Integrated Carbon Capture and Storage in the Louisiana Chemical Corridor

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

1) Project Overview
2) Technical Status
3) Research Accomplishments
4) Lessons Learned
5) Next Steps/Future Activities
6) Appendix

Project Overview

Having a **geographically-concentrated** physical location with **diversified sources** will be critical in developing positive feasibility outcomes for an industrial CCS project.

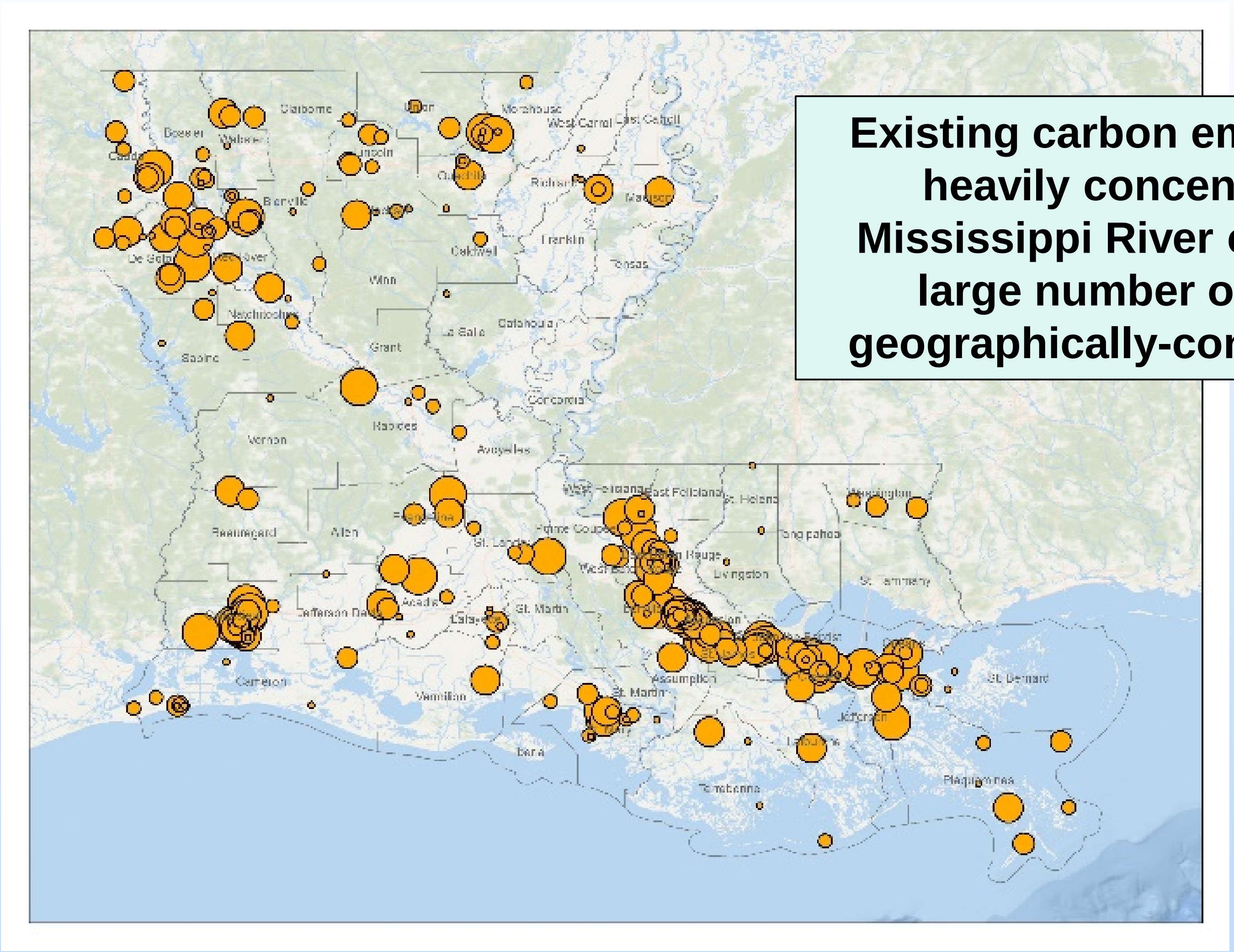
The **Louisiana industrial corridor is a well-suited location** for industrial CCS since:

1) There are a **large number of** geographically-concentrated and diversified **sources** of CO_2.
2) There are a **large number of** geographically-concentrated and diverse **storage locations (or "sinks").**
3) There are sufficient number of opportunities to develop **transportation infrastructure linking supply to storage** in these areas.
4) This is a region with a **long history and commercial experience in moving and storing a number of different hydrocarbons**, as well as other hydrocarbon wastes, into underground geological formations.

Technical Status

Task No.	Major Task Heading (sub-tasks not included)	Status Summary
1.0	**Project Management**	Ongoing
2.0	**Economic feasibility and public acceptance**	All industrial emissions data has been collected. Candidate industrial sites have been identitifed. Developing time series analysis of emissions trends. All typical cost information has been collected. Pro forma model is close to finalized. Public outreach ongoing.
3.0	**Geological analysis**	Two sink example (candidate) locations have been identified and analysis are underway on both locations. Little information on candidate locations so requiring new research. Characterization of both candidate locations is completed. Mapping has been completed. Prelliminary sands analysis completed, analysis ongoing. Development of candidate sites report ongoing.
4.0	**Geological capacity estimation**	Static estimation of the capacity for candidate site has been conducted, dynamic analysis is ongoinig. Reservoir model has been developed. Sensitivities have been identified, and conducted, for storage capacities. Risk assessment analysis ongoing utilizing NRAP tools.
5.0	**Baseline seismicity monitoring**	Baseline seismicity work is ongoing.
6.0	**Legal analysis**	Legal analysis is ongoing.

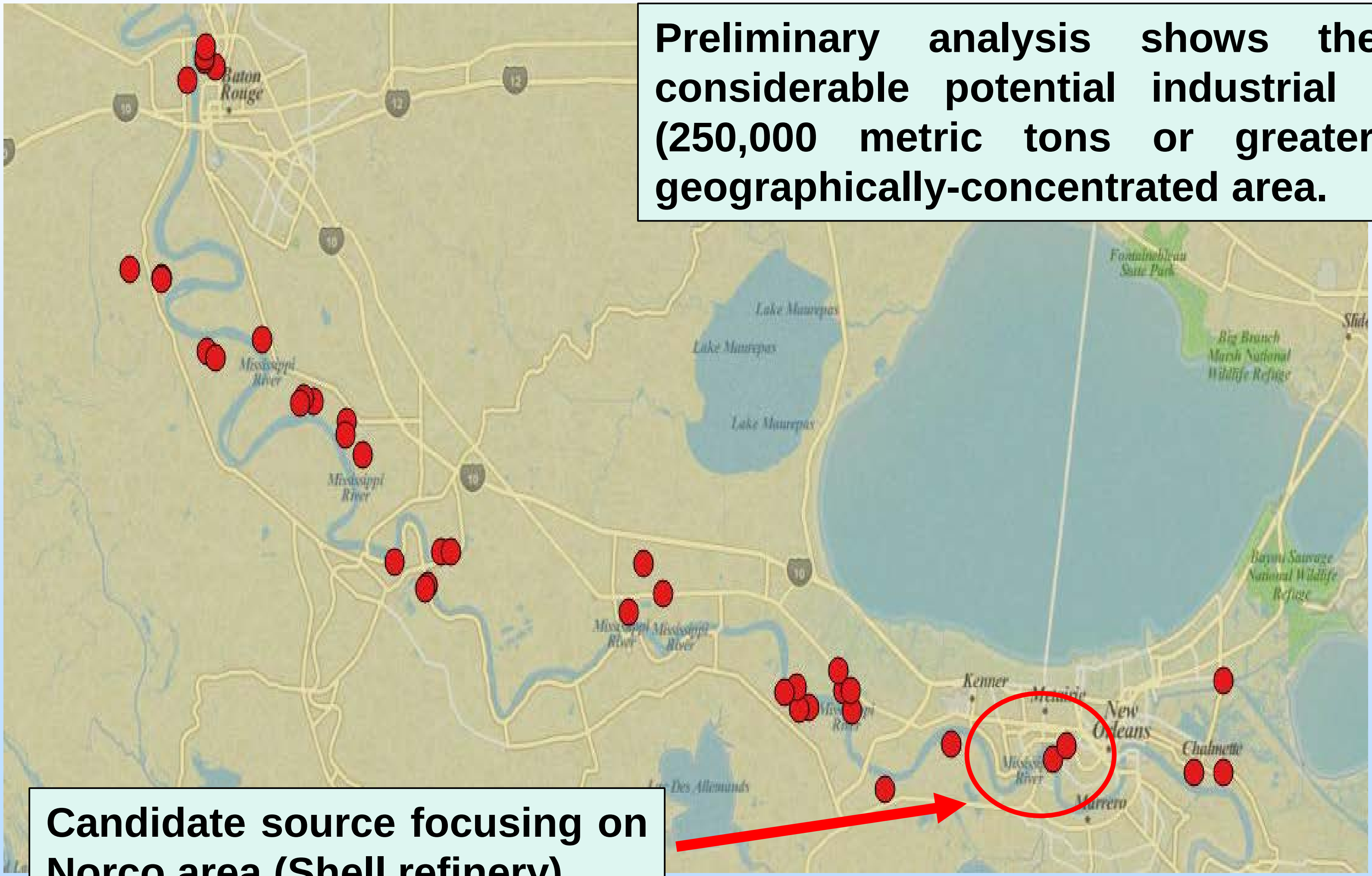
Research Accomplishments: Industrial Sources (statewide)



Existing carbon emission sources are heavily concentrated along the Mississippi River corridor and offer a large number of diversified and geographically-concentrated sources.

Research Accomplishments: Industrial Sources (corridor)

Preliminary analysis shows there are considerable potential industrial sources (250,000 metric tons or greater) in a geographically-concentrated area.



Candidate source focusing on Norco area (Shell refinery).

Research Accomplishments: Top Industrial Sources (totals)

Large number of industrial and power plant source. Shell Norco refinery is the larges source that is in relatively close proximity to our candidate sinks (Bayou Sorrel and Paradis)

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

Research Accomplishments: Top Industrial Sources (detail)

Norco's emissions are from combination of stationary combustion, chemical operations and refinery operations.

	CO_2 Emissions (mt)				
Facility	**Electricity Generation**	**General Stationary Combustion**	**Petrochemical Production**	**Oil Refining**	**Ammonia Manufacturing**
Big Cajun 2	10,624,054				
Brame Energy Center	6,725,251				
ExxonMobil Baton Rouge		4,434,125	26,892	1,784,412	
CF Industries Nitrogen		2,167,559			3,221,019
CITGO Lake Charles		3,551,025		1,215,390	
Marathon Petroleum Company		2,813,182		1,116,840	
Norco Manufacturing Complex		2,339,431	41,165	1,147,395	
R S Nelson	3,488,406	25,059			
Dolet Hills Power Station	2,943,833				
Saint Charles Operations - Dow		2,618,538	263,436		
Total	**23,781,544**	**17,948,919**	**331,493**	**5,264,037**	**3,221,019**
Approximate CO2 Purity (%)[1]	14-Dec	8	Variable	13-Mar	>95

Research Accomplishments: Top Industrial Sources (trends)

Emissions have been decreasing over the past several years at most of the major facilities. Decreases of close to 19 percent for Norco.

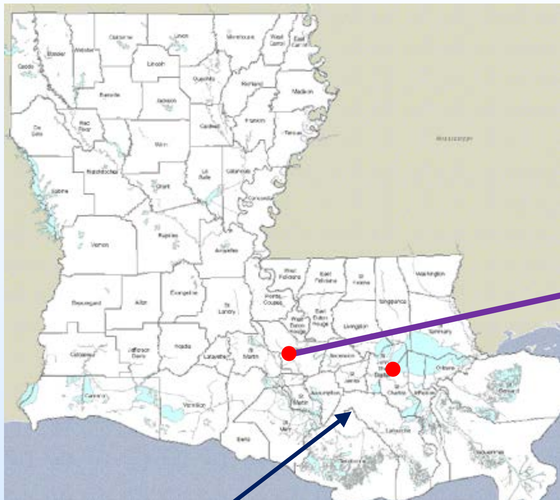
	CO_2 Emissions (mt)				
Facility	**2011**	**2012**	**2013**	**2014**	**Period percent change**
Big Cajun 2	12,364,281	10,010,815	10,776,236	10,624,054	-14.1%
Brame Energy Center	7,041,800	5,344,280	7,628,309	6,725,251	-4.5%
ExxonMobil Baton Rouge	6,213,948	6,417,019	6,302,931	6,245,428	0.5%
CF Industries Nitrogen	5,326,035	5,201,108	5,312,449	5,388,579	1.2%
CITGO Lake Charles	4,486,368	4,346,027	4,561,286	4,766,415	6.2%
Marathon Petroleum Company	3,893,234	3,934,015	3,918,742	3,930,022	0.9%
Norco Manufacturing Complex	4,355,162	3,961,999	3,498,212	3,527,991	-19.0%
R S Nelson	4,961,983	4,559,708	4,350,949	3,513,465	-29.2%
Dolet Hills Power Station	5,021,895	5,151,445	3,350,478	2,943,833	-41.4%
Saint Charles Operations - Dow	1,932,566	2,069,376	2,794,800	2,881,974	49.1%
Total	**55,597,272**	**50,995,792**	**52,494,392**	**50,547,012**	**-9.1%**
Annual Percent Change		-8.3%	2.9%	-3.7%	
Compounded Percent Change				-2.4%	

Research Accomplishments: Industrial Sources: typical costs

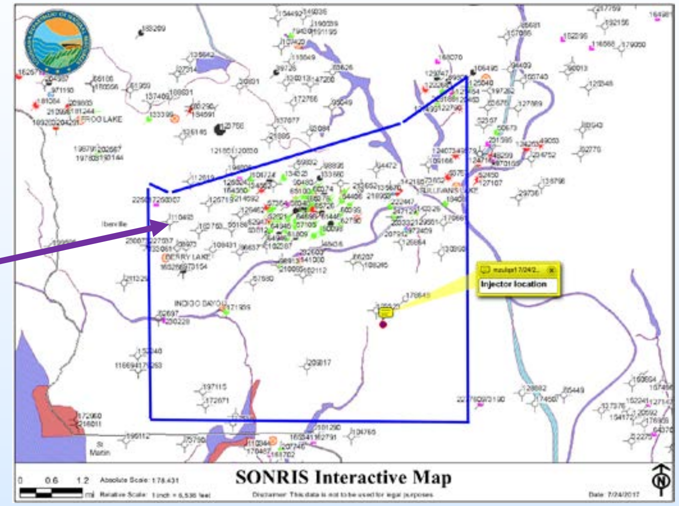
Project	Year	Emission source	Plant Modification	Capital Investment (Millions $)	Capacity (mt/year)	Unit Cost ($/mt)	Other costs included	Project status
Air Products Port Arthur	2013	SMR	Yes	$ 431,000,000	1,000,000	$ 431.00	Transport	Operating
Quest	2015	SMR	Yes	1,350,000,000	1,200,000	1,125.00	Total project costs	Operating
Alberta Carbon trunk Line	2017	Ammonia/refinery	Yes	1,200,000,000	2,000,000	600.00	Total project costs	Operating
Coffeyville	2013	Ammonia	Yes	250,000,000	800,000	312.50	Total project costs	Operating
Century Plant	2010	Ammonia	Yes	1,100,000,000	8,400,000	130.95		Operating
NETL Model	2013	Ammonia	Yes	143,570,880	458,400	313.20	None	Theoretical
NETL Model	2013	Ethylene oxide	Yes	35,903,545	121,501	295.50	None	Theoretical
NETL Model	2013	SMR	Yes	339,887,646	273,860	1,241.10	None	Theoretical
Lake Charles-Leucadia	2014	Coke-to-liquids	No	$ 435,000,000.00	4,500,000	$ 96.67	12 mile transport	Cancelled
Average				**$ 587,262,452**	**2,083,751**	**$ 505.10**		
Average of existing plant modifications				606,295,259	1,781,720	556.16		
Standard deviation				606,795,259	2,219,220	514.36		
Std deviation of existing plants				$ 523,372,955	2,739,752	$ 410.13		

- **Costs are large.**
- **Retrofit costs are more expensive, but not by significant amount.**
- **Cost variation is very large.**

Research Accomplishments: Bayou Sorrel Location

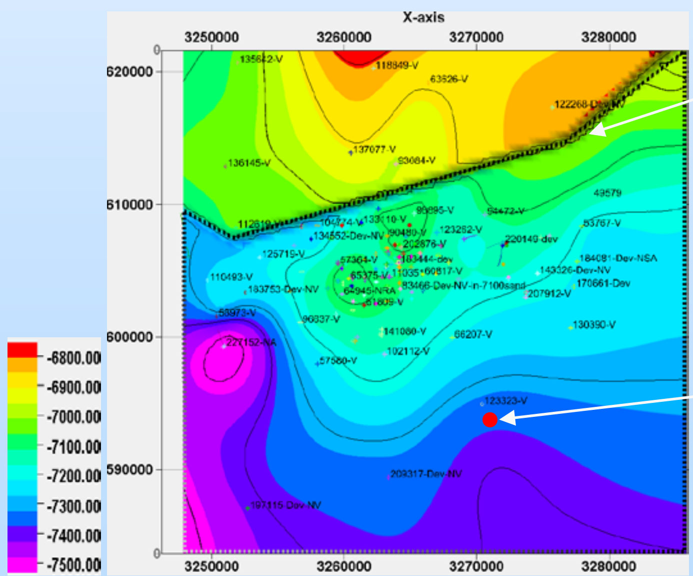


Approximate location of potential storage site



Approximate site boundaries and well locations

Shell refinery.



Fault

Approximate Injector location

Contour map of the top surface of storage zone

Research Accomplishments: Static and Dynamic Storage

– **Static storage capacity**

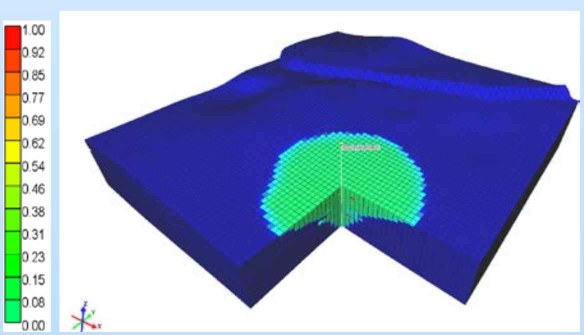
- 1,000 ft interval at an average depth of 7,100 ft

Median Depth (m)	Thickness (m)	Area (m2)	Density (Kg/m3)	Porosity Average	Storage Efficiency factor	Capacity (Mt)
2225	298.70	1.05E+08	759.00	0.28	0.02	133.11

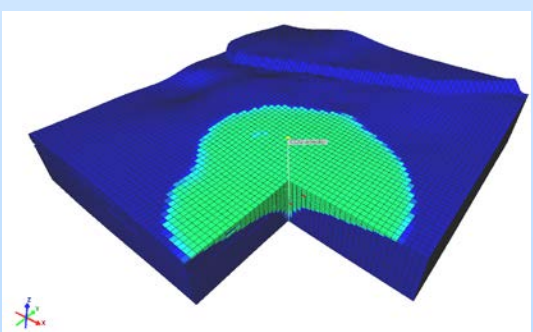
– **Dynamic storage**

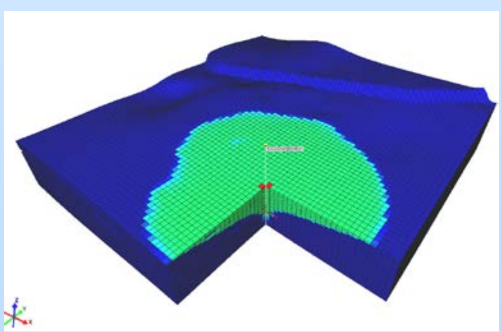
Injection Rate (Mt/y)	Zone Boundary	Capacity (Mt)	Storage Efficiency factor
2.64	Closed	93.50	0.014
	Semi-closed	129.59	0.019
	Open	132.22	0.020

CO_2-Plume extent



Closed boundaries


Semi-closed boundaries


Open boundaries

Research Accomplishments: Wellbore CO_2 Leakage Risk

Based on following four parameters

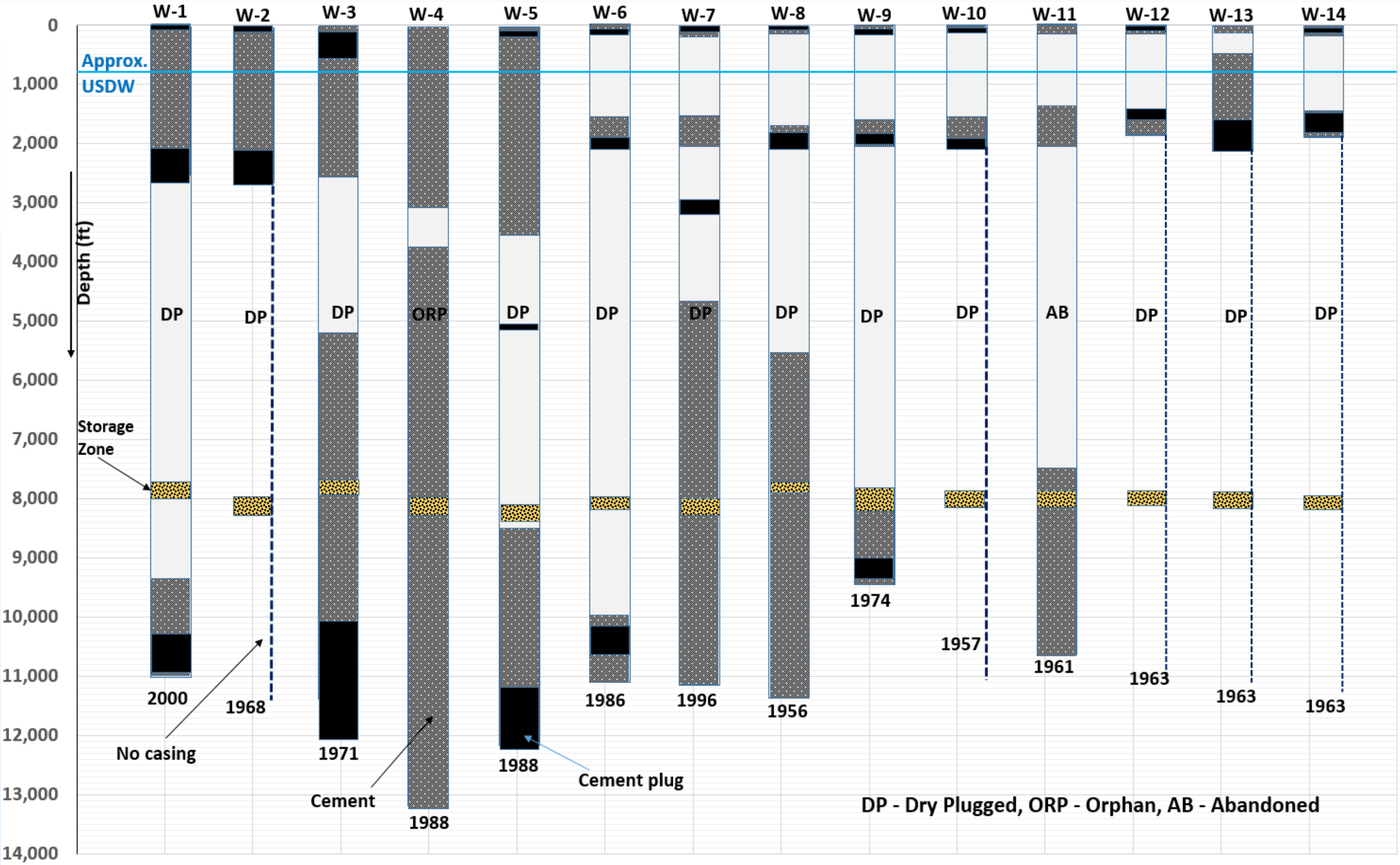
- Wellbore type (Cement Index)-*CI*
- Injector-Leaky well distance(Distance Index)-*DI*
- Overlaying buffer layers (segments) (Layer index)-*LI*
- Storage zone boundaries (Boundary Index)-*BI*

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

		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

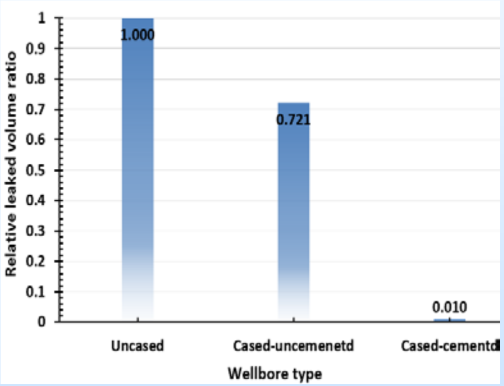
Well Tiers	WLI range	Remarks
1	<=0.03	Wells with minor leakage risk
2	0.03-0.05	Wells with moderate leakage risk
3	>0.05<0.1	Wells with high leakage risk
4	>0.1	Wells with severe leakage risk

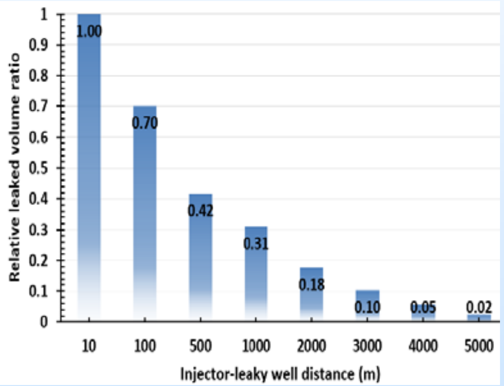
Research Accomplishments: Wellbore CO_2 Leakage Risk(cont.)

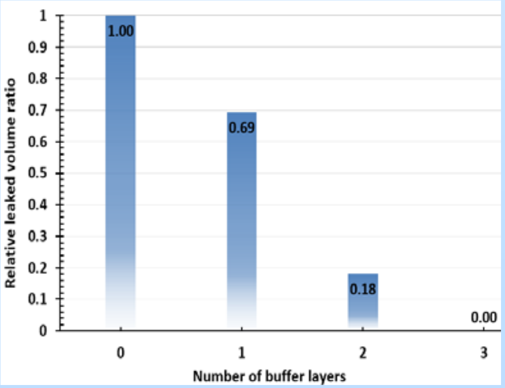


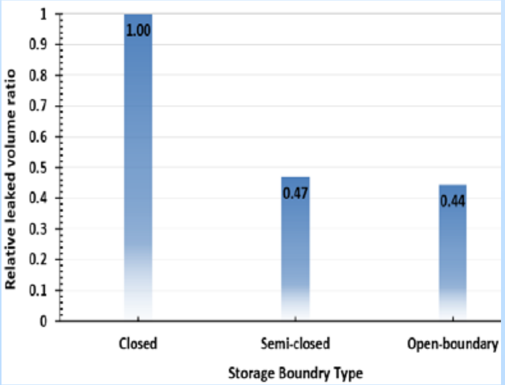
Research Accomplishments: Wellbore CO_2 Leakage Risk (cont.)

- 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









Lessons Learned: Research Gaps & Difficulties

- Industrial capture cost information is limited.
- Some emissions data from high producing sources (ethylene oxide) are simply unavailable.
- A unified wellbore leakage model needs to be developed, that can work under a variety of operating conditions and wellbore types.
- Numerical modeling of storage zones with high degree of heterogeneity (shale-sand streaks) is problematic. Numerical schemes becomes unstable under some operating conditions.

Lessons Learned: Technical Disappointments

- The wellbore leakage models seems to provide inconsistent results under some circumstances and improvements are needed. These models may needs to be validated with experimental or field data.
- Industry discussions have resulted in considerable interest but very little action. Difficult to get industry engaged at this point, despite the fact that they see both the merit and geographic specific opportunity in Louisiana for these types of applications.
- Pipeline development is going to be a sticky widget. An issue filled with economic and financial risks.

Next Steps & Future Activities

– Discussions with stakeholders on concerns and barriers to industrial CCS projects.

– Initial runs on economic feasibility models and standardized costs on modeled location.

– Finalize capacity estimation and characterization.

– Continued baseline seismicity analysis.

– Continued risk assessment.

– Continued legal analysis.

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.

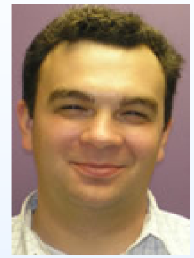
Appendix: Team Participants

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

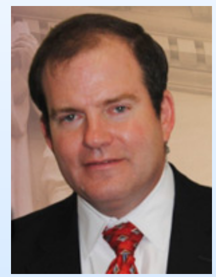
Juan Lorenzo, Geologist
Assc. Professor
Department of Geology

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

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

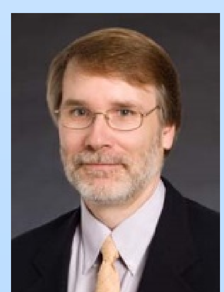


Brian Synder, Ecologist
Asst. Professor
Department of Environmental Sciences



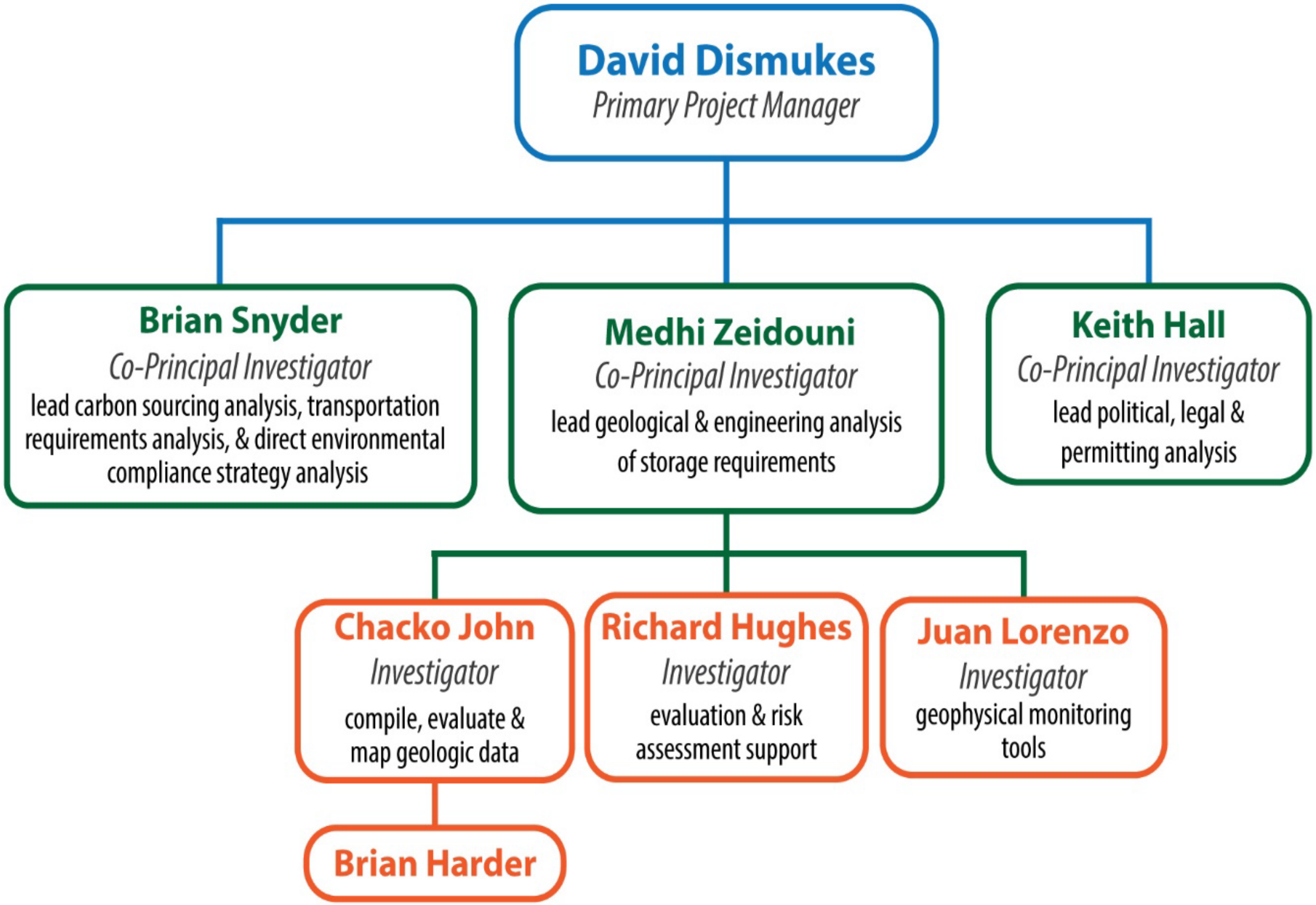
Keith Hall, Attorney
Assc. Professor & Director
Laborde Energy Law Institute

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



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

Appendix: Organization Chart



Appendix: Project Timeline (Gantt Chart)

Appendix: Bibliography

- Several presentations have been given to date that are supported by this project's research.
- To date, no articles have been published from this research, but several are under development or have been submitted to journals and are under review.