models needs enhancements to accommodate varying conditions;
- The large storage capacity of thick interval with high permeability may be under utilized if operational conditions are not optimal. Development of relationships to determine storage efficiency considering operational conditions is required;
- Reservoir models including faults needs to be improved to model high degree of heterogeneity and associated capillary pressure scaling effects;
- Simplistic models on fault leakage and dynamic storage efficiency are required which can the be integrated into current NRAP tools.

Project Summary

- Key Findings.
  - Static and dynamic storage capacity estimates have been performed
  - Sensitivity to petrophysical properties and operational conditions have been performed
  - A risk based criteria have been developed to identify the leakage potential of wells
  - Fault leakage assessment have been preformed considering fault heterogeneities and relevant trapping mechanisms

- Next Steps.
  - Work on seismicity and public acceptance will be finalized and final feasibility report will be provided.

Appendix

The following slides are provided as part of this Appendix:

A. Program benefits
B. Project overview & objectives
C. Team participants
D. Organizational chart
E. Project timeline

Appendix: Program Benefits

- Defining high development probability industrial CO_2 sources and permanent underground sinks within the Louisiana industrial corridor.
- Defining the CO_2 transportation challenges associated with moving captured industrial CO_2 to a permanent underground storage location.
- Identifying the public perception and state legal/regulatory challenges of CO_2 capture and storage.
- Identifying the reasonable business case for CO_2 capture and storage in the Louisiana industrial corridor. "De-risking" future CO_2 capture and storage projects by provided credible, objective and independent information that can lead to a public/private joint demonstration.
- Establishment of baseline natural seismic activity with which to minimize potential future seismic activity.

Appendix:
Project Overview & Objectives

- The objectives of the proposed project are to: 1) develop a multidisciplinary team of stakeholders with interest in carbon capture and storage in the Louisiana Chemical Corridor; 2) analyze the technical and economic feasibility of an integrated carbon capture and storage project that captures at least 50 million tons of CO_2 from one or more industrial sources, transports it via pipeline, and stores it in intrastate underground reservoirs; 3) provide a detailed sub-basinal evaluation of the potential for CO_2 storage in both depleted oil and gas fields and saline reservoirs in South Louisiana.

Appendix:
Team Participants

David E. Dismukes, Economist
Professor & Exe. Director,
Center for Energy Studies &
Department of Environmental Sciences

Juan Lorenzo, Geologist
Assc. Professor
Department of Geology

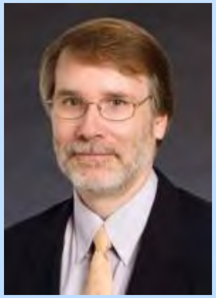
Chacko John, State Geologist
Director and Professor
Louisiana Geological Survey (CES)

Brian Harder, Petroleum Engineer
Research Associate
Louisiana Geological Survey (CES)
(estimated recent photo)

Brian Synder, Ecologist
Asst. Professor
Department of Environmental Sciences

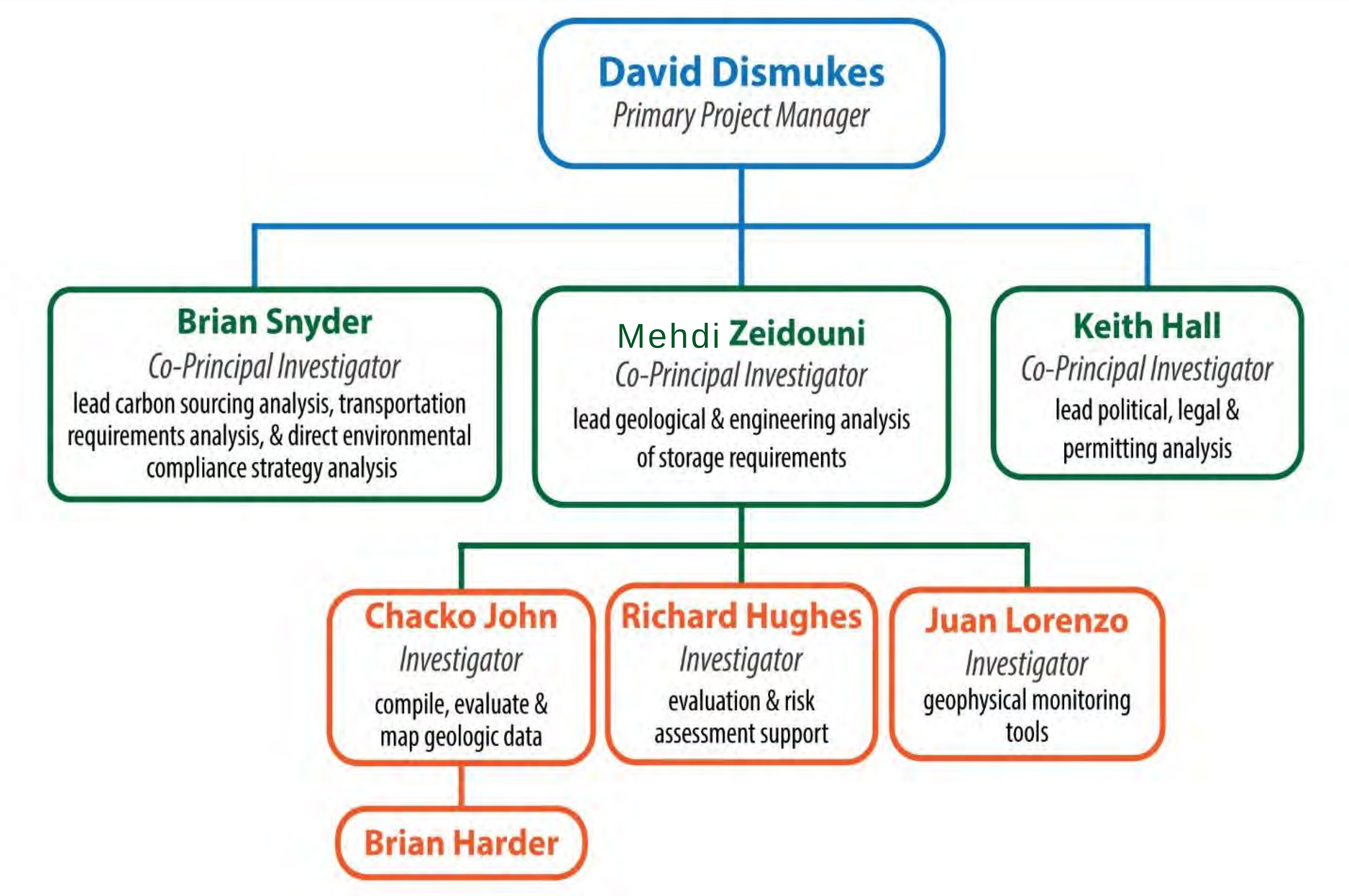
Keith Hall, Attorney
Assc. Professor & Director
Laborde Energy Law Institute

Mehdi Zeidouni, Petroleum Engineer
Asst. Professor
Department of Petroleum Engineering



Richard Hughes, Petroleum Engineer
Professional-in-Residence
Department of Petroleum Engineering

Appendix: Organization Chart



David Dismukes
Primary Project Manager

Brian Snyder
Co-Principal Investigator
lead carbon sourcing analysis, transportation requirements analysis, & direct environmental compliance strategy analysis

Mehdi **Zeidouni**
Co-Principal Investigator
lead geological & engineering analysis of storage requirements

Keith Hall
Co-Principal Investigator
lead political, legal & permitting analysis

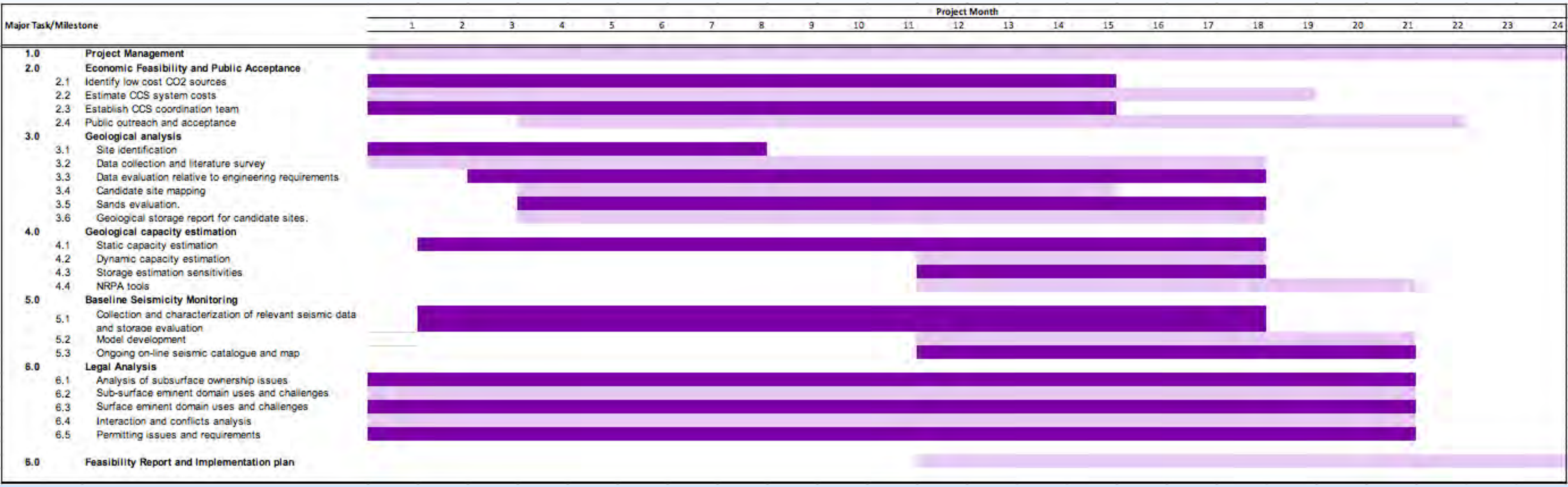
Chacko John
Investigator
compile, evaluate & map geologic data

Richard Hughes
Investigator
evaluation & risk assessment support

Juan Lorenzo
Investigator
geophysical monitoring tools

Brian Harder

Appendix:
Project Timeline (Gantt Chart)



Major Task/Milestone		
1.0		**Project Management**
2.0		**Economic Feasibility and Public Acceptance**
	2.1	Identify low cost CO2 sources
	2.2	Estimate CCS system costs
	2.3	Establish CCS coordination team
	2.4	Public outreach and acceptance
3.0		**Geological analysis**
	3.1	Site identification
	3.2	Data collection and literature survey
	3.3	Data evaluation relative to engineering requirements
	3.4	Candidate site mapping
	3.5	Sands evaluation.
	3.6	Geological storage report for candidate sites.
4.0		**Geological capacity estimation**
	4.1	Static capacity estimation
	4.2	Dynamic capacity estimation
	4.3	Storage estimation sensitivities
	4.4	NRPA tools
5.0		**Baseline Seismicity Monitoring**
	5.1	Collection and characterization of relevant seismic data and storage evaluation
	5.2	Model development
	5.3	Ongoing on-line seismic catalogue and map
6.0		**Legal Analysis**
	6.1	Analysis of subsurface ownership issues
	6.2	Sub-surface eminent domain uses and challenges
	6.3	Surface eminent domain uses and challenges
	6.4	Interaction and conflicts analysis
	6.5	Permitting issues and requirements
6.0		**Feasibility Report and Implementation plan**

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