FINAL RESEARCH PERFORMANCE PROGRESS REPORT

U.S. Department of Energy National Energy Technology Laboratory

Cooperative Agreement: DE-FE0029487

Project Title: CarbonSAFE Phase I: Integrated CCS Pre-Feasibility – Northwest Gulf of Mexico

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EXECUTIVE SUMMARY

Offshore storage achieves two major objectives for the US commercial large scale CCS deployment:

1. Adding large capacity to serve local regional, and potentially broader objectives
2. Lowering risk by providing storage with one public owner, away from population, with no conflict with water resources and reduced concern about induced seismicity.

A high-concentration CO_2 source was identified as the top candidate for the project and going forward with the CarbonSAFE Phase II proposal. The top-rated source is the NET Power facility in Houston (La Porte), Texas.

A manuscript based on analysis of results from the two-stage survey conducted in eight selected Texas counties (Brazoria, Chambers, Liberty, Galveston, Jefferson, Orange, Fort Bend and Harris) was submitted to the International Journal of Greenhouse Gas Control on August 21, 2018.

A primary confining interval (seal) is associated with MFS9 (biochronozone *Amphistegina B)* which can reach a thickness of up to 250 m. However, the *Amphistegina B* confining interval thins considerably in the onshore direction. Consequently, the most suitable portion of the Miocene section for future CO_2 sequestration in the study area is considered to be the offshore area where *Amphistegina B* is thickest.

Based on three models for capacity assessment, the study proposes a base case for the High Island 10-L Field in which 9 wells operated for 12 years each completed into 4 zones will emplace **a total of 150MMT** of CO_2 with wells placed in the water leg where all the plume will slowly migrate into the structural trap is feasible in terms of geology and engineering.

The 10-L Field was assessed in more detail than other examined oil and gas fields in the study area in order to look at some specifics about how initial future CCS projects might be accomplished in the favorable GoM of the US region and expand the sites to a larger set to experiment with matching all the possible sources to sinks. The 10-L site is large enough to accept CO_2 from multiple sinks; the expanded sinks are estimated to be large enough to accept all the CO_2 from the region plus some from outside the region.

A number of uncertainties were identified. The largest and most consequential uncertainty is the cost of offshore pipelines in the study setting, which impacts the conditions where CO_2 transport would be by ship versus the cases where pipeline would be preferred. Ships are preferred for small volumes and short durations; pipelines for larger volumes and long duration. Additional work is needed to advance the maturity of multiple sinks available, to continue outreach to industries and the public, and to develop realistic source opportunities.

The study demonstrates that industrial source clusters connected to a transport hub delivering CO_2 to a nearby storage complex is the most cost-effective and improved way to de-carbonize industrial activities, particularly, in an expected low-carbon and increasing carbon price environmental. The feasibility of the new business models should be based on the best use of the existing infrastructure and strategically build on new supporting infrastructure to drive down the costs of large-scale CCS deployment. Assessing the pre-feasibility of the commercial implementation of a CCS cluster and hub in the GoM energy ecosystem, our study links these elements successfully through an optimized combination (minimum cost) of CO2 sources on land with offshore storage.

Offshore storage achieves two major objectives for the US commercial large scale CCS deployment:

1. Adding large capacity to serve local regional, and potentially broader objectives
2. Lowering risk by providing storage with one public owner, away from population, with no conflict with water resources and reduced concern about induced seismicity.

Task 1.0 – Project Management, Planning, and Reporting

The project's signed award document was received on March 3, 2017. However, with previous assurances from NETL that the contract would be signed with a start date of February 1, 2017, the project co-PIs initiated working on the project in late February. (See Task 2.) Similarly, the project PI at Lawrence Livermore National Laboratory (LLNL) informed the Bureau of Economic (BEG) co-PI's on March 27 that the FWP (Field Work Proposal) was in place.

Co-Principal Investigator, Dr. Susan Hovorka, presented the project overview at the project kick-off meeting at NETL offices in Pittsburgh, PA on March 14-15, 2017 (Figure 1.1).

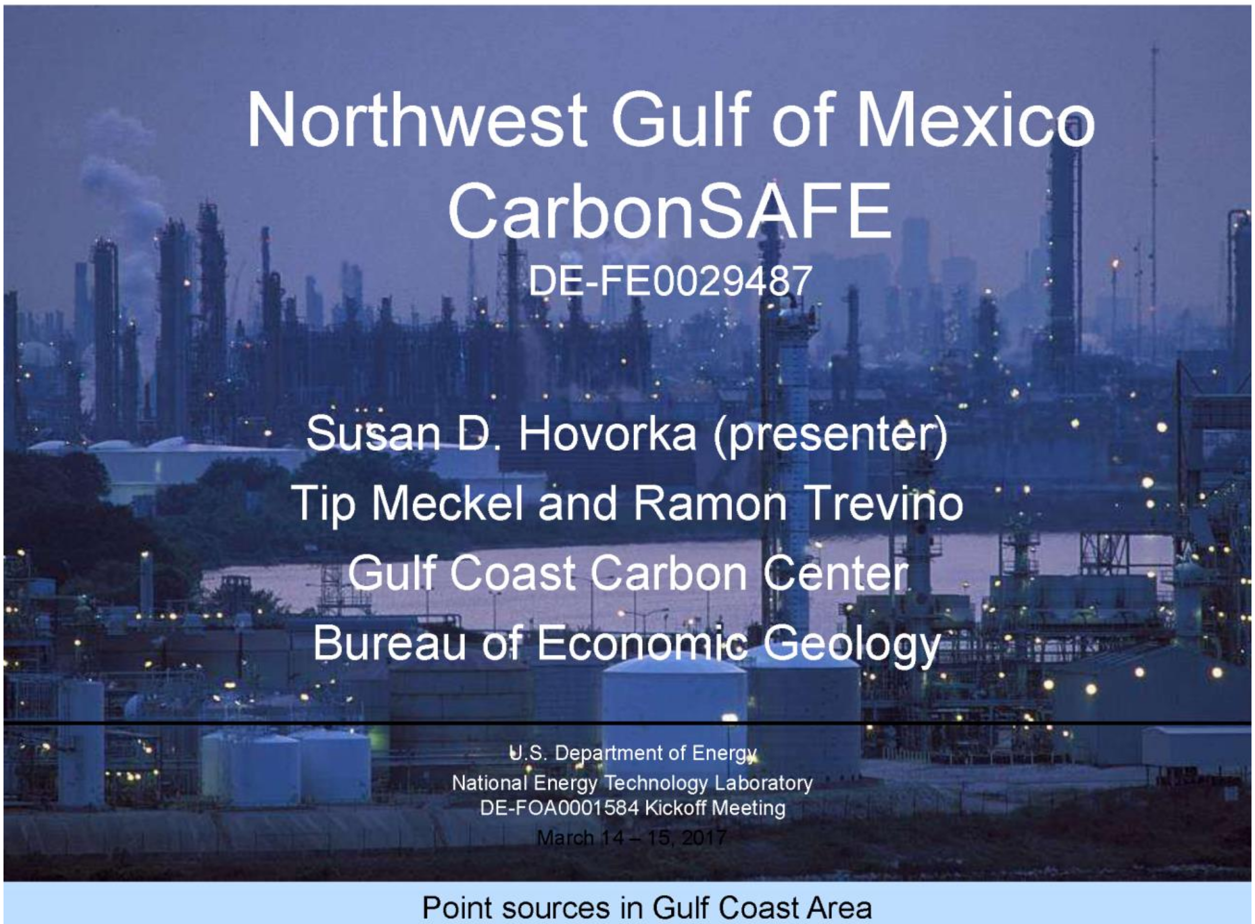

Figure 1.1 – Title slide of the project's kick-off meeting presentation.

The project established "letters of agreement" (LOA) between BEG and the University of Texas Stan Richards School of Advertising and the UT Cockrell School of Engineering, Department of Petroleum and Geosystems Engineering. Two project researchers are, respective, members of the institutions, and LOA's were necessary. A sub-agreement was also established with Lamar University.

On June 27, 2017, a service agreement was established with Trimeric Corp. after it was recognized that Trimeric's expertise was needed for successful completion of the project. (See Subtask 2.1.)

Two Graduate Research Assistants (GRA), Peter Tutton and Reynaldy Fifariz were hired. Fifariz worked on geologic characterization. Tutton analyzed the distribution of CO_2 hubs and worked closely with Trimeric Corporation.

The project provided NETL Project Officer, Dr. Jerry Carr, with a review and status report during Carr's site visit to BEG (Bureau of Economic Geology) on June 29, 2017.

In the late spring of 2018, the team reviewed presentations by graduate student Emily Beckham (fellowship-supported) and graduate research assistant (project-supported) Peter Tutton. Both students researched some of the project's topics. Beckham worked on subtask, 3.1 and Tutton on 2.1. The students also presented results of their research to the Jackson School of Geoscience community and other members of the public at the School's "Masters Saturday" end of semester event.

Data from the project were uploaded to EDX.

Preparations for winding down the project accelerated when the team was informed in mid-May, 2018 that the proposal for CarbonSAFE Phase II had been unsuccessful.

Reports for deliverables 2, 3, 4 and 5 were prepared during the final quarter of the project and submitted before the (current) final project report.

Task 2.0 – CCS Coordination Team Formation (FOA Objective 1)

As reported in Milestone 3, the first meeting of the Project's Coordination Team occurred on February 28, 2017 at the Bureau of Economic Geology's Houston Research Center, 11611 West Little York Rd, Houston, Texas 77041 (Figure 2.1). Meeting attendees are listed in Table 2.1.

Figure 2.1 – Agenda of the project's first Coordination Team meeting.

One outcome of the meeting was the establishment of a "UT-Box" site that allows coordination team members to share documents as needed. The site included a list of the meeting attendees and their contact information, a basemap of the project area of interest, the PowerPoint file used during the meeting by project PI, Dr. Tip Meckel and reference articles about CCS (e.g., public perceptions, stakeholders concerns, etc.). Dr. Meckel presented some of the basics of CCS in order to provide a foundation for discussion especially for those team members for whom CCS is a new concept (Figure 2.2). Much of the meeting was dedicated to introductions, information exchange and discussions of the various participants' questions and concerns about CCS in general and the CarbonSAFE Phase I: Integrated CCS Pre-Feasibility – Northwest Gulf of

Mexico Project in particular. Various follow-up conference calls were planned and subsequently convened to deal with specific topics of interest to Coordination Team members:

Table 2.1 – List of attendees of the first Coordination Team Meeting.

First Name	Last Name	Title	Company
Ellen	O'Connell	Market Manager, Large Project Business Development	Air Products
Hilton	Kelley	Founder/ Executive Director	CIDA, Inc.
Melvin	White	Executive Director	Digital Workforce Academy
Gary	Teletzke	Senior Technical Advisor	ExxonMobil Upstream Research
Jeff	Hayes	President	Hayes Real Estate
Bart	Owens	Business Development Manager	Howard Energy Partners
Daniel	Chen	University Professor & Scholar	Lamar University
Paul	Latiolais	Director, Innovation Center	Lamar University
Tracey	Benson	Associate Professor	Lamar University
Tanya	Wickliff	COO	Meltantec
Cortlan	Wickliff	General Counselor & Chief R&D Engineer	Meltantec
Russel	Buss	Chemical Engineer	Retired
Jamie	Olson	Sustainability Program Associate	The Cynthia & George Mitchell Foundation
Hilary	Olson	Research Scientist Associate	The University of Texas at Austin
Joe	Lundeen	VP / PJM	Trimeric Corporation
Tip	Meckel	Research Scientist	UT-Austin, BEG - GCCC
Rebecca	Smyth	Project Manager / Hydrogeologist	UT-Austin, BEG- GCCC
Ramon	Trevino	Project Manager	UT-Austin, BEG- GCCC

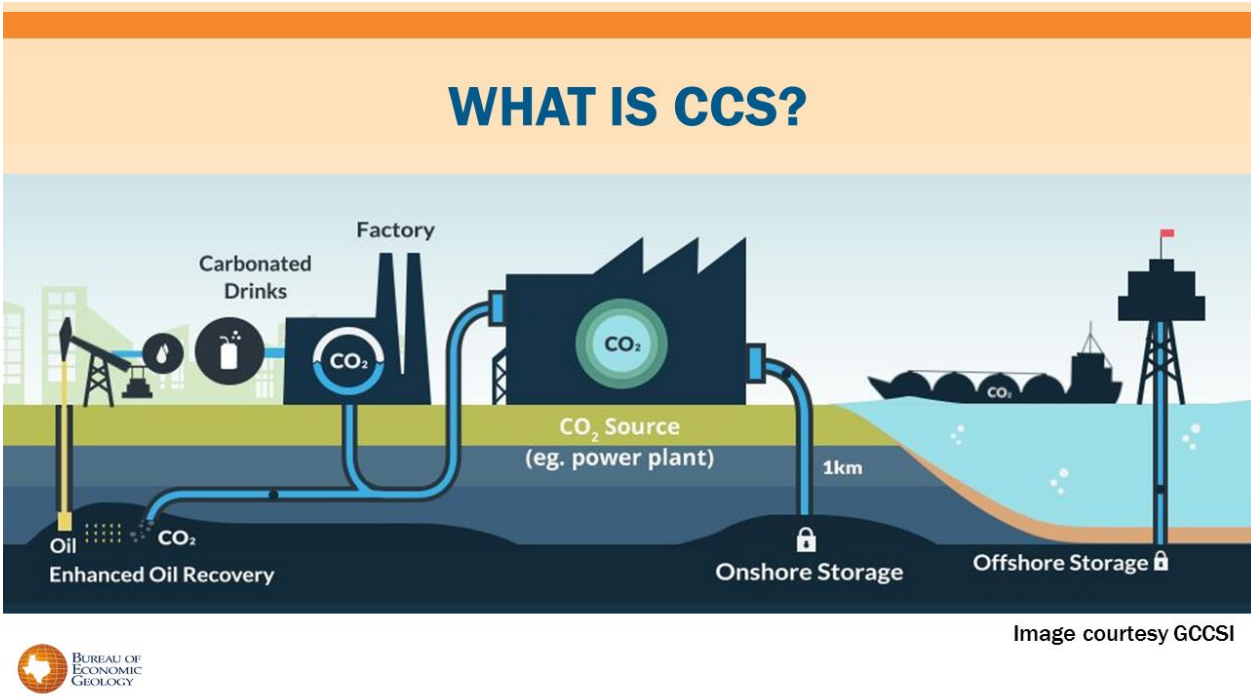

Figure 2.2 – Schematic figure explaining the general concepts related to CCS. The figure was presented by PI Meckel to the Coordination Team members as part of an introductory presentation.

1. The first conference call was held on May 2, 2017. The theme was "capture." In attendance were ExxonMobil and 8-Rivers Capital (NetPower). The discussion included how much it would cost to retrofit a refining facility to capture CO_2. The estimate was near $1 Billion. NetPower said that their demonstration facility could provide about a dozen tonnes per hour once it was operational.
2. The second conference call's topic (May 4, 2017) was "transportation." Discussion included considering existing pipelines in the upper Texas coastal area (using existing rights of way, using the existing Denbury "Green line," etc.). In attendance were representatives from Digital Workforce Academy, CIDA, Inc., Melantec, ExxonMobil, Air Products, Wood Group/Mustang, and UT-BEG. Also in attendance was Brian McDougal City Manager of Port Arthur, TX.
3. Topic for the third conference call (May 5, 2017) was "storage security." Attendees included representatives from CIDA, Inc., ExxonMobil and UT-BEG. Discussions included the history of CO_2 geo-sequestration, the possibility of onshore storage sites and community points of contact (a.k.a. opinion leaders).
4. Topic for the fourth conference call (May 8, 2017) was "outreach." The discussion focused on the upcoming outreach event in late June, 2017 at Lamar University (Beaumont, TX) and field trip to the Port Arthur, TX area. (See subtask 4.3, below.)

A consensus result from several of the conference calls was the need to consistently and continuously engage local community leaders to receive feedback and provide answers to their concerns. For example, items that were mentioned included the need for good jobs, protection of the environment (e.g., protection of natural resources such as fishing/angling that enhance economic activity). Also, a short list of possible contacts was provided.

As reported in Milestone 8, the second meeting of the Coordination Team was convened by co-PI Dr. Susan Hovorka via WebEx on March 12, 2018. Dr. Hovorka was assisted by PI, Dr. Tip Meckel, Dr. Hilary Olson, Dr. Stavana Strutz and graduate research assistant, Peter Tutton.

Dr. Hovorka introduced the meeting participants and provided an outline for the meeting. She also discussed transportation options (e.g., truck, ship, rail, pipeline) based largely on the work of project consultant, Trimeric Corporation. Peter Tutton contributed a summary of the high-quality CO_2 sources in the Port Arthur and Houston, Texas areas, respectively.

Dr. Meckel provided an overview of the project and an in-depth summary of the La Porte, Texas NET Power demonstration plant and its innovative “Allam Cycle” power generation technology. Dr. Meckel also summarized the geologic setting of the southeast Texas near-offshore region and three currently prospective carbon storage sites, historical petroleum fields 10L, 24L and 60S.

Dr. Olson reviewed efforts of the outreach team members (i.e., the University of Texas (UT) and Lamar University) and listed the groups that the team had contacted and engaged (e.g., Greater Beaumont and Port Arthur Chambers of Commerce, Golden Triangle Empowerment Center, Texas Shrimp Association, GTBR, T&L Solutions, LLC, Port Arthur International Seafarers Association, JBS (shrimp) Packing, Texas Parks and Wildlife, McFadden National Wildlife Refuge, etc.). Dr. Olson also summarized the results of a survey of eight southeast Texas counties overseen by Dr. Lee Ann Kahlor (UT). Survey results indicate an interest from the general public in receiving more information about CCS.

Following coordination team recommendations, community and stakeholder engagement continued.

Media Engagement

On September 27, 2017, Ramon Trevino presented a talk, “Carbon Sequestration: Can it Work?” to a group of journalists at the UT Energy Journalism annual workshop (Figure 2.3). The presentation included a discussion of offshore storage research in general and the CarbonSAFE Phase I project in particular. Attendees included representatives from local (e.g., KXAN television, KUT radio), regional (e.g., Dallas Morning News, San Antonio Business Journal) and national (e.g., S&P Global Market Intelligence, Virginia Public Radio, Wall Street Journal, Bloomberg News) media. See Appendix 1 for complete list of attendees.

Figure 2.3 – Presentation to journalists attending the 2017 UT Energy Journalism annual workshop.

Stakeholder Engagement

On September 20, 2017 project team members provided an overview and status update to representatives from several industrial stakeholders interested in CCS (Figure 2.4). The companies in attendance were ExxonMobil, Chevron, NRG and BHP. In addition a representative from the U.S. Geological Survey (USGS) attended. Included among the industry representatives was at least one Coordination Team member.

Figure 2.4 – Co-PI, Ramon Trevino presenting an overview of the project to representatives of industrial and government stakeholders (September 20, 2017).

Subtask 2.1 – Technical Challenge Identification

Large-scale anthropogenic CO_2 sources

With guidance from Trimeric engineers, graduate research assistant (GRA), Peter Tutton, identified and better defined the CO_2 source portion (capture / transport / industry support) of the project's goals. Tutton and Trimeric reviewed NATCARB-identified sources and identified other possible sources in the project area (northwest Gulf of Mexico).

LNG Export Terminals in the Gulf Coast Region

The development of shale gas in the United States has moved the role of the country from a substantial importer to a potential exporter of natural gas[1]. To reduce corrosion of pipelines, CO_2 is often removed from the natural gas to meet the typical 2 – 3% by volume CO_2 specification[2]. However, for LNG production this

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[1] Medlock, K. B., Jaffe, A. M., O'Sullivan, M., 2014, The global gas market, LNG exports and the shifting US geopolitical presence, Energy Strategy Reviews, Volume 5, Pages 14-25

[2] Berstad, D., Nekså, P., Anantharaman, R., 2012, Low-temperature CO Removal from Natural Gas, Energy Procedia, Volume 26, Pages 41-48

limit is set at 50 ppm CO_2, as CO_2 would freeze at the cryogenic production temperatures involved[3]. As a result, LNG export facilities utilize CO_2 removal techniques to transform the gas from a pipeline quality to a LNG quality feed. These facilities present ideal candidates as sources of CO_2 for offshore storage because they already have capture facilities and they are located close to the coast.

Three different LNG projects were investigated to determine the potential CO_2 emissions from each as well as their assessment of the suitability of CCS as a Best Available Control Technology (BACT) for greenhouse gas emissions. The Federal Energy Regulatory Commission's Online eLibrary[4] was used to collect data on these proposals.

These liquefaction facilities utilize amines to reduce the CO_2 volume to acceptable levels. Thermal oxidizers are also used after the acid gas removal. In this step H_2S is partially combusted creating sulfur, water and sulfur dioxide. Any remaining hydrocarbons are also combusted in this step, increasing the CO_2 emissions. The CO_2 emissions already in the feed are inert and not affected in the thermal oxidizer. The permit applications and environmental assessments submitted to the FERC gave the emissions limits from the thermal oxidizer. This is likely to overestimate the potential volume of CO_2 available to be captured as it assumes a work case of 2% of CO_2 in the pipeline gas.

Port Arthur LNG (Sempra Energy and Woodside Petroleum Ltd)

RN104517826

Latitude: 29.78527778

Longitude: -93.94888889

Estimated Emissions (tpy CO_2) from Acid Gas Vent or Thermal Oxidizer:

- 296,600 (40 MMscfd of CO_2 removed by Amine Unit at maximum pipeline concentration)
- 106,060 (14.3 MMscfd of CO_2 removed by Amine Unit at average pipeline concentration)
- 886,759 (443,379.61 from each of two thermal oxidizers connected to acid gas removal units)

Acid Gas Removal: n-methyldiethanolamine, MDEA, (50% methyldiethanolamine/piperazine in water)

Two liquefaction trains each with the capacity to produce 5.0 million metric tonnes per annum of LNG. Feed gas from the mercury removal unit is routed to the H_2S removal package and then the Acid Gas Removal Unit. This utilizes amine treatment to remove carbon dioxide and hydrogen sulfide. The feed gas is contacted with lean amine. This is then routed to the rich amine flash drum where acid gases are stripped out of the solution. These acid gases flow through the amine regenerator reflux drum and onto the thermal oxidizers.

The report analyzed the potential of CCS as a greenhouse gas control technology. It notes that CCS is not technically feasible for certain sources of CO_2 such as the flue gas from combustion turbines. The BACT analysis for the thermal oxidizers states that the emissions will include those from the combustion of waste gas and from fuel gas combustion. It notes that 'for the thermal oxidizers, emissions of GHG are almost entirely based on CO_2 emission (greater than 99.9% of the total CO_2e)'. It goes on to state that as discussed in the BACT section for combustion turbines, CCS is technically infeasible for the thermal oxidizers and will not be considered further'. It is also stated that no LNG plant permitted recently has been required to install CCS as a part of a PSD BACT determinations.

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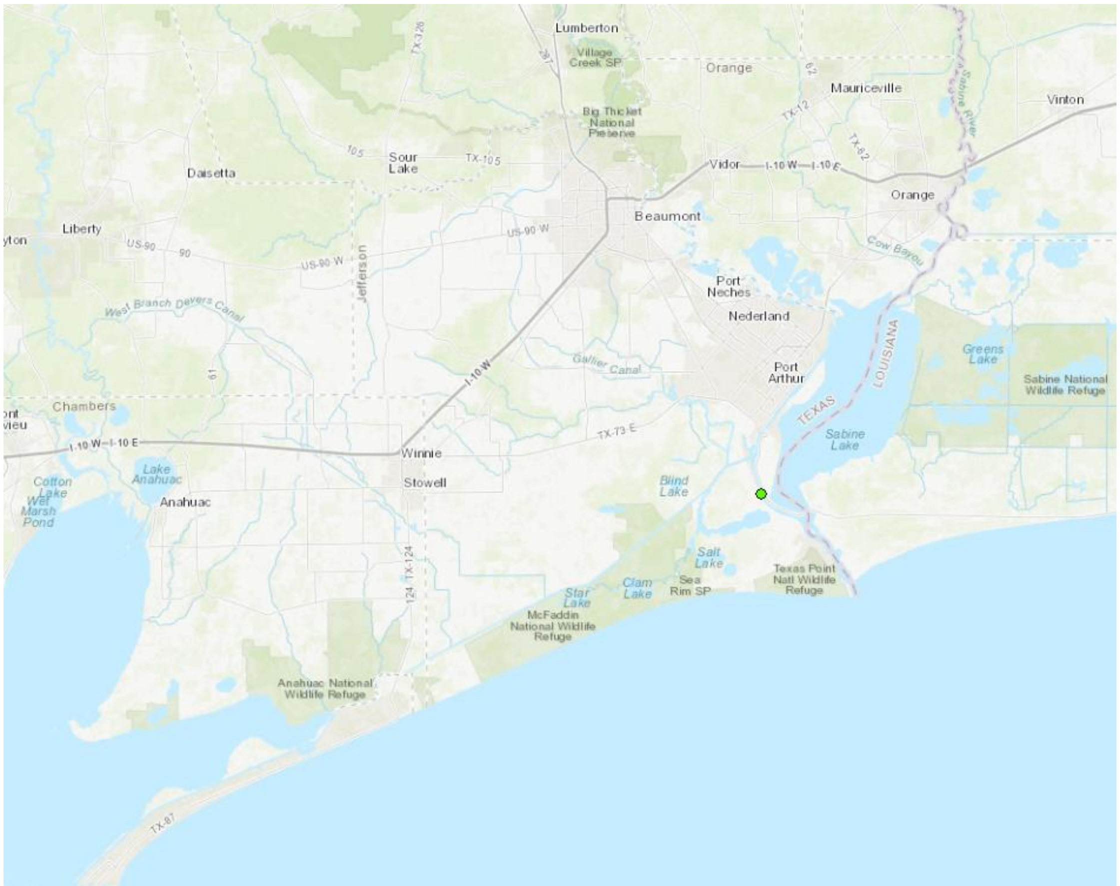
[3] Bahadori, A., Natural Gas Processing: Technology and Engineering Design, Gulf Professional Printing, 2014, Print
[4] https://elibrary.ferc.gov/idmws/search/fercgensearch.asp



Sabine Pass LNG (Cheniere Energy Partners)

Latitude: 29.7528

Longitude: -93.8764

Estimated Emissions (tpy CO_2) from Acid Gas Vent or Thermal Oxidizer:

- 744,000 (4 Trains 1-4 each 186,000 from the 'Controlled Acid Gas Vent without Thermal Oxidizer Emissions)
- 1,085,656 (Independent calculations for the acid gas vents for the four trains)
- 792,000 (Trains 1-4 each 197,810 from the 'Controlled Acid Gas Vent with Thermal Oxidizer Emissions)
- 692,000 (Trains 5 and 6 each 396,000)

Throughout the permitting process, there seems to have been numerous disagreements over the scale of the emissions from the acid gas removals vents.

Acid Gas Removal: methyldiethanolamine (MDEA)

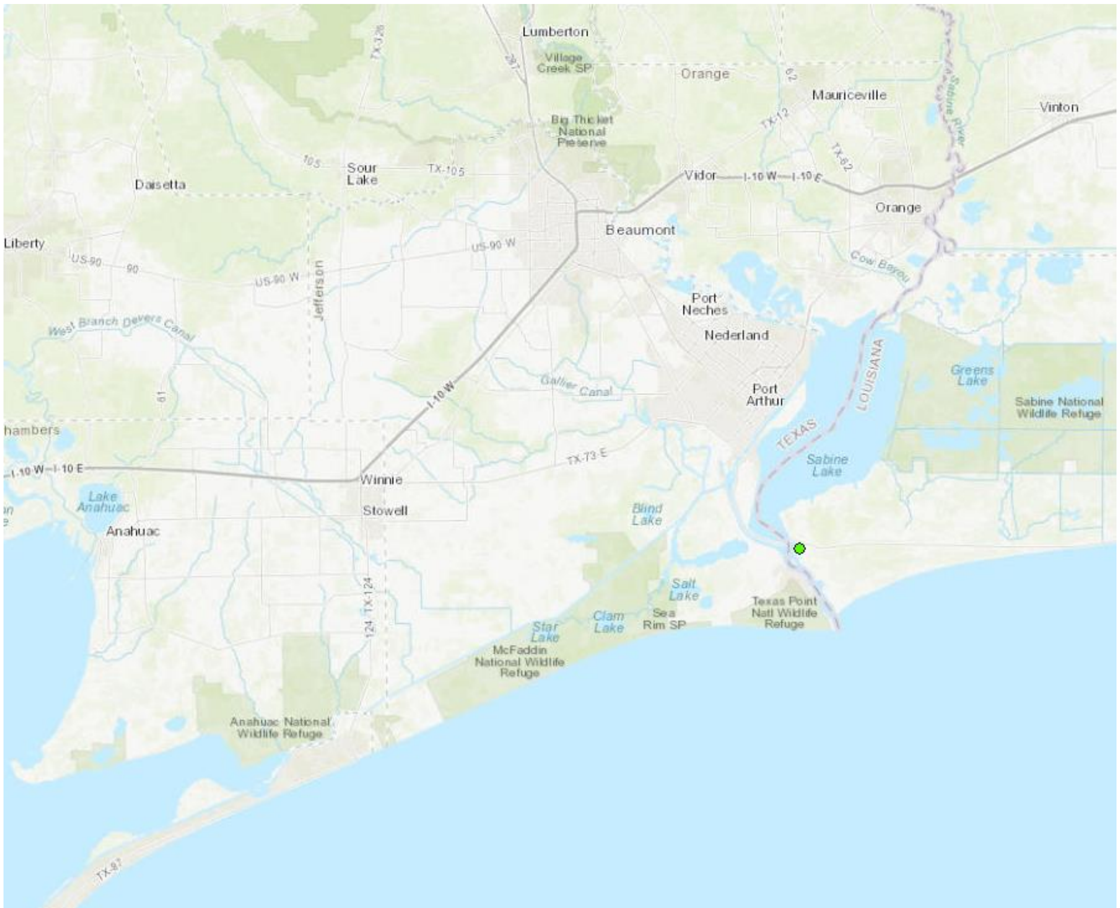
Six liquefaction trains each with a capacity of 4.5 million metric tonnes per annum have been built of permitted by Sabine Liquefaction. These trains will be located adjacent to the current import, re-gasification facilities. Trains 1-3 have been completed, with train 4 due to be completed in the second half of 2017, train 5 currently under construction and train 6 fully permitted.

Pipeline tariffs would limit the carbon dioxide to no more than 1.3% by volume, with a design capacity at Sabine Pass to handle up to 2%. Amine solution would be used to remove carbon dioxide and hydrogen sulfide, which are then removed periodically by regenerating the amine solution. Concentrations of up to 92.9% by volume carbon dioxide would be obtained. In the Air Permit Application, dated March 28th 2011, the concentration of carbon dioxide at the acid gas vents is listed as 95.91% by weight. The acid gas stream feeds to a thermal oxidizer which has a 99.99% destruction efficiency.

The CCS BACT analysis lists several different reason for it being an infeasible technology. Firstly, it notes that solvents have only been used on a commercial scale and solid sorbents and membranes are currently in the research phase. They also describe how '*there is no commercially available carbon capture system of the scale that would be required to control the CO2 emissions from compressor turbines, thermal oxidizers, and flares'*. It also lists the capture from the acid gas vent stream as challenging, with additional compression needed and an auxiliary power load, along with additional fuel, required. With regards to the storage, the application also states that the region does not have any geologic formations conducive to sequestration.

Sabine Pass Liquefaction also list some of the near and long-term concerns applicable to CCS, such as the climate policy, carbon price and regulatory framework. The market conditions surrounding CO2 transportation also is of concern, with it being mentioned that there is currently only one in the region, Denbury, who would therefore be able to regulate the price of carbon. They don't see contracting with a single supplier as a feasible solution. In spite of this, they performed and analysis into construction of a pipeline from the facility to the Denbury Green pipeline 28.5 miles north. The route would be 34-36 miles and require a compressor to increase from atmospheric pressure to approximately 1600 psig in the Green pipeline.

Given the above reasons, they concluded that it is not economically feasible and that even with economic feasibility there would be adverse energy, water and environmental impacts from the alternative system implementation.



Golden Pass LNG (Qatar Petroleum – 70%, ExxonMobil – 17.6% and ConocoPhillips – 12.4%)

RN104386354

Latitude: 29.760894

Longitude: -93.918464

Estimated Emissions (tpy CO_2) from Acid Gas Vent or Thermal Oxidizer: 1,124,904 (from four thermal oxidizers)

Acid Gas Removal: methyldiethanolamine (MDEA)

The facility will consists of three liquefaction trains each with a capacity of 5.2 million metric tonnes per year, for a total of 15.6 million tonnes per annum of LNG.

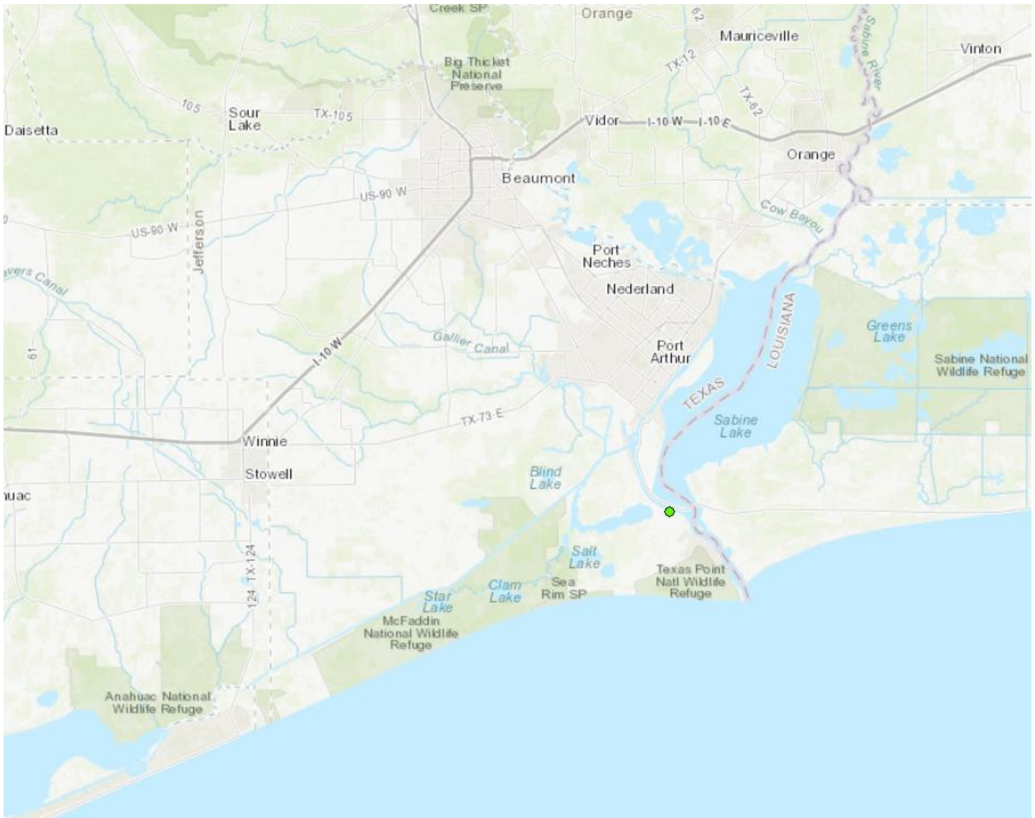
The pre-treatment consists of a mercury removal unit, an amine system for the removal of carbon dioxide and hydrogen sulfide, a molecular sieve dehydration unit and a heavy hydrocarbon removal system. The removal of CO_2 is via contact with an amine-based solvent. The acid gas system is designed to deal with 2 mole percent CO_2. Regeneration of the amine releases the carbon dioxide, producing a stream up to 96 mole percent. The CO_2 stream from the Acid Gas Removal Unit (AGRU) continues to the scavenger solution where the hydrogen sulfide is removed. This solution is disposed of and the exhaust gas is routed to four thermal oxidizers. The CO_2 free stream exiting the AGRU is sent to a chiller then dehydrator beds containing a molecular sieve to remove water.

With regards to CCS, they concluded that it was not technically feasible in all aspects and so not practical to implement at the Golden Pass Terminal. One reason given for this was that the region does not have any geological formations that support sequestration and as a result transportation to distant storage options would be required. Secondly, the adverse environmental impacts of building a new pipeline and the uncertainty in the transportation and storage markets were also given as reasons. Finally, the lack of other similar projects where CCS had been utilized on LNG export facilities was given as a reason for it being technically infeasible. It was suggested out that the facility could run a pipeline 15-30 miles to the Denbury Green pipeline and that the current Golden Pass natural gas pipeline runs within 0.25 miles of an existing CO_2 pipeline. The current Golden Pass pipeline could be utilized for CO_2 transport or a new pipeline could utilize the existing rights of way and be constructed parallel to it.

Calculations of the cost of CCS were performed, with the estimated capital costs totaling $2.4 billion:

- $1.7 billion for CO2 capture and compression
- $200 million for transportation (via a 30-mile pipeline to connect to the Denbury pipeline and 20-mile pipeline to a potential geologic storage site)
- $450 million for storage.

The total annualized control costs for the terminal are estimated to be $82 per ton of CO2 emissions avoided.



Further investigations into LNG export facilities were performed, specifically the Freeport LNG application. These applications showed potential viability of geologic CO_2 storage into the Jasper aquifer below the pretreatment facility. The costs that were included for capturing 896,000 metric tons per year of CO_2 is shown below:

- $4 million for the injection well
- $39 million for the electric driven compression facilities
- $9 million annual operating and maintenance costs(90% of this being for power and compressors)

Based on 30 years of injection, this results in $14/ton of CO_2 sequestered using an 8% interest rate. Due to the location of the storage site, they managed exclude any transportation costs. The application also stated that Denbury had been contacted about purchasing the CO_2 however their current purchase price is significantly lower than $22/ton (price including a pipeline tie-in to the green line).

This figure was reassessed by Atkins and a new value of $70/ton was presented. However, this included the cost to capture from the combustion turbines also.

Hydrogen and Syngas Production

Following is a summary of some of the plants that produce hydrogen/syngas in the region. The summary includes information about what the plants currently do with their carbon dioxide stream, how they obtain the carbon dioxide and what purification methods they employ.

The Electronic Greenhouse Gas Reporting tool (e-GGRT)[5] was used along with the TCEQ (Texas Commission on Environmental Quality) Document Search[6], SEC filings and other internet resources, for determining gasification sites in the Gulf Coast Region stretching from Freeport, TX to Cameron, LA. These were assessed first to determine gasification processes involved and the methods involved in reusing or venting the carbon dioxide stream. The data sources were then compared to those in the Gasification and Syngas Technologies Council's (GSTC) database[7]. Two facilities from Louisiana were included. In these cases the LDEQ EDMS was used for gathering further information on sources.[8]

The study was conducted to assess the suitability and potential for these high purity sources of CO_2 to employ capture technology for offshore sequestration. Multiple methods of gasification exist with steam methane reformers and partial oxidation being the two most common in the Gulf Coast region. Partial oxidation is a sub-stoichiometric reaction between the feedstock and pure oxygen. This produces an exhaust with a high hydrogen concentration. It can be used with a selection of feedstock including heavy liquid hydrocarbon wastes. Steam methane reforming reacts natural gas and steam in the presence of a nickel catalyst. In both processes, water shift is usually employed to convert the carbon monoxide and steam to carbon dioxide and hydrogen.[9]

The carbon dioxide then must be removed; there are many methods of doing this. They include absorption, adsorption, cryogenic and membrane methods. Absorption and adsorption are commonly used and can be via either chemical or physical processes.[10] Pressure swing adsorption is often utilized for purifying the hydrogen stream. Hydrogen has a weak adsorbent force; so, is not adsorbed at all. Whereas, impurities such as carbon monoxide, methane and carbon dioxide are adsorbed. Depressurization, desorption and regeneration of the adsorbent then take place to release the impurities.[11] This PSA tail gas usually contains 45-50% concentration CO_2 for an SMR.[12]

Name: Air Products Port Arthur Facility

GHGRP ID: 1006402

City: Port Arthur

2015 CO_2 Emissions from Hydrogen Production/Gasification/Gasification (metric tons): 1857447

Age: 2000 expanded in 2006

Gasification: 2 x SMR

Purification: Vacuum Swing Absorbers

Comments: CCS project. Part of Valero refinery.

[5] https://ghgdata.epa.gov/ghgp/main.do
[6] https://webmail.tceq.texas.gov/gw/webpub
[7] http://gasification-syngas.org/resources/map-of-gasification-facilities/
[8] http://edms.deq.louisiana.gov/app/doc/querydef.aspx
[9] http://www.gasification-syngas.org/technology/syngas-production/
[10] Songolzadeh, M., Soleimani, M., Takht Ravanchi, M., Songolzadeh, R., 2014, Carbon Dioxide Separation From Flue Gases: A Technological, Review Emphasizing Reduction in Greenhouse Gas Emissions
[11] http://www.chemengonline.com/psa-technology-beyond-hydrogen-purification/?printmode=1
[12] http://ieaghg.org/docs/General_Docs/IEAGHG_Presentations/18_-_S._Santos_IEAGHGSECURED.pdf

Name: Praxair Texas City Hydrogen Complex

GHGRP ID: 1000043

City: Texas City

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons): 1402080

Age: Expanded in 2006.

Gasification: 2 x SMR

Purification: Membrane contactor

Comments: At Marathon site. There is a Praxair Carbon Dioxide facility adjacent to this site, which utilizes the CO_2 from the hydrogen reformer.

Name: Linde Gas North America LLC, La Porte Plant

GHGRP ID: 1002072

City: La Porte

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons): 1135091

Age: 1979 expanded in 2015

Gasification: POX

Purification: Rectisol

Comments: CO_2 either flared or recycled to the offsite methanol production facility. As the expansion came online in 2015, this may not be reflected in the total emissions. There are plans for further expansion.

The methanol plant is co-owned by Linde and the LyondellBasell owned Millennium Chemicals. The syngas is used for methanol production. This methanol is also combined with the CO to produce acetic acid.

Name: Praxair Port Arthur #379

GHGRP ID: 1011080

City: Port Arthur

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons): 1014083

Age: 2013

Gasification: SMR

Purification: PSA

Comments: At the Valero refinery along with the Air Products SMRs.

Name: Air Products and Chemicals Inc. – Lake Charles Facility

GHGRP ID: 1003013

City: Westlake, LA

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons): 801530

Age: 2004

Gasification: SMR

Purification: PSA

Comments: CO_2 obtained from de-aerated condensate. Tail gas from PSA recycled into reformer furnace. 100 MMSCF per day hydrogen supplies Conoco Philips. Steam is exported.

Name: Praxair Port Arthur Facility

GHGRP ID: 1002023

City: Port Arthur

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons): 721830

Age: 2004

Gasification: SMR

Purification: PSA

Comments: Contains 12 adsorbers for different impurities. The regeneration purge gas is returned to the reformer furnace as fuel for combustion. At Motiva Refinery.

Name: La Porte Steam Methane Reformer (American Air Liquide)

GHGRP ID: 1010702

City: La Porte

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons): 691029

Age: 2012

Gasification: SMR

Purification: PSA

Comments: 120 MMSCF per day hydrogen supply. PSA purge gas is recycled to reformer furnace as fuel for combustion.

Name: Linde Gas North America LLC, Clearlake Plant

GHGRP ID: 1003049

City: Pasadena

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons): 601476

Age:

Gasification: POX

Purification: PSA, Rectisol and molecular sieve

Comments: Carbon dioxide is used downstream to produce 'methanol, downstream chemicals and cleaner transportation fuels'. By-product Carbon dioxide (CO_2) from the Ethylene Oxide and the Vinyl Acetate Units is also used as a feed gas. A molecular sieve station for the removal of trace amounts of CO_2 and a Cold Box is also used to separate the CO from the H_2. Most of the CO_2 removed in the Rectisol is recycled to the reactors by the CO_2 recycle compressor.

Name: Air Liquide Large Industries US - SMR

GHGRP ID: 1006711

City: Pasadena

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons): 575493

Age: 2006

Gasification: SMR

Purification: PSA

Comments: Bayou cogeneration plant at the same site. PSA purge gas recycled as feed gas to reformer furnace.

Name: Praxair Inc.

GHGRP ID: 1002608

City: Sulphur, LA

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons): 563013

Age: 1984

Gasification: SMR

Purification: PSA

Comments: Originally Liquid Carbonic plant. PSA and de-aerator for condensate. Purge gas is vented to atmosphere or recycled to reformer furnace.

Name: Air Products LLC - Pasadena SMR

GHGRP ID: 1006943

City: Pasadena

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons): 501160

Age: 1996

Gasification: SMR

Purification: PSA

Comments: 80 MMSCF per day hydrogen. PSA purge gas recycled to reformer.

Name: Praxair Texas City

GHGRP ID: 1006562

City: Texas City

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons): 400554

Age: 1996 and SMR added in 2006

Gasification: POX

Purification: MDEA and molecular sieve

Comments: Owned and operated by Praxair on Texaco/Valero refinery. IGCC – 42 MW cogeneration facility. The syngas is sent to the absorber for CO_2 removal using MDEA. The HyCO Unit dryer also uses a molecular sieve to remove residual carbon dioxide. The CO_2 is recycled back to the gasifier.

Name: Air Products Baytown Plant

GHGRP ID: 1002430

City: Baytown

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons): 241998

Age: 2000. Expanded in 2006

Gasification: 2 x de-asphalter rock, DAR, gasification units. These are proprietary heavy oil POX units.

Purification: Rectisol

Comments: Takes raw syngas from the Exxon plant (1007542), where the gasification takes place, and processes it. Vents CO_2 from the Rectisol unit. The Exxon Baytown plant also has hydrogen provided by processing units, such as the demethanizer, and acid gas removal.

Name: Air Liquide – Freeport HyCO Plant

GHGRP ID: 1003730

City: Freeport

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons): 157956

Age: Expanded in 2013

Gasification: SMR

Purification: Amine capture

Comments: The CO_2 is preferentially absorbed from the syngas into an amine solution. The CO_2 removed in this step can either be re-circulated back to the reformer feed with the use of a compressor or vented to the atmosphere. The CO_2 recycle vents comprise approximately 99% CO_2.

Name: Air Products La Porte Facility

GHGRP ID: 1003160

City: La Porte

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons):

Age: 1995 and 2 x SMR

Gasification: POX

Purification: MEA and PSA

Comments: IGCC. The two SMRs employ CO_2 removal by MEA absorption, cryogenic separation, and finally a pressure swing adsorption unit for final H_2 purification at HYCO-1. The POX unit has a carbon removal system using a water wash, a CO_2 removal process using MEA absorption, a temperature swing adsorption (TSA) system for drying the gas, cryogenic separation of the CO and H_2, and finally a PSA unit for final H_2 purification.

Name: Clear Lake Plant (Celanese)

GHGRP ID: 1006867

City: Pasadena

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons): 28888 from methanol. *It should be noted that the methanol production came online in 2015, so this number is likely to be lower than future emissions.*

Age: 1977 (production increases in 1986 and 1988) and 2015 (methanol unit)

Gasification: Combined reformer (SMR and ATR in parallel) and 3 x Shell Gasifiers

Purification: Rectisol and molecular sieve

Comments: The GSTC lists Clear Lake Oxochemicals and Clear Lake Methanol II as two separate gasification locations, with 3 gasifiers at the oxochemicals plant and 1 reformer at the methanol plant. Natural gas and plant by-product CO_2 are fed to three parallel Shell Gasification Process reactor heat exchanger trains to produce synthesis gas. The 3 Shell Gasifiers are used to supply CO to the acetic acid unit. At the location is also ethylene oxide production which produced 128026 metric tons CO_2 in 2015.

The e-GGRT lists the plant as a supplier of CO_2 to the Linde flare on site. TCEQ documents also note that 'Most of the CO_2 is recycled to the reactors' from CO production using the Shell Gasifiers.

The plant is located 12 miles from the Green Pipeline. Praxair plans to build HyCO facilities at the site, to go online by 2019. These facilities will have MDEA for CO_2 purification.

Name: Channelview Complex (LyondellBasell)

GHGRP ID: 1002859

City: Channelview

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons): 253782 (reformer furnace flue gas)

Age: 1984

Gasification: SMR

Purification: N/A

Comments: Plant was built in 1984, but stopped producing methanol in 2004 due to high natural gas prices. It was restarted at the end of 2013. The plant has the capacity to make 273 million gallons of methanol per year using natural gas as a feedstock, but also has the capability of injecting CO_2 as a supplemental feed. Purge gas is used as fuel in the reformer fuel gas.

The reformer furnace flue gas is given as ~4% CO_2. The facility is thirty miles from Denbury Green Pipeline.

Name: OCI Beaumont LLC

GHGRP ID: 1010636

City: Nederland

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons): 293321 (reformer furnace flue gas)

Age: 1977 and 2000

Gasification: 2 x SMR

Purification: PSA

Comments: Integrated methanol and ammonia facility acquired in 2011 and brought back online in 2012. Further debottlenecking was done in 2015. The methanol line consists of two SMRs for syngas production. The hydrogen is also used in the ammonia synthesis loop.

The have a CO_2 stripper however this is only now used for MSS. CO_2 increases methanol production and so the process gas leaving the reformers is combined with by-product CO_2. OCI are looking for a supplemental source of CO_2.

When the ammonia plant is in operation, purge gas is routed to a PSA. The remaining purge stream, after hydrogen is removed, is sent to the reformers as fuel gas.

Name: Beaumont Waste to Liquids Plant (Fair Energy Operations)

GHGRP ID: NA

City: Beaumont

2015 CO_2 Emissions from Hydrogen Production/Gasification (metric tons): NA

Age: NA

Gasification: NA

Purification: NA

Comments: Beaumont approved Fair Energy Operations to purchase municipal solid waste. This source is listed in the GSTC. They plan to convert the waste to liquid diesel. The landfill will supply 1,400 tons per week to the company. This equates to a very low potential CO_2 emissions size.

Other locations were also listed by the GSTC, but either had no available information on the processes employed at the site or were included in the analysis of other locations. In each case, other syngas/hydrogen production facilities in the vicinity are likely to supply the location:

- Baytown Flexicoker – ExxonMobil
- Baytown Refinery Hydrogen Plant – ExxonMobil
- Baytown Syngas Plant – ExxonMobil
- Beaumont Refinery Hydrogen Plant – ExxonMobil

Exxon Baytown locations in the list above employ POX gasification technology as well as hydrogen production from process units. However, the cleanup of the syngas is performed at the Air Products Baytown Plant.

The Exxon Beaumont facility is tied into the Air Products hydrogen pipeline[13].

Subsequently, Trimeric Corporation used the following script to contact companies with potential CO_2 sources in order to solicit information and possible interest in the project.

"The University of Texas Bureau of Economic Geology and Trimeric Corporation are working on a U.S. DOE funded project called CarbonSAFE that is evaluating several large-scale CO_2 capture and storage opportunities. Lamar University is also a local team member. The timeframe envisioned for this project currently goes through 2025. Are you interested in learning more about your options for reducing CO_2 emissions via the mechanism of carbon capture and storage, including EOR? Many companies like yours are interested in knowing more about long-term CO_2 capture, utilization, and storage options and related government incentives such as the recently proposed expansion of 45Q tax credits. We would like to know specifically if your company would provide a letter of interest in support of our project. We can provide an example template of the letter. We would also like your help confirming some basic, public information regarding CO_2 emissions at your facility as this would be helpful for a related master's thesis that project participant Peter Tutton is working on at the University of Texas in parallel with this project. We would be glad to provide more information by email, a phone conference, or a visit your facility to give you a presentation on this work."

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13 http://www.ogj.com/articles/2000/06/exxonmobil-awards-cryogenic-system-hydrogen-pipeline.html

The list of CO_2 sources for the Port Arthur (above and Figure 3.1.1) and Houston (above and Figure 3.1.2) areas was further refined. Additional CO_2 sources, such as proposed hydrogen and LNG projects, were investigated and added to the existing list. These were then ranked by suitability for capture based on a number of factors including magnitude of emissions, distance from sink and ease of capture. A working file was created, to share contact information between the BEG and consultant, Trimeric, Inc., for the CO_2 sources and to document progress. The information on sources was also provided to colleagues at Lamar University, for them to initiate dialogue with their contacts in the Port Arthur area.

An ArcGIS model was built to calculate the least cost path from each source to multiple sinks in a user defined set. Literature provided factors for calculating the cost surface, utilizing layers for land use, roads, railroads, National Parks, State Parks, waterways as well as topographic gradient. The output from the calculations was a node network with least cost arcs, in which shared arcs or trunk-lines were considered. These values were then used in a mixed integer linear programming optimization, which considered the least cost network for storing a certain value of CO_2.

CO_2 Capture Clusters

To move beyond dealing with matching individual sources and sinks one-to-one, it is useful to assess CO_2 clusters (or hubs) where multiple sources can feed into an integrated pipeline. The Global CCS Institute (GCCSI, *2016*) defines industrial clusters as, "A geographic concentration of interconnected businesses, suppliers, and associated institutions in a particular field […] For CCS, the idea of clusters takes advantage of the fact that around the world, many emissions-intensive facilities (both industrial and power) are located in tight geographical clusters".

Advantages of sharing infrastructure are recognized for transport and storage. A number of initiatives, worldwide, have already started to explore clustering of CCS facilities and bringing CCS to commercial deployment. In addition to the economic scales in transportation and storage, Clusters also result in lower costs of organization, permitting and public engagement. Clusters could also be a way for small emitters to take advantage of the value of working at commercial scale when the cost of a solo project would not be competitive.

According to the IEA (*2013*) "*it may not be possible to decarbonize industrial sectors without CCS.*" Consequently, clusters could be the most cost-effective way to achieve it. In a low-carbon and increasing carbon price environmental, CCUS Clusters will enhance improve the competitiveness of their industries and of the region. The Global CCS Institute (*2016*) proposes that this kind of CCS ecosystem has a strategic significance as it reduces cost by sharing infrastructure, enabling CCS from small sources, reducing commercial and storage risk, enabling CCS in regions without access to suitable local storage and enabling low carbon industrial production. So, it is very important in the first stages of CCS commercial deployment to accelerate CCS momentum, make best use of existing infrastructure and strategically build new supporting infrastructure to drive down the costs of large-scale CCS deployment allowing to faceable business model. Our study adds the element of linking onshore sources with offshore storage, which could favor shared infrastructure.

Optimization inputs

Optimizations were run to determine the least cost network for storing CO_2 over 12 years. This timespan was chosen as a semi-arbitrary test case, as applicable projects will be eligible to receive tax credits under the current 45Q formula for up to 12 years. The results provide a way of matching sources with the sink, via a suitable transportation method, depending on the target storage scenario. A two part optimization was used to generate least cost networks from sources to injection sites. The method utilized GIS, for generating a candidate network of transportation options, while MIP (mixed integer programming) was used to select the optimal combination of sources, reservoir location and transport mode. This method of combining GIS and MIP has been used multiple times for the optimization of CCS networks (Middleton and Bielicki, 2009, and Morbee et al., 2011). For results of the optimization results, see the Deliverables 4 & 5 report.

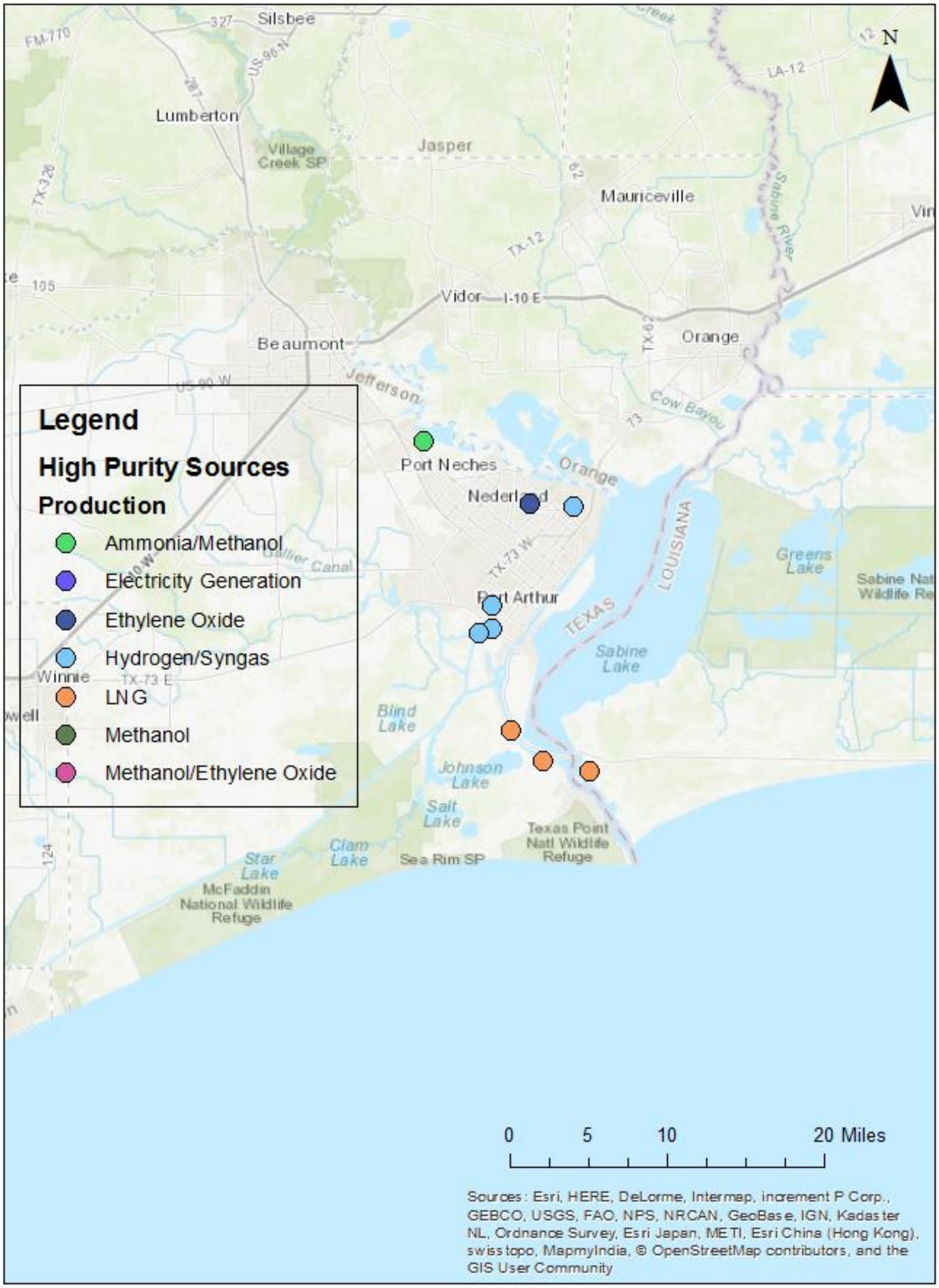


Figure 3.1.1 – Map of locations of prospective sources, Golden Triangle hub

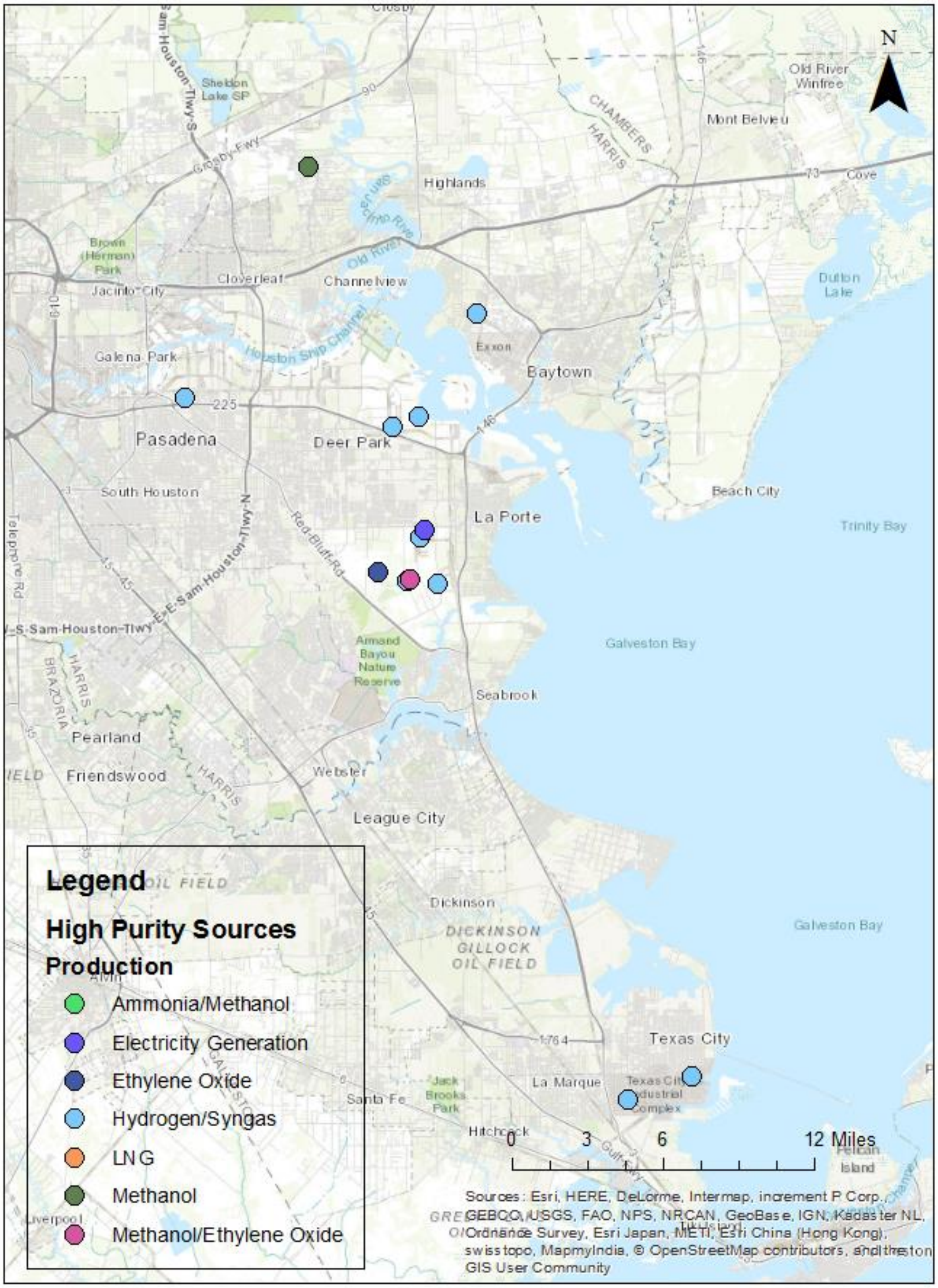


Figure 3.1.2 – Map of locations of prospective sources, Houston hub

Top Candidate CO_2 Source Identified

A high-concentration CO_2 source was identified as the top candidate for the project and going forward with the CarbonSAFE Phase II proposal. The top-rated source is the NET Power facility in Houston (La Porte), Texas. The facility hosts a demonstration plant for novel oxy-combustion electricity generation (called the Allam cycle) with the goal of becoming an emissions-free source of gas-fired electricity. Rather than developing environmental control equipment for existing power systems to make emissions cleaner (which inevitably leads to increased electricity costs), the NET Power team decided to develop an entirely new power cycle from the ground up. NET Power designed a process that inherently addresses the emissions clean-up challenges faced by traditional power plants. In 2016, NET Power LLC began construction of a 50 MWth (25 MWe) first-of-its-kind natural gas-fired power plant located near Houston, Texas, in order to test at large pilot-scale NET Power's proprietary Allam Cycle Technology, which uses CO_2 as a working fluid in an oxy-fuel, supercritical CO_2 power cycle to generate electricity. Regarded as a potential breakthrough in power generation technology, the Allam Cycle uses a high-pressure, highly recuperative, oxyfuel, supercritical CO_2 cycle that makes carbon capture part of the core power generation process rather than an afterthought. The result is high-efficiency power generation that inherently produces a pipeline-quality CO_2 byproduct at no cost to the system's performance. In order to create growth opportunities and scale up this promising technology, the existing demonstration facility seeks a low risk and economic solution for current CO_2 emissions. It appeared to be the ***ideal*** candidate source for the CarbonSAFE project region.

References Cited

Middleton, R.S. and Bielicki, J.M. 2009. *A scalable infrastructure model for carbon capture and storage*: SimCCS, Energy Policy, Vol. 37, Issue 3, pp. 1052-1060.

Morbee, J., Serpa, J., Tzimas, E. 2011. *Optimal planning of CO2 transmission infrastructure*: The JRC InfraCCS tool, Energy Procedia, Vol. 4, pp. 2772-2777.

Subtask 2.2: Non-Technical Challenge Identification

As offshore Southeast Texas is one of the locations being considered for carbon capture and sequestration (CCS), a two-staged survey was conducted in eight selected Texas counties in that area (Brazoria, Chambers, Liberty, Galveston, Jefferson, Orange, Fort Bend and Harris). The sample population was drawn from the KnowledgePanel®, a probability-based web panel designed to be representative of the United States, supplemented by an opt-in sample source. The sample for this survey consisted of non-institutionalized general population adults (18+ year olds) residing in Texas in Harris, Jefferson, Orange, Chambers, Liberty, Galveston, Brazoria and Fort Bend counties who were screened in-field to confirm residency. Those who did not meet these criteria were terminated from the study.

The survey was fielded in English in two stages: A Pretest survey and a Main survey. For the Pretest survey, GfK Custom Research, LLC (GfK) sampled randomly eligible adults from KnowledgePanel(KP). For the Main survey, GfK sampled randomly eligible adults and worked with an opt-in sample vendor to sample residents from the selected counties. Selected KP members for each survey received an email invitation to complete the survey and were asked to do so at their earliest convenience.

The Pretest survey was designed to test the functionality and length of the instrument in a small sample. The median completion time of the Pretest survey was 11 minutes. Upon review of the Pretest results, the Main survey was programmed using the Pretest as a basis. The median completion time of the Main survey was 14 minutes. Starting on July 11, 2017, the Pretest was out in the field and closed with a respond rate of 42.9%. The field period of the Main survey is from July 24 to August 14, 2017. Of the 973 qualified Main interview cases, 3 cases were removed from the final deliverable for data inconsistencies, resulting in a final deliverable dataset that contains 970 valid interviews.

Preliminary results

Sample – N=970

Approximately 54% of respondents were female, and 46% were male. Age ranged from 18 to 75+, with the majority in the range of 30-44. About 40% had at least a bachelor's degree, and the median household income was $50,000-$59,999. About 40% of the respondents identified themselves as white, non-Hispanic, and another 30% identified as Hispanic. Note that 70% of our respondents were residents in Harris County.

Knowledge

We asked respondents to identify their current knowledge about the risks and benefits associated with CCS and how much they think there is a need to know more about this technology. The results indicated that, in total, roughly 68% of our respondents knew nothing (35%) or very little (33%) about risks and benefits associated with CCS, and only 8% stated that they had extensive knowledge about this issue. 33% of our respondents expressed some need to know more about the risks and benefits associated with CCS, and another 31% expressed the need to know "quite a bit." These findings suggest that, although respondents by and large had very little knowledge about CCS, most of them welcome the possibility of knowing more about the topic.

Data were analyzed regarding the following:

- Perceptions of risk and benefits related to CCS
- Emotional response to potential risks and benefits posed by CCS
- Attitudes towards seeking information about CCS
- Perceived norms related seeking information about CCS
- Perceived ability to seek information about CCS
- Awareness of CCS
- Trust in information sources about CCS
- Climate change beliefs
- Sense of attachment to the community
- Investment in prevention of disaster in the community
- Experience with disasters

As reported in the appendix of the October 1 – December 31, 2017 quarterly report, a white paper was prepared in November, 2017. The white paper summarized methods, data, results and conclusions of the survey. Subsequently, a manuscript based on analysis of results from the two-stage survey conducted in the eight selected Texas counties was submitted to the International Journal of Greenhouse Gas Control on August 21, 2018.

Task 3.0: High-level technical Evaluation of sub-basinal storage and integrated risk assessment

Subtask 3.1: Storage Complex Geologic Characterization

Regional Geologic Characterization

Approximately, 700 wells with SP curves were used for detailed subsurface correlation. The entire Miocene interval was subdivided 1) upper - MFS 1 to MFS 6, 2) middle - MFS 6 to MFS 9 and 3) lower – MFS 9 to MFS 12, and maximum flooding surfaces (MFS 1 to 12) have been mapped in every log and correlated laterally. Figure 3.1.1 shows the distribution of offshore wells with digital data in the and three regional lines of section whose, respective, strike (AA', BB') and dip (CC') cross-sections are shown in Fig 3.1.2 and 3.1.3. The potential reservoir interval for CO_2 storage was interpreted to correspond to the stratigraphic interval from *Amphistegina B* (MFS 9) to *Rhobulus B* (MFS10). A primary confining interval (seal) is associated with MFS9 (biochronozone *Amphistegina B)* which can reach a thickness of up to 250 m. However, the *Amphistegina B* shale thins considerably in the onshore direction. Consequently, the more suitable area for future CO_2 sequestration is considered to be in the offshore area of Texas and Louisiana (Fig. 3.1.1).

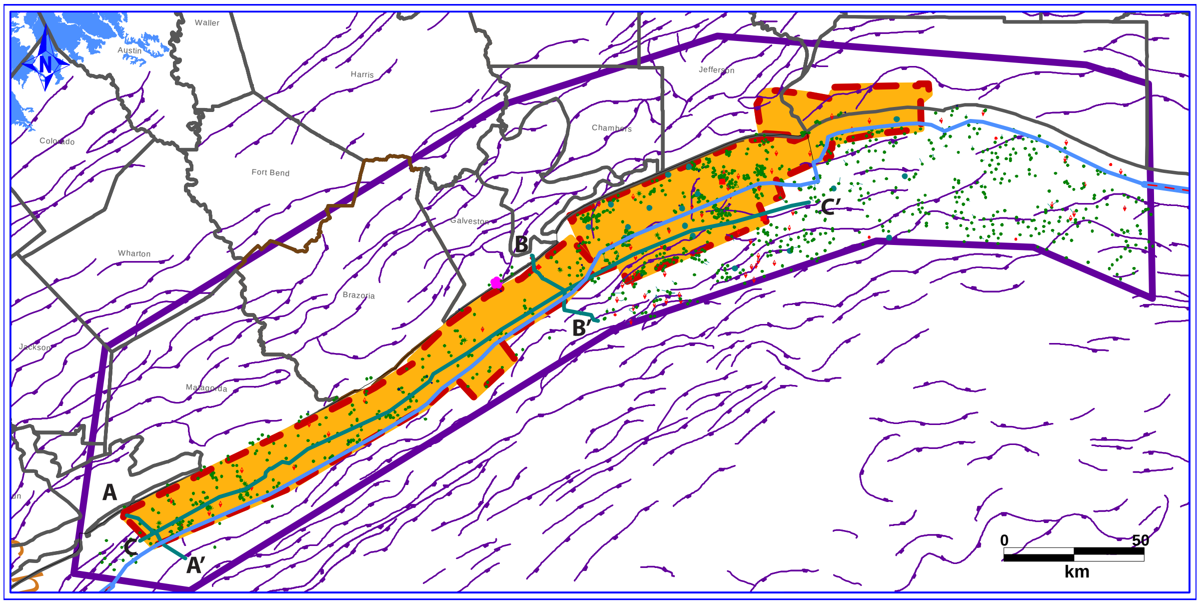
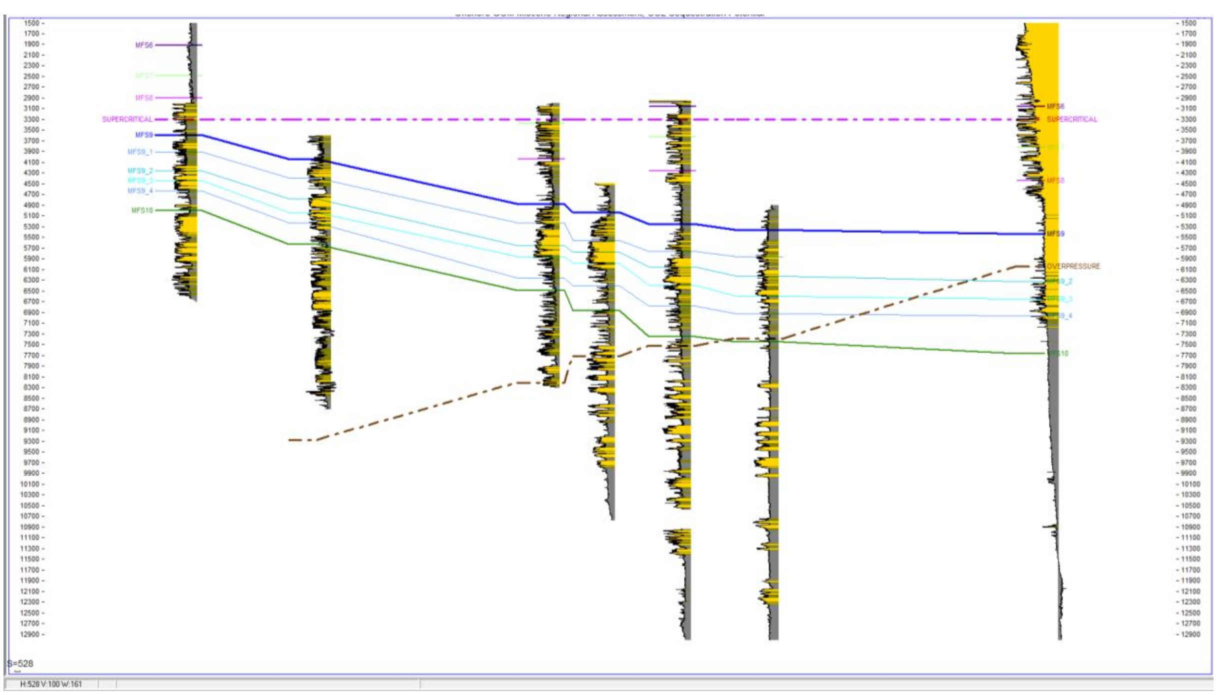


Figure 3.1.1. Map of the study area illustrating the distribution of digital logs in the offshore area of Texas and Louisiana. The state - federal waters boundaries are demarcated by the blue lines subparallel to the coast. Among the 1270 wells with digital wireline data 1203 logs have SP curves (green dots), 86 have gamma ray (red rhombs) and 2 wells have whole core (olive-green squares). Regional strike (SW-NE) and dip-oriented (NW-SE) cross-sections are shown in green. The two 3D seismic surveys (Texas OBS and TexLa3D) are indicated in orange; faults are shown in purple.



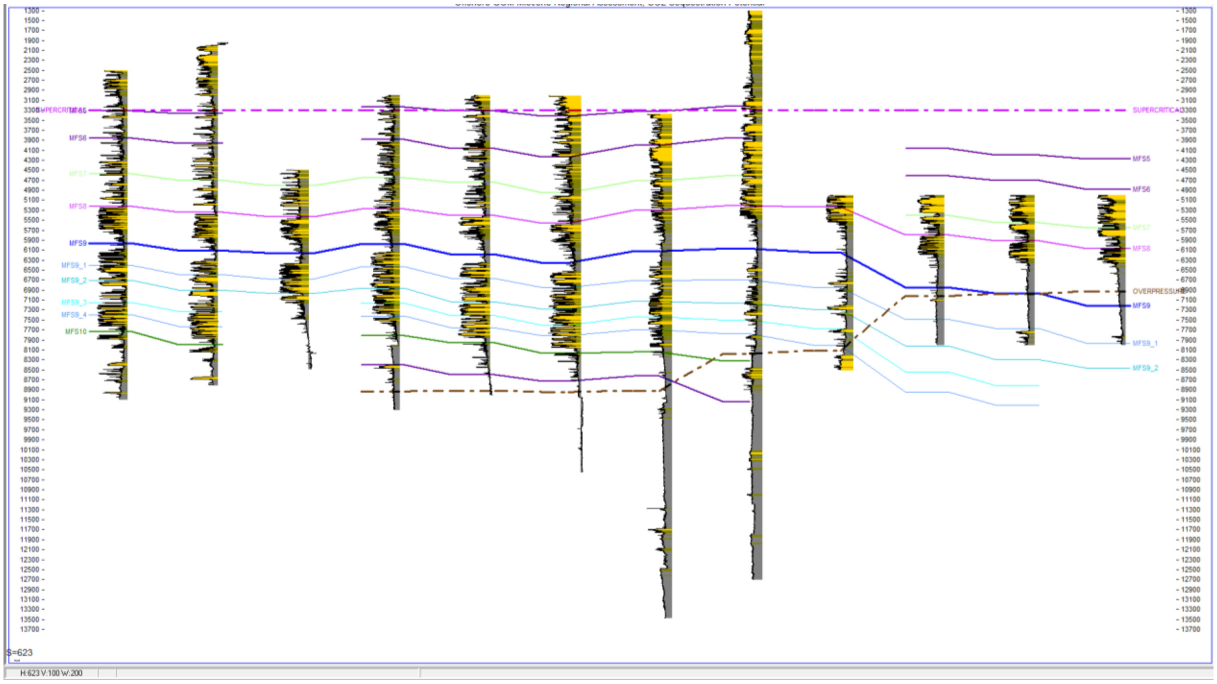


Figure 3.1.2. Dip-oriented (NW-SE) structural cross-sections (AA' and BB' in Fig.1) upper Texas coast. The upper depth limit (3300 ft) for CO_2 injection (SUPERCRITICAL) is determined by the minimum temperature and pressure conditions at which CO2 is supercritical. The lower depth limit for CO_2 injection (OVERPRESSURE - dashed brown line) is determined by the depth at which the hydrostatic pressure in the subsurface is significantly exceeded. The top of overpressure coincides roughly with MFS12 updip, but due to section displacement and expansion seaward it corresponds to MFS10 and even MFS9 farther downdip. The interval between MFS 9 and MFS 10 has been subdividided in five 4th order cycles by flooding surfaces MFS 9_1 to MFS9_4.

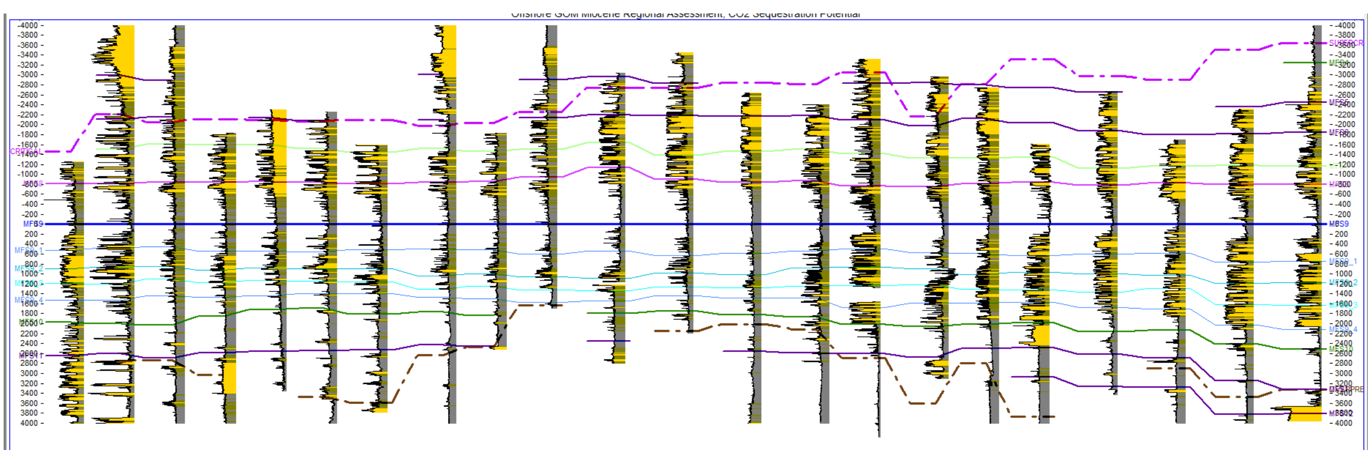


Figure 3.1.3. Strike-oriented stratigraphic cross-section offshore Texas (CC' in Fig. 1) flattened on MFS 9 equivalent to *Amphistegina B* biochronozone The supercritical depth corresponds roughly to MFS 6 and the overpressure to MFS 12. The sandstone gradually becomes thinner laterally to the west and more interbedded with shale.

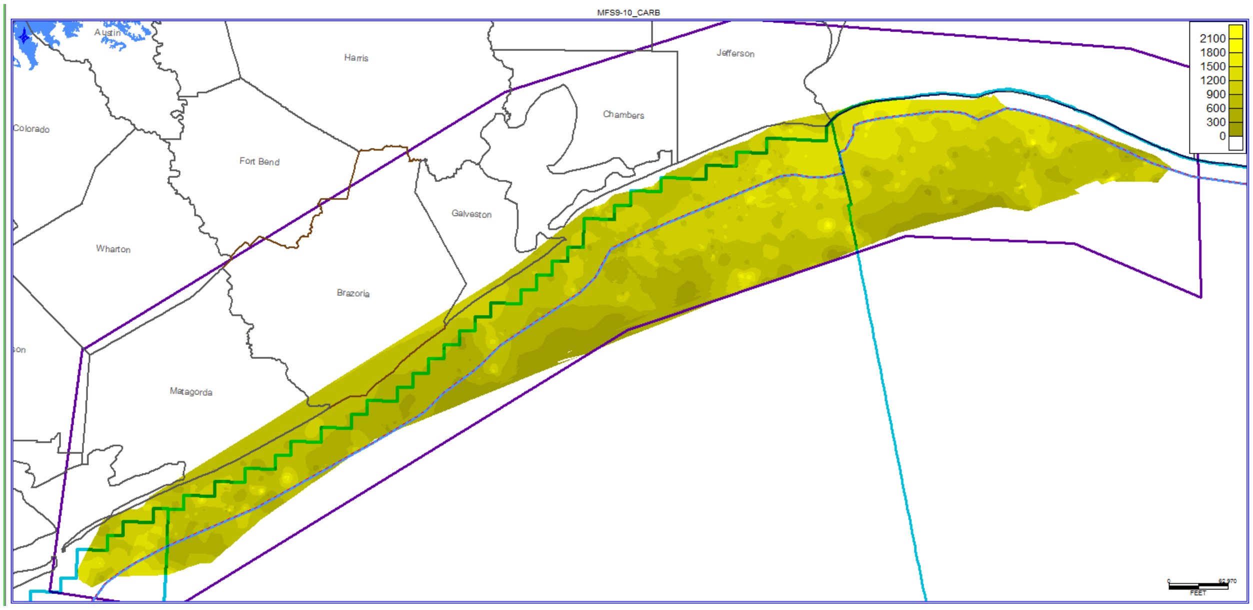


Figure 3.1.4 – Net sandstone map of the stratigraphic interval from *Amphistegina B* (MFS9) to *Robulus B* (MFS10). The sandstone thickness is relatively high up-dip (along the present day coastline) and decreases downdip and lateraly to the west, which indicates the possibility of greater capacity offshore Texas, in the High Island area (i.e., eastern Galveston, Chambers and Jefferson Counties).

Integrating key regional stratigraphic surfaces in the Texas/Louisiana littoral zones.

The MFS09 surface (Fig. 3.1.5) was interpreted in the TexLa Merge 3D, Texas OBS 3D seismic, Glenda 3D, West Cameron 3D, Vermilion 3D, and 2D seismic datasets. Interpretations were continued along the southern edges of the TexLa Merge 3D volume and proceeded systematically to interpret key horizons using the 2D-seismic lines. Horizon interpretations become less constrained as the chronostratigraphic horizons extend into deeper water and become speculative in the deeper portion of the data. In addition, over 600 fault planes that penetrate MFS09 have been interpreted. The MFS09 is an important horizon since it is the base of an important shale interval (between the SB-M08 and MFS09 horizons) that serves as a reservoir seal for potential sites of permanent geologic storage of CO_2. Consequently, MFS09 was the first horizon to be extended to the Texas OBS 3D dataset.

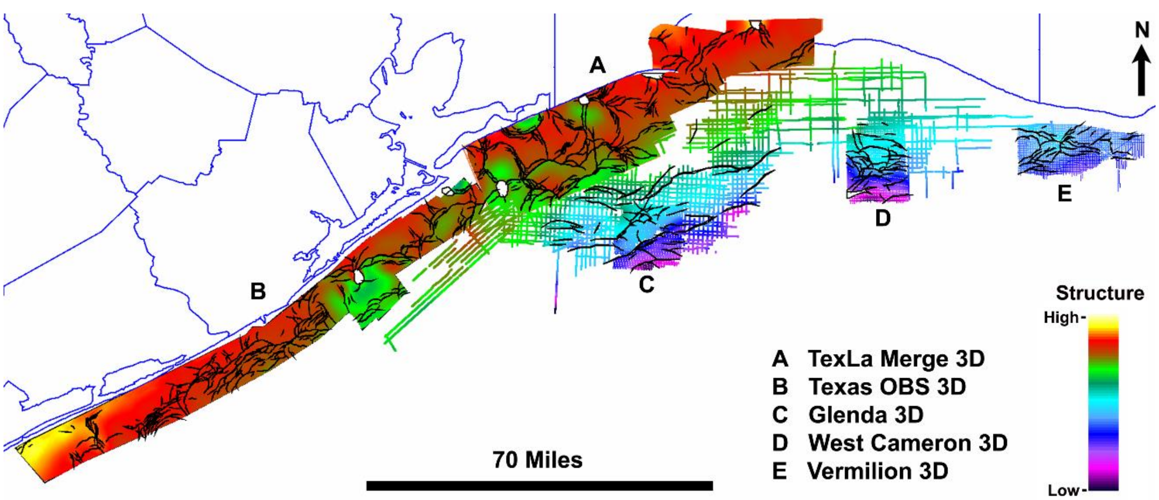


Figure 3.1.5. Regional Two-way time structure of the MFS09 surface.

Seismic Amplitude Assessment

RMS amplitudes help define the spatial distribution of genetically related depositional successions

Seismic reflection amplitude information can help identify geologic features influencing CCS, (e.g., unconformities, reefs, channel and deltaic sands, lithology, and gas/fluid accumulations). Root-mean-squared (RMS) amplitudes are calculated as the square root of the average of the squares of the amplitudes from each vertical sample within an analysis window. This calculation magnifies zones of high amplitudes and diminishes low-amplitude zones. Often, vertical seismic sections fail to clearly identify important stratigraphic features because they are typically manifested as subtle variations in amplitude strength, phase shift, or polarity reversal, and are easily overlooked by interpreters. Mud-dominated rocks (e.g., mudstone, shale) are displayed commonly as low-amplitude zones/areas in seismic data. The RMS amplitudes are sensitive to sand-bearing units (usually manifested as high amplitudes) within the geologic successions and help define the spatial distribution of genetically related depositional successions. Such RMS amplitude maps can image potential stratigraphic traps that may be used for carbon-sequestration. Imaging these potential traps in a horizontal map view adds additional information of spatial reservoir distribution to the typical seismic cross-section geometries used to interpret seismic facies and, thus, infer depositional systems patterns that lend insight into the associated reservoir quality (Fig. 2).

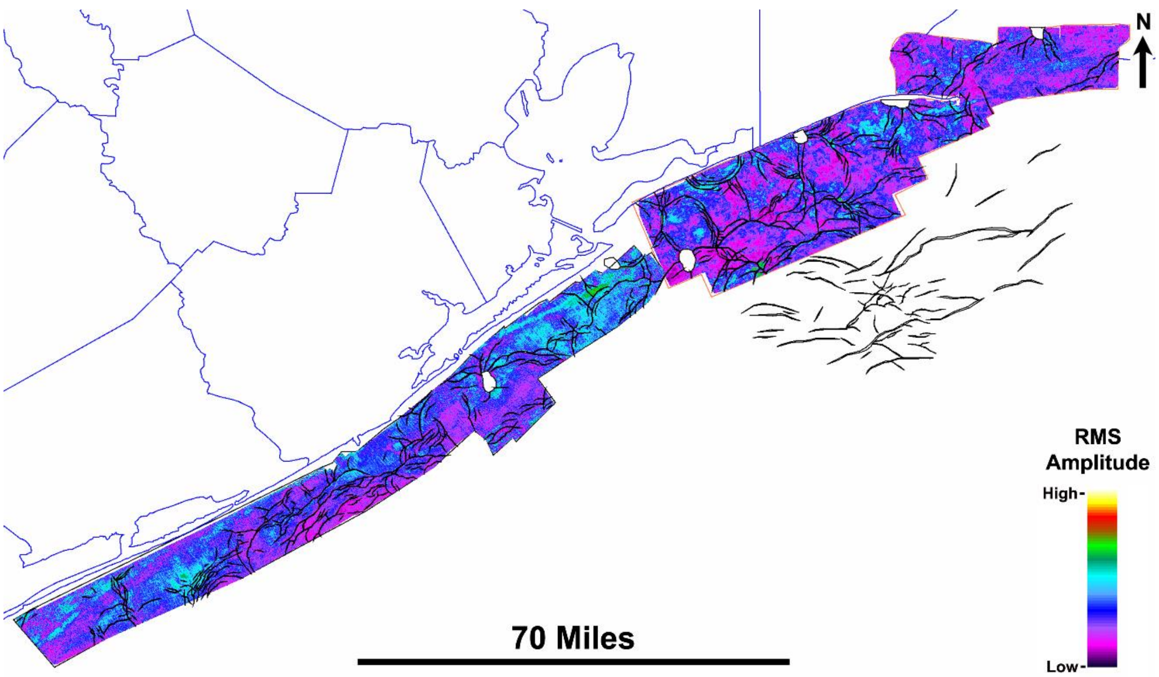


Figure 3.1.6 – Regional RMS amplitude map of MFS09 plus 50 ms.

The focus of this study is the location of dedicated geologic sites (sinks) that can be utilized by large-scale integrated CCS facilities (i.e., have the capacity to accommodate a minimum of 30 megatons of CO_2 generated from adjacent onshore industrial sources). Industrial facilities that are involved in chemical production, natural-gas processing, oil refining, and fertilizer production can generate significant quantities of CO_2 per annum. Suitable locations require sufficiently large footprints regarding structural closure and genetically related depositional successions. In addition, seismic derived RMS amplitudes were analyzed to identify probable zones/areas that contain sufficiently high porosities and thickness (accessible pore volume) to accommodate large amounts of injected CO_2.

Assessment of Potential Storage Sites

Based on previous screening for CO_2 storage sites using structural closure analysis on structure maps generated from the TXLA Merge 3D seismic dataset, three potential CO_2 storage sites were selected to be furtherly characterized. They are ST TR 60-S, High Island Block 10-L, and High Island Block 24-L fields (**Figure 3.1.7**).

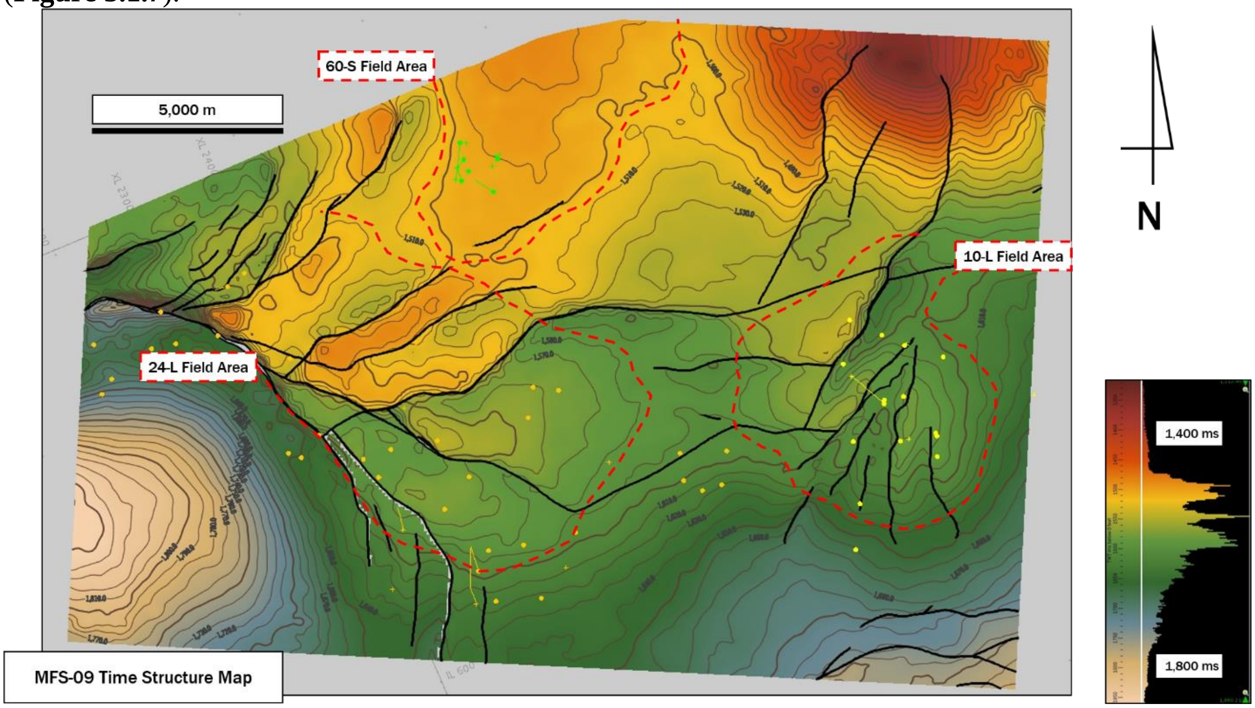


Figure 3.1.7 Time structure map of MFS-09 horizon or the bottom of Amph-B shale that is known as regional seal in the area showing the distribution of the three fields that were chosen for further investigation of CO_2 storage sites characterization.

The ST TR 60-S Field site

The ST TR 60-S Field is located less than 2 miles off the coast in Texas state waters (**Figure 3.1.7**). Based on the latest data from the Railroad Commission of Texas (as of April 2018), the total cumulative oil production for ST TR 60-S Field is 3,600,360 Bbls (barrels) from multiple sand reservoirs (informally known as I, J, G, and G1 Sands). The total cumulative gas production for ST TR 60-S Field is 11,429,529 Mcf (approx. 11.4 BCF) from multiple sand reservoirs (H1, K, and L Sands). These sand reservoirs were included in the LM1 P.2. Play, lower Lower Miocene in age, and interpreted as western progradational sandstones. The field was discovered in 1990 with reservoir depth ranging from 8,000 – 8,400 ft. The porosity is reported to be as high as 29.6 % (**Figure 3.1.8**). The total cumulative productions for all fields in the State Waters up to April 2018 are approximately 42.4 MMBO and 4.2 TCF. The oil production from ST TR 60-S Field is significant, constitutes about 8.5% of the whole Texas state waters total oil production.

Play	Age	EOD	Year Disc.	Resservoir Depth (ft)	Area (acres)	HC Type	Pay (ft)	Drive	Trap	Porosity	Water Sat
LM1 P.2.	Lower Lower Miocene	Western Progradational Sandstone	1990	8000 - 8400	2594	Oil, Gas	43	SG, COMB	Faulted Anticline	29.60%	46.00%

Figure 3.1.8   Detailed field and reservoir information of the ST TR 60-S Field

The interval of interest for CO_2 injection is located shallower than the hydrocarbons producing intervals. Based on seismic interpretation, the interval is located between the MFS09 and MFS10 seismic horizons. Time structure maps were generated based on the seismic horizons. Time structure map of the MFS09, equivalent to the bottom of Amph-B shale that is known as regional seal, shows the structural configuration of an anticline around the ST TR 60-S Field that opens up northward truncated by the limit of the offshore seismic data coverage along the coastline

(**Figure 3.1.9**).

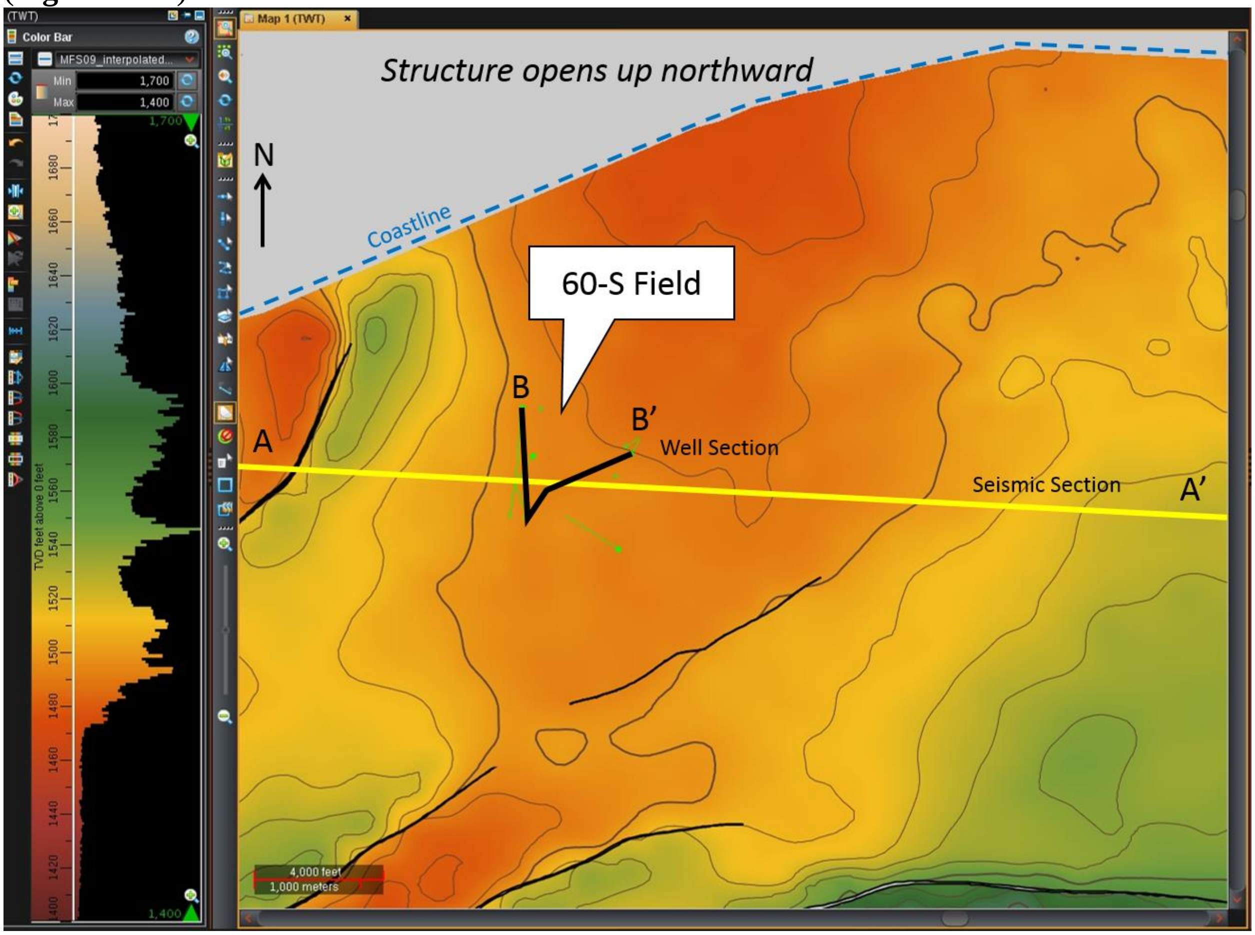


Figure 3.1.9   Structural configuration of the ST TR 60-S Field showing the anticlinal structure that opens up northward at shallower interval (MF09 horizon, bottom of the Amph-B shale as regional seal). Coastline position is marked by blue dashed-line.

In the seismic section, the interval between MFS09 and MFS10 is characterized by parallel to subparallel of alternating low-medium and high amplitude seismic reflectors within a gentle anticline structure. Deeper faults in the hydrocarbon producing intervals appear to not penetrate shallower interval of interest for CO_2 injection (**Figure 3.1.10**). This represents the presence of alternating deltaic sands and shales that can act as multiple reservoirs and seals within the interval of interest of 5,500 – 7,500 feet that is suitable for CO_2 injection into the geologic formations as shown in the well section (**Figure 3.1.11**).

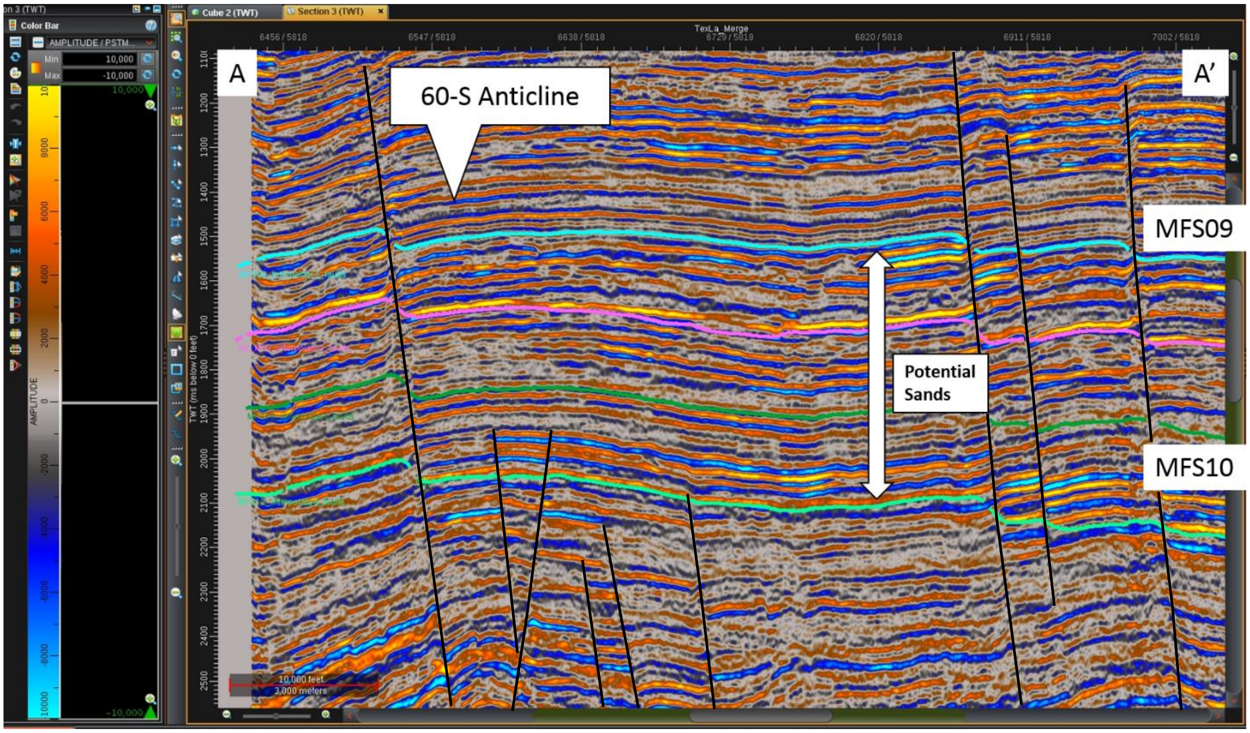


Figure 3.1.10 A to A' (west to east) seismic section crossing the ST TR 60-S Field showing the anticlinal structure and potential sands within an interval between MFS09 (light blue) and MFS10 (light green) seismic horizons.

More data and further subsurface analysis and mapping are needed in order to assess the full potential of this site as a CO_2 storage site. Although, at shallower interval of interest the site's structure opens up northward, it has a possibility of closing onshore. Particularly, its proximity to the coastline and CO_2 sources makes the ST TR 60-S Field site highly attractive for further investigation in the future.

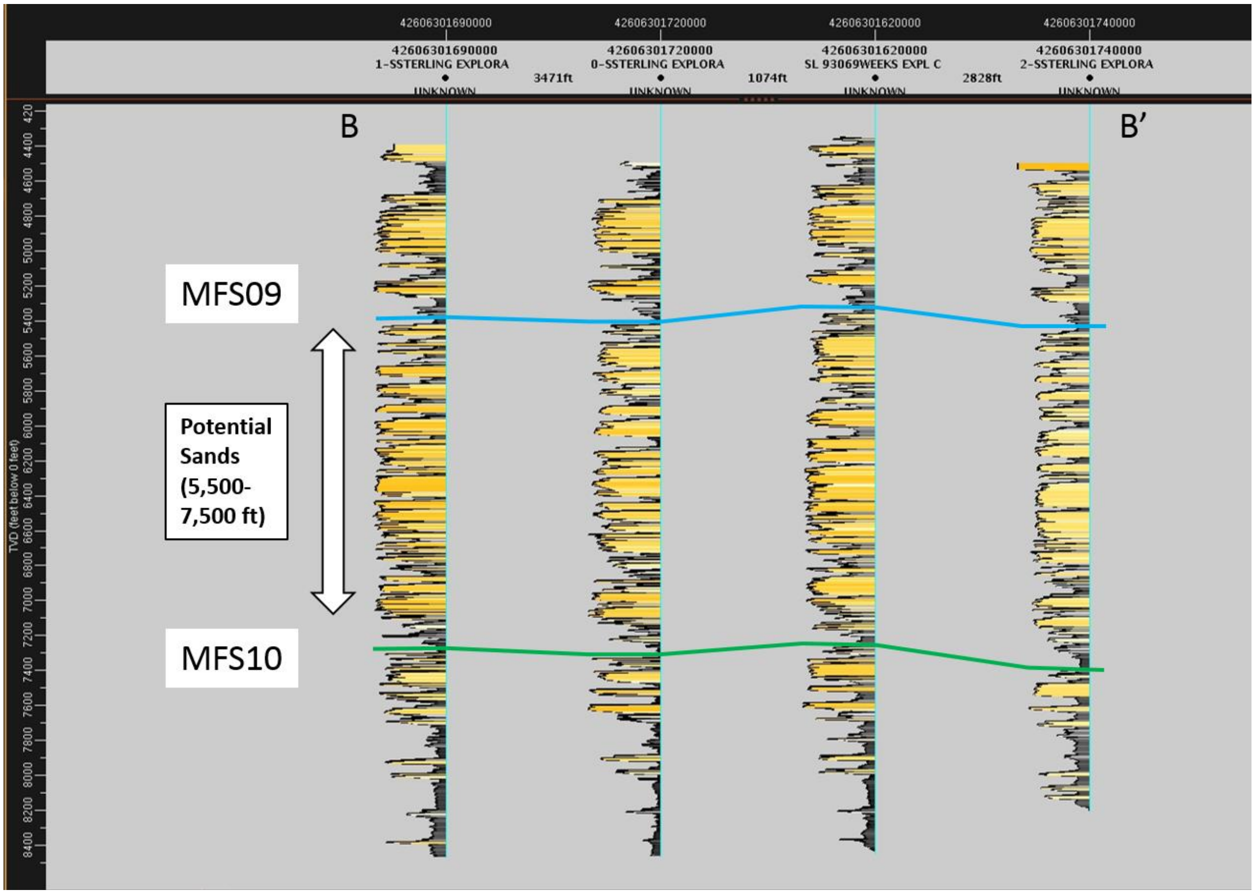


Figure 3.1.11 B to B' (arbitrarily west to east) well section of four wells in the ST TR 60-S Field showing the potential aggradational sands reservoirs within an interval between MFS09 (blue) and MFS10 (green) located at depth ranging from 5,500 – 7,500 feet.

The High Island Block 10-L Field Site

The High Island Block 10-L Field is located approximately 6 miles southeast of the ST TR 60-S Field in Texas state waters (**Figure 3.1.7**). Based on latest data from the Railroad Commission of Texas (April 2018), the total cumulative oil production for High Island Block 10-L Field is 945,404 Bbls (approx. 1 MMBO) from multiple sand reservoirs (A-2, BIG 3, 6000 SD, 6950 SD, and D-6 Sands). The total cumulative gas production for High Island Block 10-L Field is 8,609,721 Mcf (approx. 8.6 BCF) from multiple sand reservoirs (A-2, AMPH B-1, FB-1, SIP. 1, FB-2, SIP. 1, FB3, B-4A, and SIPH D1 Sands). These sand reservoirs were included in several plays in the lower, middle, to upper Lower Miocene sandstones. The field was discovered in 1990 with reservoir depth ranging from 4,800 – 8,200 ft. The porosity is reported to be as high as 33.4 % (**Figure 3.1.12**).

Play	Age	EOD	Year Disc.	Resservoir Depth (ft)	Area (acres)	HC Type	Pay (ft)	Drive	Trap	Porosity	Water Sat
MM9 A.3A, MM4 R.1, MM4 A.1B, LM4 P.4, LM2 P.1B	lower, middle, and upper Lower Miocene	Progradational, Aggradational, & Retrogradational Sandstones	1969	4800 - 8200	500 - 2500	Oil, Gas	~26	SG, WD, WOMB	Rollover Anticline, Growth Fault	~33.4%	18.8 - 57.7%

Figure 3.1.12 Detailed field and reservoir information of the High Island Block 10-L Field

The interval of interest for CO_2 injection is located within the hydrocarbon producing interval, between the MFS09 and MFS10 horizons (**Figure 3.1.13**, black double-arrow line in well section and yellow double-arrow line in seismic section). By utilizing the structure map, structural closure analysis was performed using PERMEDIA software. This closure analysis quickly highlighted the five largest closure within the High Island Block 10-L Field site (**Figure 3.1.14**). The areal coverage of the largest closure is 4.28 km^2 with maximum closure height of approximately 31 meters. This site has potential as a "*stacked storage*" with shale strata above sand reservoirs with proven hydrocarbon accumulations (**Figure 3.1.13**, blue, black, and red correlation lines between MFS09 and MFS10). The reservoirs' thickness mostly exceeds the maximum closures height. This means that in any given closure sand reservoirs are expected to always be present above the contour of the closure spill point (high net-to-gross).

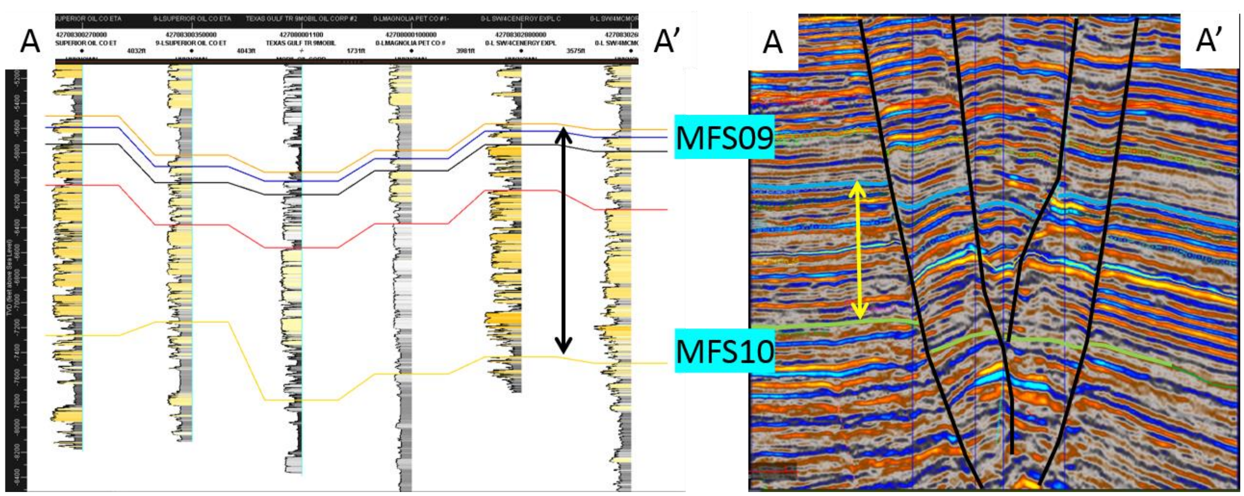


Figure 3.1.13 A-A' (north to southeast) well section (left) and seismic section (right) of the High Island Block 10-L Field site showing the interval of interest located at depth ranging from 5,500 – 7,500 feet for CO_2 injection marked by double-arrow line between MFS09 and MFS10.

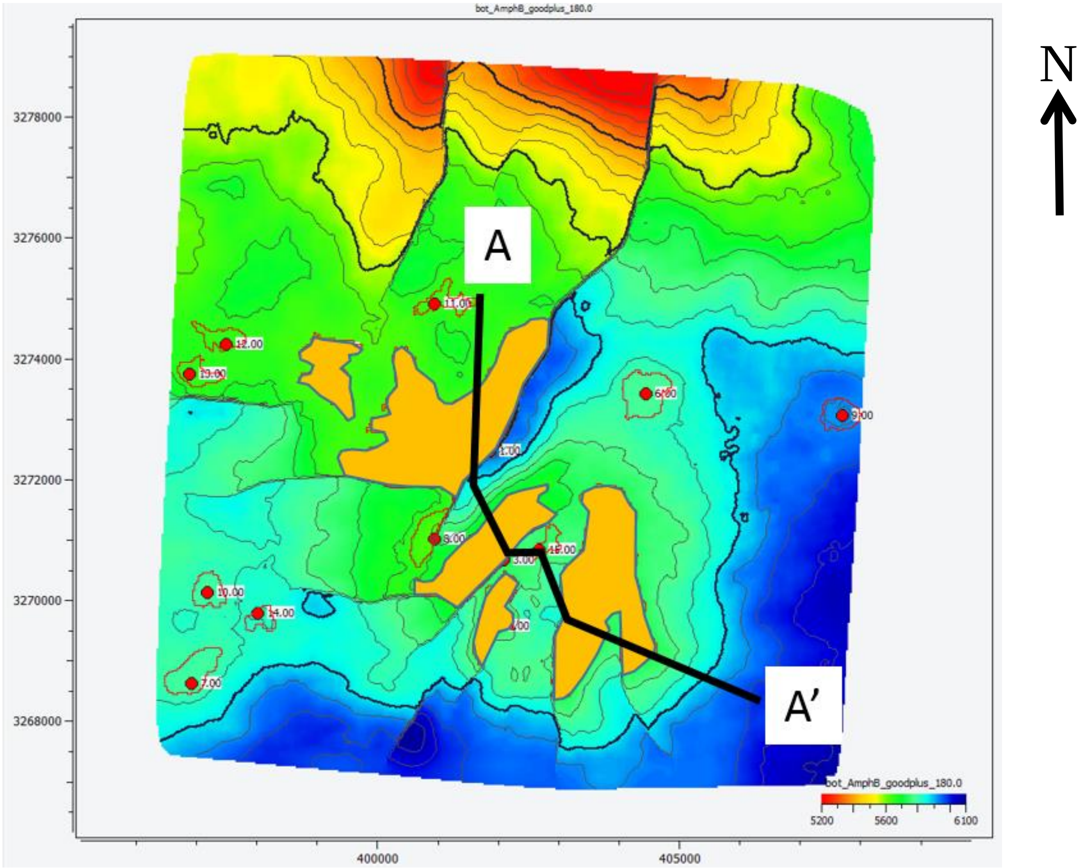


Figure 3.1.14 Structural closure analysis using PERMEDIA software on the MFS09 depth structure map. The structural configuration of the High Island Block 10-L Field site is growth-faulted rollover anticline. Five largest closures are highlighted by orange-filled polygons.

High Island 10-L Capacity Assessment

As mentioned in the report for Deliverables 4 & 5, the high-level evaluation of the 10-L Field was conducted in order to assess its capacity to be a CO_2 storage site and provide a detailed case study for an ecosystem study. The interval of interest is approximately 2,500 feet thick between 5,500 – 8,000 feet TVD and includes the lower, middle, to upper Lower Miocene sandstones. A regional, transgressive, 400 feet thick, shale-dominated seal interval (aka confining zone) overlies the prospective injection interval. The injection interval is bounded at the top by MFS-09 (bottom of regional *Amph B* shale) and at the bottom by MFS-10. MFS-09 and MFS-10 essentially serve as mudstone – dominated confining systems above and below, respectively, the prospective storage interval. Within the storage interval, both sandstone reservoirs and shale layer confining systems appear to have extensive lateral distribution. A study based on seismic and well-log interpretations defines a sequence of 15 sandstone units that have average thickness of 33 m. Porosities are as high as 33.4 % and average 25% (Seni, et al, 1997) and permeability averages 460 millidarcies.

At least 7 hydrocarbon reservoirs with historic production are identified in the field (Fowler, 1987). Hydrocarbon reservoirs occupy the structurally highest part of the field where they ‘float’ on hydrologically connected brine in the ‘water leg’. Faults (interpreted to be sealing) partly compartmentalize the top of the structure, but the terminations of the faults allow the compartments to be hydrologically connected and fluids can migrate from one compartment to another. Hydrocarbon retention indicates that the structure is suitable for retaining injected CO_2.

Reservoir layers were defined by pairs of sandstone (as reservoirs) and shale (as seals). Based on well correlations, 15 reservoir and overlying seal trap sequences were defined (Figure 19 and 20).

Many types of capacity assessments can be used to determine how much CO_2 the 10-L structure and associated pore volume can accept. For this study we integrate three methods: **1)** Calculate a CO_2 volume equivalent to replacing the volume of hydrocarbon historically produced with CO_2 at reservoir pressure and temperature (1-to-1 liquid volume replacement); **2)** Using a static geometric method, assess how much CO_2 could be trapped as buoyant phase inside the domed and fault-bounded structures, and **3)** using a quick-look dynamic analytical method, consider how much CO_2 could be injected into this geometry during a limited time frame and deploying a limited number of wells. In all these cases, the capacity assessments are preliminary and subject to improvement during ongoing studies. Prior to investment, and to honor the complex geologic system, a full geocellular fluid flow model including in a reasonable representation of heterogeneity of the rock facies, multiphase fluid flow physics, and fluid properties for brine, oil, gas, and CO_2 would be constructed and used to validate and refine the estimates.

Hydrocarbon-based capacity

Initially we can consider a volume defined by replacing the volume of hydrocarbon produced with CO_2 at reservoir pressure and temperature. This analysis could be extended to consider the potential for increasing storage capacity and improving project economics by producing hydrocarbon. However, this type of assessment depends on the quality of production data and analysis of how much hydrocarbon remains in the reservoir, as well as complex considerations of reservoir properties and economics outside the scope of the study, and does not consider the capacity of saline-water bearing formations in the volume.

Based on data from the Railroad Commission of Texas (up to April 2018), the total cumulative oil production for High Island Block 10-L Field is 945,404 Bbls (approximately 1 MMBO) from multiple sand reservoirs (A-2, BIG 3, 6000 SD, 6950 SD, and D-6 Sands). The total cumulative gas production for High Island Block 10-L Field is 8,609,721 Mcf (approx. 8.6 BCF) from multiple sand reservoirs (A-2, AMPH B-1, FB-1, SIP. 1, FB-2, SIP. 1, FB3, B-4A, and SIPH D1 Sands). These sand reservoirs represent several plays in the lower, middle, to upper Lower Miocene of *progradational*, *aggradational*, and *retro-gradational* depositional systems, with present depth ranging from 4,800 – 8,200 ft.

Using the CH_4-CO_2 Volumetric Replacement Assessment (Meckel & T. Rhatigan, 2017), if it is known that 10-L Field cumulative gas production is 8.61 BCF and if 1 BCF equals ~50 KT CO_2 (Cumulative Distribution Function/CDF), then the potential CO_2 storage quantity of the 10-L Site based on simple volumetric replacement of produced hydrocarbons is at least 0.43 MT CO_2. However, this number represents an underestimation of the full potential for CO_2 storage due to the lateral continuity with downdip brine reservoirs in the area.

Geometrically-based static method

The area within the 10-L site main structure was evaluated using PERMEDIA™ closure analysis to identify structural traps. In these traps, buoyant CO_2 can be securely retained, similar to prior hydrocarbons. Approximately 10.2 km^2 of structural closures were delineated, with a maximum closure height of 51 m. At the deepest trap layer, 8.72 km^2 of chosen structural closures were delineated with maximum closure height of approximately 48 m. Volumetric analysis for the interval between the shallowest and the deepest trap layers was done proportionally considering the bulk pore volume ratio. Structural closures generated from this analysis are considered conservative estimates in term of lateral extent and can be multiplied with stacked storage (reservoirs) scenario.

By proportionally estimating the bulk rock volume for all 15 trap layers, reducing it using an average net-to-gross of 65%, and obtaining a pore volume using an average porosity between 20% - 30%, the estimated total pore volume for all of the trap layers ranges from 246 to 369 million cubic meters with an approximate average pore volume of 308 million cubic meters.

The next consideration is the efficiency with which CO_2 will occupy the identified pore space. Many factors will limit the access of CO_2 into pores, leading to low and uncertain values of storage efficiency. For example, if CO_2 was injected directly into the structure, most of the flow will occur in the highest permeability zones; other porous zones will be bypassed. Flow in thief zones might cause CO_2 to migrate outside of the structural trap. For our study case, we consider an ideal emplacement of CO_2, where injection occurs into the lower water leg part of the compartment of the partly fault-bounded area ("fetch area") of each reservoir layer, and has time to migrate and slowly accumulate at the top of the structure, displacing all but the capillary bound water by effective stable gravity-driven displacement. Assuming 25% irreducible water saturation, a mass of CO_2 to fill the stacked layers of the trap is about 150 MMT. To make this conceptualization conservative, we did not consider CO_2 trapped and dissolved as CO_2 migrates to stable configuration.

Dynamic methods using EASi-itool

The third estimate of storage capacity considers how pressure build-up may limit the rate at which CO_2 can be added and water displaced. Managing pressure to assure that injection does not open preexisting weakness or create new fractures in an uncontrolled way is a basic rule of injection. We selected the dynamic (e.g., pressure- and rate-dependent) CO_2 injection capacity estimator Enhanced Analytical Simulation Tool (EASiTool) developed to make these types of initial injection volume calculations (Ganjdanesh and Hosseini, 2017). EASiTool is calibrated with full physics simulations but runs based on look-up tables so that it quickly provides "ballpark" estimates. As in the static calculation more refined calculations can be made in a follow-up study using detailed geologic and fluid parameters and a geocellular fluid-flow model.

EASiTool inputs the same parameters as the static geometric model, with the addition of the hydrologically connected areas where no CO_2 will be placed but can accommodate elevated pressure (brine and rock can be compressed and displaced brine accommodated). The size and type of boundary – hydrologically open or closed – have a large impact on rate-dependent calculations. The lateral and vertical geometry of the reservoir however has only minor impact; we can generalize the volumes. However, all the injection wells are placed in the fetch area, where the CO_2 will ultimately migrate into the designated structural trap. For this case study, we can conceptualize the field as four boxes each with a 'basin' area that accommodates pressure and an injection target in the fetch area. (Table 3.1.1)

Table 3.1.1 – EASiTool capacity estimation of, respective, structural traps (compartments) A, B, C and D of the High Island 10-L Field.

Area	Basin km^2	Injection area km^2	closed sides	number of wells	years of injection	MMT injection per reservoir	MMT total injection
A	65	35	1	9	12	79	1185
A	65	35	1	1	12	8.8	132
B	7.5	6	3	1	12	.8	13
C	7.5	4.5	3	1	12	.8	13
D	40	15	2	4	12	35	525

Area (aka compartment) A is a large area on the east side of field, but only the southern part drains to the closed structure. If we assume that this area is hydrologically open, then the amount of CO_2 that can be injected into the stack of relatively thick high-permeability sandstones is limited by 1) the maximum per-well injection rate and, 2) the intersection of one CO_2 plume with another as volumes increase. The open reservoir does not become over pressured. The largest amount under model constraints that can be injected at the highest rate is 1,185 MMT via 9 well clusters (each cluster injecting into 15 stacked layers) over 12 years. Capacity of block D is similar to A. However, the maximum injection for the compartment overfills the structural trap. Reducing the assumption about the number of zone accessed per well to 4 might be more realistic as the total well diameter limits injection rate. The boundary conditions for smaller compartments B and C are more closed, which greatly limits the rate-dependent capacity to less than 1 MMT, therefore injecting directly into these blocks would be less cost effective as the structurally trapped volume can only be emplaced over long time frames. In this structure the capacity might eventually be utilized by overfilling the structures that feed the smaller compartments.

Using the simplified tools, we propose a base case that 9 wells operated for 12 years each completed into 4 zones to emplace **a total of 150MMT** with wells placed in the water leg where all the plume will slowly migrate into the structural trap is feasible in terms of geology and engineering. A competed detailed 3-D earth model, a full reservoir model and a well completion plan would be needed to model and optimize all these parameters.

Eugene Island 330 and 331 Fields

A search for mudlogs was conducted as mudlogs can be used to infer fluid distribution in a reservoir. The search resulted in identification of a report from the Houston and the New Orleans Geological Societies, which contains 153 mud logs in the Texas and Louisiana offshore (Moore et al., 1993). By overlaying the well location of the mudlogs obtained from Lexco's OWL 7 database onto structural and cross section data an interpretation can be made on the fluid distribution in the reservoir. Eugene Island Blocks 330 and 331 Fields are being interpreted for fluid distribution interpretation with structural data from Alexander and Handschy (1998) that also contains a fluid distribution interpretation along a nearby fault for comparison (Figure 3.1.15). This technique was also applied to studies of structure and stratigraphy of High Island 10L, High Island 24L, and St. Tr. East 60S. Fluid distribution interpretation can aid in identifying the most suitable candidates for CO_2 enhanced oil recovery.

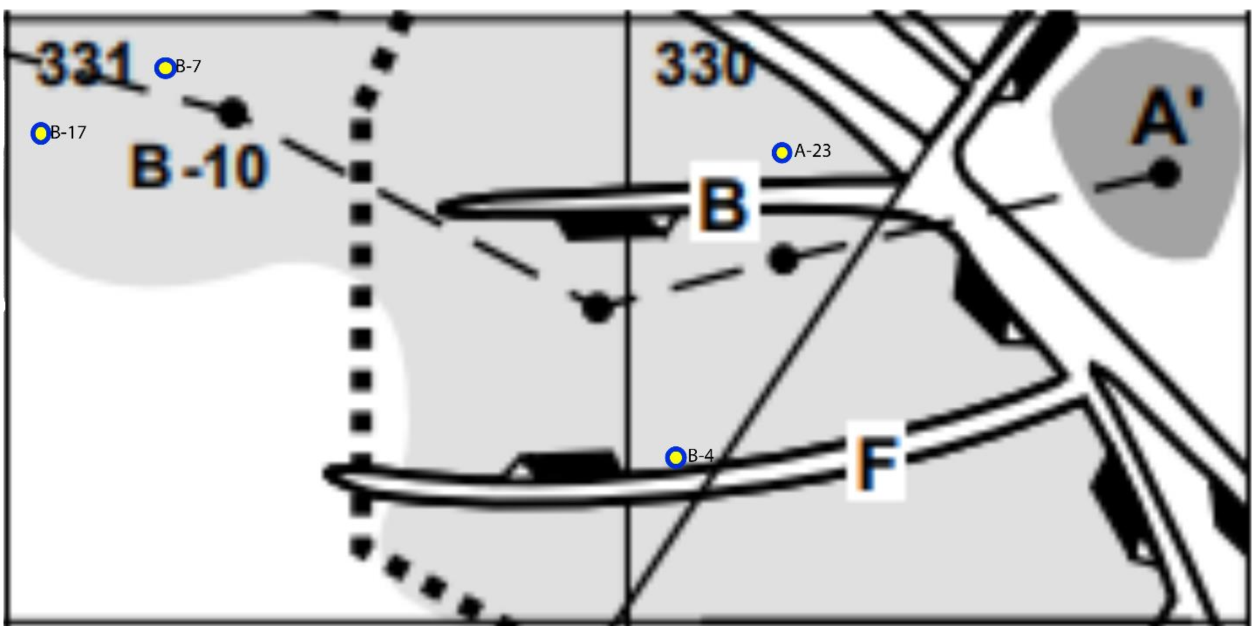


Figure 3.1.15 Eugene Island 330 and 331 cross section area with mudlog locations overlain. Modified from (Alexander and Handschy, 1998).

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Subtask 3.2: Integrated Risk Assessment Modeling (IAM)

DELIVERABLE D3 REPORT:

Quick Look Report on NRAP Toolkit Assessment

U.S. Department of Energy National Energy Technology Laboratory

Field Work Proposal LLNL-FWP-FEW0217

CarbonSAFE Phase I: Integrated CCS Pre-Feasibility—Northwest Gulf of Mexico

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Submission Date: 30-July-2018

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Abstract

The Carbon Storage Assurance Facility Enterprise (CarbonSAFE) initiative—funded by the DOE Office of Fossil Energy, Carbon Storage Program—seeks to develop an integrated CCS storage infrastructure capable of handling commercial-scale volumes of CO_2 by the 2025 timeframe. This initiative is supporting a number of pre-feasibility and feasibility studies for future large-scale CCS operations in the United States. One of these projects is exploring the feasibility of large-scale storage in the Northwest Gulf of Mexico. It is well known that the Gulf of Mexico has sufficient storage capacity to become a major CO_2 storage hub. At the same time, however, there remain many technical and non-technical questions regarding the feasibility of large scale disposal operations in this offshore environment.

In parallel, the DOE Carbon Storage Program has supported the National Risk Assessment Program (NRAP), whose mission is to develop better quantitative risk assessment methods for carbon storage systems. As part of this initiative, a number of software tools have been developed—collectively referred to as the NRAP Toolkit—for assessing risk for various components of a storage system. In order to ensure the relevance of this toolkit for real storage projects, one element of the CarbonSAFE initiative is an assessment of the validity and usefulness of the NRAP toolkit for specific sites of interest.

Several CarbonSAFE projects are systematically studying the feasibility of storing large volumes of CO_2 in offshore reservoirs. The Northwest Gulf-of-Mexico project—led by the Bureau of Economic Geology at UT Austin, with support of several research partners—is a central component of this offshore assessment. In the early stages of the NRAP toolkit development, however, the focus was entirely on onshore storage systems. As a result, there is an understandable bias towards onshore storage designs. This report provides a critical analysis of the current NRAP toolkit and its applicability to offshore storage systems, using the Gulf of Mexico as a concrete case study. For each NRAP tool we discuss the relevance, model appropriateness, availability of input data, and key gaps that need to be filled. The goal is to support the continued development of the NRAP tools so that they are well positioned to support large-scale deployment of *both* onshore and offshore systems.

Contents

1. Introduction

The Carbon Storage Assurance Facility Enterprise (CarbonSAFE) initiative—funded by the DOE Office of Fossil Energy, Carbon Storage Program—seeks to develop an integrated CCS storage infrastructure capable of handling commercial-scale volumes of CO_2 by the 2025 timeframe. This initiative is supporting a number of pre-feasibility and feasibility studies for future large-scale CCS operations in the United States. One of these projects—The Northwest Gulf of Mexico Pre-Feasibility Project led by the Bureau of Economic Geology, UT Austin—is exploring the feasibility of large-scale storage in the Northwest Gulf of Mexico (Figure 3.1). It is well known that the Gulf of Mexico has sufficient storage capacity to become a major CO_2 storage hub, and lies in close proximity to large volume CO_2 point sources. At the same time, however, there remain many technical and non-technical questions regarding the feasibility of large scale disposal operations in the offshore environment.

In parallel, the DOE Carbon Storage Program has supported the National Risk Assessment Program (NRAP), whose mission is to develop better quantitative risk assessment methods for carbon storage systems. As part of this initiative, a number of software tools have been developed—collectively referred to as the NRAP Toolkit—for assessing risk for various components of a storage system. In order to ensure the relevance of this toolkit for real storage projects, one element of the CarbonSAFE initiative is an assessment of the validity and usefulness of the NRAP toolkit for specific sites of interest.

Several CarbonSAFE projects are systematically studying the feasibility of storage large volumes of CO_2 in offshore reservoirs. The Northwest Gulf-of-Mexico project is a central component of this offshore assessment. In the early stages of the NRAP toolkit development, however, the focus was entirely on onshore storage systems, primarily in support of the DOE's existing Regional Partnership Projects. In general, we find that the majority of existing tools in the toolkit are relevant to offshore systems, but that specific updates are necessary to better account for key risk drivers in offshore settings.

This report provides a critical analysis of the current toolkit and its applicability to offshore storage systems, using the Gulf of Mexico as a motivating case study. For each NRAP tool we discuss the relevance, model appropriateness, availability of input data, and key gaps that need to be filled. The goal is to support the continued development of the NRAP tools so that they are well positioned to support large-scale deployment of both onshore and offshore systems.

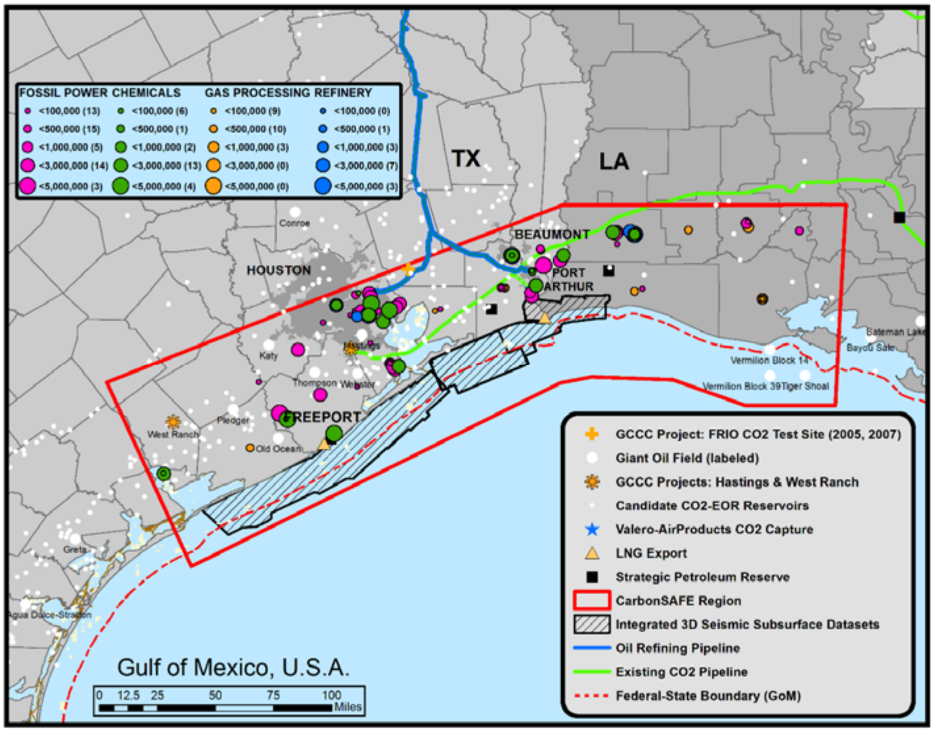

Figure 3.1: Map of the CarbonSAFE study area, showing CO_2 sources, existing pipeline infrastructure, and potential offshore storage targets in the Houston-Beaumont-Port Arthur region.

2. CCS in the Northwest Gulf of Mexico

Carbon storage in the Gulf of Mexico (GoM) provides a number of important advantages for a burgeoning CCS industry, including [Treviño & Meckel 2017]:

- A richly characterized subsurface due to decades of oil and gas development;
- A highly suitable geology, with huge potential storage volumes and proven trapping systems;
- Close proximity to CO_2 point sources, including refineries, petrochemical plants, fossil-fuel power plants, and cement facilities;
- Close proximity to existing pipeline infrastructure;
- A reduced risk to public resources, particularly protected drinking water aquifers;
- A low induced seismicity risk;
- A higher likelihood of public acceptance than onshore storage.

In particular, the thick, high porosity Miocene-age section in the GoM is expected to provide numerous high-porosity storage reservoirs (Figure 3.2) [Nicholson 2012]. These strata are at sufficient depth to maintain supercritical CO_2 conditions, and individual storage targets are sufficiently large (10-100 Mt capacity)

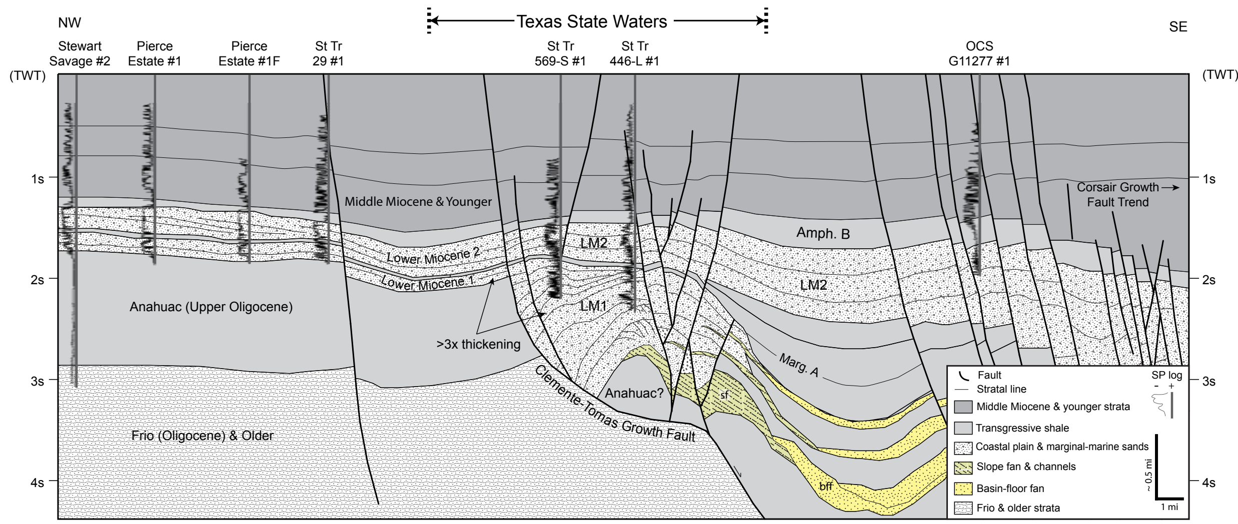

Figure 3.2: Representative dip-oriented structural cross-section through Texas state waters, showing Miocene-age storage targets, stratigraphic seals, and shore-parallel faulting. Reproduced from [Nicholson 2012].

to enable commercially viable operations [Meckel & Rhatigan 2017]. The prevalence of existing natural gas accumulations also provides strong evidence of both stratigraphic and structural integrity in these systems. There is also evidence that the Miocene age strata in many locations are laterally well connected, suggesting that CO_2 storage operations could experience higher injectivity and lower overpressure than highly compartmentalized systems. The magnitude of pressure perturbation is a key driver for both hydrologic and geomechanical risks, and therefore high injectivity and/or pressure-depleted systems are appealing.

3. NRAP Toolkit Assessment

The CarbonSAFE Northwest GoM pre-feasibility project has made significant progress in identifying the key elements necessary for an integrated CCS infrastructure—i.e potential sources, transportation options, and sinks. As the effort works towards identifying specific storage targets, several NRAP risk assessment methods become useful. The remainder of this report provides a systematic evaluation of the existing toolkit (Table 1) and its relevance in the GoM context. For each NRAP tool we discuss the model appropriateness, availability of input data, and key gaps that would need to be filled. Note that specific application of the NRAP tools to GoM data is pending a downselect to specific storage locations in the CarbonSAFE region. To organize the discussion, we focus on three broad topic areas: (1) geo-hydrologic risks, (2) wellbore leakage risks, and (3) risk-based monitoring design.

Table 1: Risk analysis tools available in the NRAP Toolkit. Note that some supporting tools and tools-in-development have been omitted.

1	**Integrated Assessment Model** This tool allows users to rapidly compute probabilistic risk estimates for a storage system, by combining relatively simple models for each component piece (reservoir, leakage pathway, receptor). To date, the tool has largely focused on wells as the primary leakage pathway, though fault and seal leakage pathways are expected to be supported in future releases.
2	**Reservoir Reduced-Order Model Generator** This tool allows users to convert a suite of high-resolution reservoir simulations into a reduced-order model format so it can be imported as a new reservoir component in the Integrated Assessment Model above.
3	**Wellbore Leakage Analysis Tool** This tool provides models for brine and CO_2 leakage through various wellbore pathways (open tubing, imperfect cement, etc). It can be used in stand-alone mode or as part of the Integrated Assessment Model above.
4	**Natural Seal Reduced-Order Model** This tool provides a simplified model of multiphase flow through a stratigraphic barrier, including capillary and buoyancy effects. It may be used as a stand-alone tool or within the integrated assessment model.
5	**Aquifer Impact Model** This tool estimates the impact that brine and CO_2 leakage may have on drinking water aquifers–i.e. changes in Ph, salinity, trace metals, and/or organics. May be used as a stand-alone tool or as part of the Integrated Assessment Model.
6	**Atmospheric Release Model** This tool estimates the impacted area from an atmospheric release of CO_2 under specific meteorological conditions (wind speed, temperature, etc.). May be used as a stand-alone tool or as part of the Integrated Assessment Model.
7	**Probabilistic State-of-Stress Tool** This tool allows users to perform a probabilistic state-of-stress analysis by using Bayesian inference applied to available state-of-stress indicators. It can be used to estimate fault reactivation potential and inform similar geomechanical risk assessments.
8	**Ground-Motion Prediction Tool** Uses empirical ground motion prediction equations to provide an estimate of anticipated ground motion due to an earthquake (tectonic or induced) with a given magnitude, depth, and distance. Can be used to identify radius of seismically vulnerable infrastructure, as well as in choosing site-specific magnitude thresholds for stop-light management methods.
9	**Short-Term Seismic Forecasting Tool** Uses ongoing microseismic and injection rate measurements to build a statistical model for seismic frequency. This model can then be used to forecast seismic hazard over a short-term window, as a complement to existing stop-light induced seismicity management strategies.
10	**Monitoring Design for Risk Evaluation and Management** This tool provides a framework for computing optimal monitoring schemes under practical constraints stemming from monitoring technology sensitivity, budgetary limits, site access limits, etc.

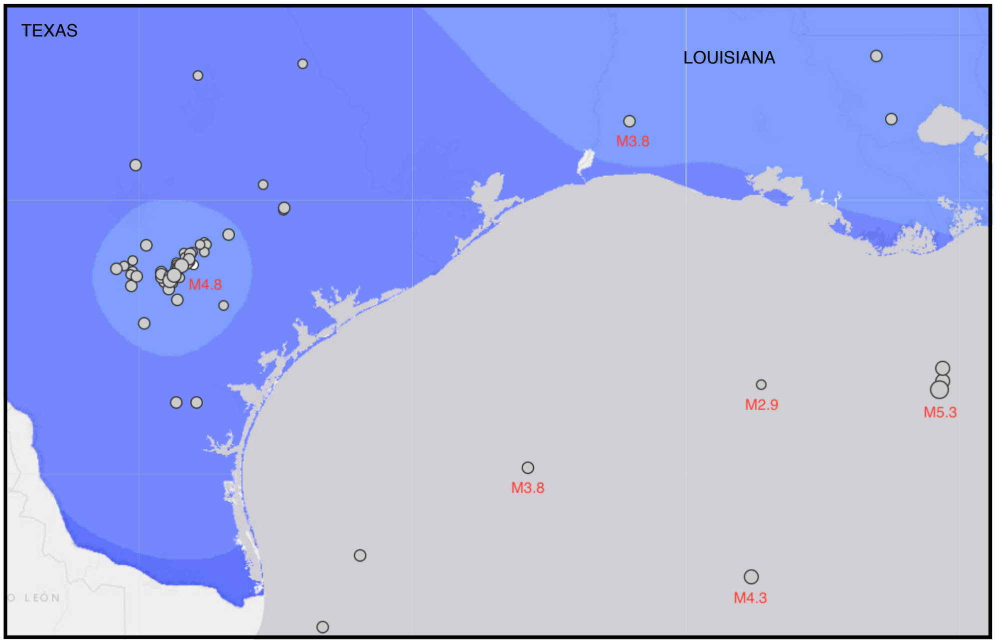

Figure 3.3: Historical seismicity in the Northwest Gulf-of-Mexico [Data: Advanced National Seismic System Comprehensive Catalog [ANSS 2018]].

3.1. Geo-hydrologic Risks

There are a variety of geo-hydrologic risks that any storage project must consider. By *geo-hydrologic*, we refer to risks associated with the behavior of the geologic storage system itself, as opposed to engineered components such as wells and facilities. In the current offshore context, three particular risk types merit consideration: (1) induced seismicity, (2) fault leakage, and (3) deformation risks.

3.1.1. Induced Seismicity

Induced seismicity has become a major public concern in the past decade, with a number of highly publicized earthquakes induced by wastewater disposal, geothermal, and hydrocarbon production activities [National Research Council 2012]. To date, no dedicated CCS project has triggered felt earthquakes, but microseismicity has been observed at several projects [Zhou et al. 2010, Whittaker et al. 2011, Oye et al. 2013, Kaven et al. 2015]. Felt events have been observed during CO_2-EOR operations at the Cogdell field in west Texas [Gan & Frohlich 2013, Davis & Pennington 1989]. As the CCS industry grows towards gigatonne scale injection, induced seismicity will be a pervasive concern and will need to be addressed by appropriate risk management strategies.

At a given site, two primary factors determine the overall induced seismicity risk: (1) seismic hazard, and (2) seismic vulnerability. The hazard quantifies the frequency and magnitude of earthquakes that can be expected at a given site. The vulnerability measures the likelihood that earthquakes will cause damage to fragile infrastructure or create a public nuisance. Good project design can modify both components—hazard *and* vulnerability—in order to minimize the potential for undesirable impacts [White & Foxall 2016]. A key advantage of the CarbonSAFE study area is that both the seismic hazard and community vulnerability associated with offshore storage operations is expected to be extremely low.

Figure 3.3 shows historical earthquakes with magnitude 2.5+ observed in the Northwest Gulf-of-Mexico in the Advanced National Seismic System Comprehensive Catalog [ANSS 2018]. The central and northwest GoM has an extremely low seismicity rate due to its location in an intra-plate region and the ductile nature of the sedimentary system. The rare seismicity that has been observed may result from sediment loading processes, due to the high sediment deposition rate [Frohlich 1982]. Most faults in the system are expected to creep aseismically rather than rupture dynamically. In 2006, however, a series of larger earthquakes, including magnitude 5.3 and 5.9 events, occurred in the central Gulf, suggesting the region may be more tectonically active than previously thought [Gangopadhyay & Sen 2008]. These two events were located sufficiently far offshore (several 100 km) that no damage from either event was reported. To date, no significant earthquakes have been observed in Texas State Waters, the focus of the CarbonSAFE study.

The NRAP toolkit contains three tools relevant to induced seismicity risk assessment and management: (1) The Probabilistic State-of-Stress Tool; (2) The Ground Motion Prediction Tool; (3) The Short-Term Seismic Forecasting Tool. While all have an important purpose, they differ in the impact they are likely to have on a future GoM storage project.

The Probabilistic State-of-Stress Assessment Tool is broadly useful tool for understanding a variety of geomechanical hazards in the offshore environment—i.e. more than just the potential for induced seismicity. It provides a convenient platform for incorporating direct and indirect stress observations—e.g. density logs, leakoff and formation integrity tests, borehole breakouts and tensile fracturing observations, focal mechanism estimates, etc.—into a probabilistic model of the stress state at a given site [Burghardt 2017]. The tool uses Bayesian inference to compute the posterior probability that a particular stress configuration is the "true" configuration given a set of observed stress indicators and some physical constraints on the allowable range of stress magnitudes. The results are presented using probabilistic stress polygons (Figure 3.4) an extension of the classic stress polygon technique for constraining state-of-stress [Zoback et al. 1987, Moos & Zoback 1990].

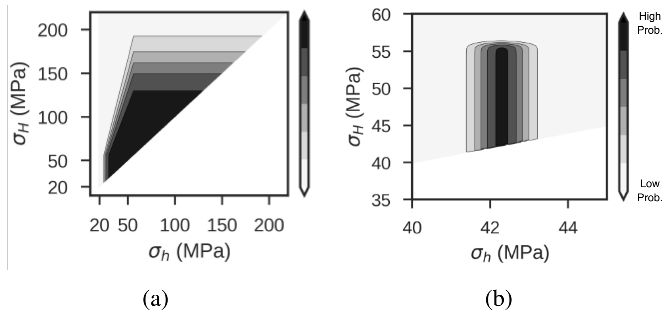

Figure 3.4: Typical stress polygon results computed using the NRAP Probabilistic State-of-Stress Assessment Tool, using data from the Southwest Regional Partnership Farnsworth Project. Grey contours indicate the probability that a given combination of minimum and maximum horizontal stresses is correct given a set of observed stress indicators: (a) Model constrained only with regional and indirect observations, leading to a wide range of feasible stress magnitudes. (b) Model constrained with local stress measurements, leading to a much narrower range of feasible stress magnitudes.

An analysis of available stress data for the CarbonSAFE region [Meckel et al. 2017] has been used to estimate the likelihood that faults could be reactivated during injection, either seismically or aseismically. This analysis suggests that the typical pressure increase required for fault reactivation is substantially larger than the typical capillary entry pressure. That is, capillary trapping considerations, and not fault stability, may be the most critical threshold defining safe injection pressure limits. In the future, the NRAP state-of-stress tool could provide a useful probabilistic framework for integrating stress observations to confirm this general conclusion for a specific storage site. It also provides a framework for value-of-information analysis, quantifying the benefit, in terms of uncertainty reduction, that can be achieved by acquiring additional stress measurements.

The second induced-seismicity focused tool in the NRAP toolkit is the Ground Motion Prediction Tool [Bradley et al. 2016]. The primary goal of the tool is to help operators estimate the radius of infrastructure and communities that may be impacted by seismicity at a given site. Given a scenario earthquake (location, depth, magnitude) as well as basic geologic and soil characteristics, the tool uses empirical ground motion prediction equations to estimate the level of shaking that may be expected at increasing hypocentral distances from the site. The tool can then be used to define appropriate thresholds for action within a stoplight seismicity management scheme. One major advantage of offshore storage is that hypocentral distances to the nearest vulnerable infrastructure will be larger than for onshore projects, and therefore earthquake magnitude tolerances are higher. That said, offshore projects are not immune from seismicity considerations. For example, in 2013 gas storage operations at the Castor project led to induced seismicity, including a magnitude 4.2 earthquake 22 km off the coast of Spain, which raised significant public concern and led to a project suspension [Ruiz-Barajas et al. 2017].

The final induced seismicity tool in the NRAP Toolkit is the Short-Term Seismic Forecasting Tool. This tool is intended for use during the operational period of a project, and is not relevant to the site selection and project design stages. It relies on sensitive microseismic monitoring data to build a statistical model for seismic frequency and its relationship to injection rate. Unfortunately, sensitive microseismic monitoring would be difficult to deploy at an offshore project, given cost and access and challenges. As a GoM project already has a low probability of an induced seismicity problem, we will not consider this tool further here.

3.1.2. Aseismic Reactivation and Fault Leakage

Natural gas accumulations with fault-controlled trapping are prevalent in Miocene age sediments, and reservoirs with some form of fault-control account for a large fraction of the potential CO_2 storage volume. Therefore, detailed studies of existing gas accumulations provide a valuable indication of future carbon storage behavior. A statistical analysis by Meckel et al. [Meckel & Rhatigan 2017] of existing gas reservoir sizes in the Federal Outer Continental Shelf database, subdivided by trapping types, suggests that Miocene faults serve as excellent seals and fault leakage mechanisms do not appear to be the primary control on accumulated natural gas volumes. Indeed, extremely large natural gas accumulations (approaching 1 TcF) occur in fault-trapped reservoirs. At the same time, CO_2 storage volumes necessary to have a significant global impact could exceed historical natural gas accumulations, and therefore further analysis is necessary to understand how large storage volumes could impact seal performance. Simplistic fill-to-spill estimates of storage capacity that ignore fault leakage mechanisms will likely overestimate the available storage capacity of fault-bounded systems [Nicholson 2012, Meckel et al. 2017]. Despite these additional restrictions, however, capacity estimates remain sufficiently large to support the concept of a globally-impactful CCS hub in the GoM region.

One major shortfall of the NRAP Toolkit is that is does not currently contain any tools to support fault leakage analysis within the Integrated Assessment Model. The major reason for this is that the physics of fault leakage is complex and depends on a number of site-specific factors. It is very difficult to develop simplified (reduced-order) models that accurately reproduce fault leakage mechanisms. While the Natural Seal Reduced-Order Model has some relevant capabilities, it is primarily focused on modeling stratigraphic rather than structural seals. As a result, full-physics simulators with appropriate coupling between geomechanics and multiphase fluid flow are the preferred strategy for assessing fault-related risks [Chen et al. 2013].

While direct simulation of fault leakage mechanisms in a challenging task, the GCCC has developed a complete workflow for fault seal analysis [Nicholson 2012]. It employs readily available data including: fault geometry and throws observed from 3D seismic, log derived lithologic data leading to Shale Gouge Ratio (SGR) estimates, and capillary pressure constraints inferred from observed trapped column heights at existing gas fields. This workflow is generically useful for many carbon storage projects, and one can imagine developing a simple set of tools to aid future analysts in implementing this approach. Expertise in probabilistic methods could also provide a framework for rigorous uncertainty quantification, as many of the inputs to this analysis have large intrinsic uncertainties.

While we strongly recommend detailed studies of possible fault leakage mechanisms at specific storage sites, we remark that the risk of fault leakage at well chosen sites in the GoM appears quite low. Fault seals with intrinsically low permeability and high capillary entry pressures can be identified. The state-of-stress conditions do not favor reactivation of large growth faults, and excessive overpressure may not be necessary to achieve sufficient injectivity. The ductile nature of the shale and mudstone units also suggests permeable pathways would likely creep closed rather than sustain leakage. Fault reactivation concerns can be further mitigated by the large thickness of the primary seals—notably the Amph. B unit (Figure 3.2). These seals are sufficiently thick that very large fault displacements are required to completely offset them and create a new, permeable pathways that penetrates the seal. See, for example, the detailed analysis in [Nicot et al. 2014] along these lines. Finally, the offshore environment does not have vulnerable drinking water aquifers at depth that are the primary concern in onshore storage. While seabed leakage could cause serious environmental degradation, the likelihood of CO_2 finding a percolating pathway all the way to seabed through hydrologic pathways is low.

3.1.3. Deformation Risks

The target storage reservoirs and seals are composed of relatively weak sedimentary rocks that may exhibit substantial ductile deformations under load. Hydrocarbon reservoirs in the GoM are known to exhibit complicated behavior—particularly creep and depletion-driven compaction [Fredrich & Fossum 2002, Zoback 2010]. It is an open-question whether target CO_2 reservoirs may undergo ductile deformations during injection, how these deformations might impact monitoring observations, and whether the deformations might be sufficiently large to impact storage performance and safety. These deformations will be controlled

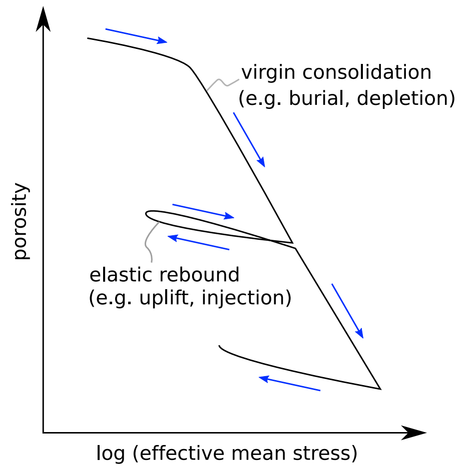

Figure 3.5: Schematic consolidation behavior of sedimentary materials. Under increasing effective stress, the material follows a virgin consolidation line and loses porosity. Upon unloading, the material rebounds elastically, but a large component of the accumulated volumetric strain (porosity loss) is irreversible. For CO_2 injection into a normally consolidated reservoir, the initial reservoir state lies somewhere on the virgin consolidation line. Fluid injection will decrease the effective stress, leading to elastic rebound. This is the reverse of hydrocarbon production or geologic burial, where an increase in effective stress causes additional compaction.

by the stratigraphy, structure, and engineering design of the storage operation. We note that stress conditions induced by CO_2 injection will be substantially different from hydrocarbon production (Figure 3.5). Increasing fluid pressure reduces effective stress, while fluid production increases effective stress. As a result, injection can induce an elastic unloading process in the reservoir, rather than enhancing plastic compaction as is seen in hydrocarbon production systems. That said, the inflation of a reservoir, particularly in proximity to complex fault structures, can engender very complex stress perturbations (with both volumetric and shear components). As a result, 3D geomechanical models are typically required to fully understand these systems.

Given the importance of deformation for hydrocarbon production and wellbore stability in many GoM reservoirs, sandstone core, triaxial testing data, and calibrated rock constitutive models are relatively easy to find. In contrast, drill cores from the confining mudstone successions (e.g. the Amph B) are relatively rare since they are not of direct interest to traditional hydrocarbon operations. The GCCC has identified relevant core samples and performed petrographic analysis [Lu et al. 2017] but it can be extremely challenging to obtain intact core due to the fissile nature of poorly consolidated sequences. As a result, even when available triaxial testing data will often be biased towards stronger, intact samples. Also, core strength measurements alone are not sufficient to predict large-scale geomechanical response. They must be supplemented with additional information inferred from well logs and seismic. Nevertheless, even approximate material property measurements can be used to assess whether substantial deformations may be observed at a site, sufficient to warrant more detailed investigations and perhaps dedicated deformation monitoring—e.g. tilt meters and fiber-optic strain measurements.

Unfortunately, this type of analysis is not well suited to reduced-order modeling, as hydromechanical interactions are quite complicated and strongly depend on local structure and stratigraphy. As a result, the NRAP toolkit is not directly applicable, and full-physics geomechanics simulation is more appropriate. We also remark that other types of deformation hazards exist in offshore systems—e.g. wellbore stability issues, seafloor infrastructure stability, and submarine landslides. These hazards are no different than traditional oil and gas operations, however, and so are not discussed further here.

3.2. Wellbore Leakage

Wellbore leakage—particularly through legacy wells at a site—is a primary concern for all CO_2 storage projects. The primary purpose of the NRAP Integrated Assessment Model and supporting Wellbore Leakage Analysis Tool is to support probabilistic assessments of wellbore leakage potential. One challenge, however, is that a key input to such assessments is a probabilistic understanding of how frequently various wellbore components may fail, and what the resulting leakage rates may be. The Wellbore Leakage Analysis Tool contains a number of failure distributions based on available observation data [Carey 2017]. In particular, the tool contains a failure probability distribution for Gulf-of-Mexico wells, based on sustained casing pressure observations reported in [Bourgoyne et al. 2000] and subsequent effective permeability analysis reported in [Tao et al. 2011]. This data forms a reasonable starting point for well leakage risk analysis, though the data provenance and its relevance for the specific site under consideration should be born in mind.

3.3. Monitoring Design

The NRAP Monitoring Design for Risk Evaluation and Management (DREAM) Tool provides a framework for choosing optimal monitoring locations for leak detection, within specific cost and site access constraints. It was originally designed for onshore applications where site access is straightforward and well drilling costs are (relatively) cheap. In its current version, it focuses on pressure monitoring and water sampling as leak detection techniques. While the design optimization methodology adopted in the tool is quite general, these specific assumptions limit its utility for offshore applications. In the offshore environment, well drilling and workover costs are substantially higher, limiting the number of downhole monitoring locations that are feasible. There is therefore a strong reliance on remote geophysical monitoring such as 3D and 4D seismic. It should be noted that future versions of the DREAM tool plan to include remote geophysical monitoring techniques to expand its range of applicability.

To date, the workhorse monitoring techniques for offshore projects are pressure monitoring at the injection well (and possibly a few other wells in the reservoir or above zone) and 4D seismic. Given open questions about the geomechanical behavior of the storage system, it is also interesting to consider direct deformation measurement techniques–e.g. tilt meter, fiber optic strain, and seafloor deformation surveys [Hatchell et al. 2017]. These latter techniques, however, have a much lower technical readiness level than comparable onshore techniques. Preliminary modeling studies should also be performed to identify the required deformation sensitivity and whether such monitoring techniques can provide useful information about storage system behavior.

4. Conclusions and Recommendations

This report has provided a brief but critical analysis of the current NRAP risk assessment toolkit and its relevance for future offshore systems like the CarbonSAFE Gulf-of-Mexico feasibility study. In general, the tools fall into three categories:

1. Tools that are immediately useful in their current form or with minor modifications. In this category we place the State-of-Stress Tool, Ground Motion Prediction Tool, Wellbore Leakage Analysis Tool, and Reservoir Reduced-Order Model Generator.
2. Tools that are useful in principal, but may require some substantial modification to make them more relevant for offshore studies. In this category we place the Monitoring Design Tool and the Integrated Assessment Model.
3. Tools that have limited relevance for offshore storage in the GoM. Here we include the Aquifer Impact Model, Atmospheric Release Model, and the Short-Term Seismic Forecasting Tool.

This report has also highlighted the importance of geomechanical processes in fault-bounded, ductile Gulf-of-Mexico reservoirs. As specific storage targets are identified, we recommend comprehensive geomechanical modeling studies be performed to understand these processes and whether they pose any substantial hazards to the storage system. These studies can also be used to test whether novel deformation monitoring techniques may be a useful (and cost-effective) supplement to standard monitoring techniques.

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Task 4.0: Site Development Plan

A manuscript encompassing subtasks 4.1 and 4.2 was in progress for submission to a scholarly journal. The draft abstract follows:

> The upper Texas coast is an area where numerous high purity high volume CO2 sources are found within a few km of high quality, low risk, publically-owned, potential geologic storage. Historically, this area has been an incubator of advancing energy technology. From the Texas Spindletop boom which, in the early 20th century, transformed petroleum into an economically feasible fuel for mass consumption, to the current shale gas and renewables revolution, this region is a "hot spot" of global importance in innovation and energy transition. We have developed a pre-feasibility plan for how this region can respond in order to remain competitive in a carbon-emissions constrained world.
>
> The region's crude oil refining and petrochemical sectors include more than 45 industrial CO_2 sources (refineries, chemical complexes and LNG producing large amounts of high concentration CO_2) as well as 10 coal- or gas-fired electricity generation facilities, which could be served by nearby CO2 geo-sequestration. Future geological storage infrastructure could also accommodate CO_2 transported from other areas that lack good quality storage.
>
> High quality Miocene age sandstone reservoirs >700 m in thickness are the primary storage targets, and a reliable regional seal has been identified in mudrocks of the *Amphistegina B* bio-chronostratigraphic zone. Confidence in performance of both reservoir injectivity and seal quality is high because of the geological trapping of hydrocarbons in the area and extensive available geological characterization of the subsurface. Offshore submerged lands from the coast to approximately 10 miles are owned and managed by the State of Texas General Land Office which, provides significant benefits for access and liability management. Abundant available wells log and conventional and recently-acquired high-resolution 3D seismic data have allowed for the generation of static geological model at both regional and site scale. An area of particular interest was selected as a candidate for potential C02 storage, the High Island 10-L field located 13.5 miles southwest of Sabine Pass near the highest storage capacity zones in Texas state waters.
> Various viable mechanisms for transporting CO_2 from source to sink were evaluated (pipe, cold liquid by truck and / or boat). Developing a CO_2 management strategy included conducting optimized and targeted risk assessment, evaluating regulatory pathways, analysis of regional proximity, stakeholder analysis and a community outreach plan aiming for public and stakeholder's engagement. This study is a pre-feasibility approach to a site development plan with cost estimates to guide next steps in a commercial scale CCUS system deployment in the upper Texas coast region as a path to continuing its outstanding tradition of energy innovation and transition.

Subtask 4.1: Technical Requirements

See above.

Subtask 4.2: Economic Feasibility

See above.

Subtask 4.3: Public Outreach

One early member of the Coordination Team was Mr. Hilton Kelley of CIDA, Inc. "Community In-Power and Development Association Inc.," a non-profit (501 (C)(3) status) that worked to empower residents in low-income communities in Port Arthur, Texas. According to Mr. Kelley, "We help them to take action against the neighboring chemical manufacturers, refineries and incinerator facilities." The project PI established broad-based communications with Mr. Kelley and CIDA.

In addition, the PI continued long-established communications with stakeholders in the Beaumont-Port Arthur area (e.g., Jeff Hayes). See Task 2.0.

On June 20, 2017 Dr. Tip Meckel (Figure 4.3.1) co-led a field trip with Mr. Jeff Hayes (Figure 4.3.2). The field trip's purpose was to present the southeast Texas region in general and the Beaumont / Port Arthur area in particular as a CCS hub to national and international CCS experts. Field trip stops included (in Port Arthur) GT-Omniport (a potential CO_2 transportation hub), Air Products / Valero steam-methane reformer and a stop at Sea Rim State Park. The final stop on the field trip was at the Port Arthur Museum of the Gulf Coast. The June outreach events were also later covered in the local media, the Beaumont Business Journal (Figure 4.3.3). On June 21, the CarbonSAFE project held a coordination team meeting and "open house" at Lamar U. (Figure 4.3.4). Attendees included interested members of the local community in addition to CCS experts from around the nation and the world. The CCS experts had recently attended Second International Workshop on Offshore Geologic CO2 Storage at the Center for Innovation, Commercialization and Entrepreneurship at Lamar University. Stakeholders from China, South Africa, Japan, Norway, France, the Netherlands, UK, Canada, and across the United States attended. Elements of that event were supported by CSLF.

Figure 4.3.1 – Dr. Tip Meckel (center, blue shirt) lecturing at Sea Rim State Park Beach on June 20, 2017 as part of a project outreach event (field trip).

Figure 4.3.2 – Mr. Jeff Hayes lecturing about Port Arthur history, economy and current and future industrial facilities on the bus between field trip stops.

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on problems

Ten nations were represented at the second International Workshop on Offshore Geologic CO2 Storage held June 19-21 at Lamar University's Center for Innovation, Commercialization and Entrepreneurship (CICE).

The workshop, hosted by Lamar University and University of Texas Geosciences, included sessions on finding offshore storage, environmental and overburden monitoring, offshore assessment and more.

"This was an amazing group of scientists and engineers … seeing Beaumont/Port Arthur for the first time," said Paul Latiolais, director of the CICE. "They were stunned with the amount of industry and growth and did not fully understand that

https://beaumontbusinessjournal.com/article/news/scientists-around-world-converge-lamar-tackle-co2-emission-problems[7/7/2017 8:13:01 AM]

Figure 4.3.3 – News item in the Beaumont Business Journal covering the project's June outreach events.

Figure 4.3.4 – PI, Dr. Meckel, (right at podium) presenting ultra-high resolution 3D seismic data from the project's offshore study area and explaining its applications to offshore CCS. The presentation was part of a coordination team meeting and community "open house."

Extensive outreach efforts by project team members from The University of Texas at Austin and from Lamar University continued in the fall of 2017 as follows:

Meetings and Phone Conversations (phone conferences week of Oct. 30-Nov. 3 and Beaumont/Port Arthur trip on Monday and Tuesday, November 6-7, 2017)

Hilary Olson and Victoria Osborne, The University of Texas at Austin

Paul Latiolais, Tracy Benson and Daniel Chen, Lamar University

Monday Nov 6

LAMAR UNIVERSITY AND UT AUSTIN PLANNING

9:30am-12:15pm Meeting: Lamar University, CICE Bldg
440 S Martin Luther King Jr. Pkwy, Beaumont, TX 77705

Lamar: Paul Latiolais, Tracy Benson, Daniel Chen

UT: Hilary Olson, Victoria Osborne

T & L SOLUTIONS

1:15pm Meeting: Lamar University, CICE Bldg

- **T&L Solutions**: **Travis Woods**, President (409-781-2217, c)
- Lamar: Paul Latiolais, Tracy Benson
- UT: Hilary Olson, Victoria Osborne

Notes: Travis already has a copy of the industry flyer and is well aware of the project.

Travis is a consultant in Technology to help industry find solutions. He had heard $125B in industry projects being spent in Beaumont to Lake Charles. Now the number he is hearing is $200B. Cameron, LA – has no infrastructure. $60B proposed in new plants in their backyard – so they've opened an office. Lake Charles is spending $70B. So if Lake Charles people are busy, the Texas people can drive over there and he can bring contractors. He is president of the contractors group in Lake Charles and the one in Port Arthur. Once a month special guest speakers. Ernst and Young recently spoke in Lake Charles – speech about tax abatements. When a plant is asked for a tax abatement, you as a contractor can get benefits as well. He started the Gulf Coast Industrial Group – 115 members in Lake Charles. Port Arthur Chamber of Commerce wanted one a year and a half ago in Port Arthur and asked Travis to start it. Held in Chamber of Commerce office 2 months then instantly outgrew their space. 300 members now in Port Arthur. Travis has been approached by The Woodlands Chamber of Commerce to do the same.

Are industrial plants worried about CO_2 emissions? They have alarms like for any other gas. No, they aren't concerned about CO_2 emissions. XOM has been recently cited by the EPA. They will put up $300M to reduce emissions in TX and LA. Concerns for CO_2 is nominal. It is monitored as part of the overall process.

Travis says folks in TN seeking a pilot plant to look at turning the CO_2 into fuel they can sell.

New power plants in Sulfur, Corpus Christi, LaPlace LA. Spending $7B+ on new power plants. Always goes over the estimated budget by about 25-35%. None are combined cycle, they are all natural gas plants.

Travis was involved in building a wet gas scrubber in 2005-2006 for Air Products. Strictly an emissions project. Just last month 2 bus loads of Valero managers from all over the country came to Valero to walk around to see how much more emissions they could take out of the air. Valero wants to adopt another system to reduce more emissions – and over all their plants, not just here.

Recommendation: We go back to Valero and ask about the 2010 project with Air Products and what the motivating factors were. There was an economic driver – the Federal Government. And a partner was able to make money off of it – Air Products. Did Air Products give Valero part of the profit? We need to find out what that arrangement was? **Hilary to check in with Tip and Sue to see what they might know about the business side of it.**

Paul has heard another company, size of Valero, is interested in the CO_2 recovery process. Can't say name right now.

Travis could get us in touch with any company we need to. Travis is on the Board of the Chamber of commerce for Port Arthur. Jeff Hayes will be chair of Chamber of Commerce of Port Arthur next year.

The outreach team asked Travis what he knew about the potential of Aurora Group setting up an office for CarbonSAFE in the Port Arthur area. He is thinking Christus will donate Aurora the building and land maybe on Jan. 1st. Then Aurora would start making plans for how to allocate some of the space. [See note below from phone conversation with Jeff Hayes for more detail.]

<u>BEAUMONT CHAMBER OF COMMERCE</u>

2:00pm Meeting: Lamar University, CICE Bldg

- **Beaumont Chamber of Commerce**:

Ana Pereda, VP Economic Development

- T&L Solutions: Travis Woods, President (409-781-2217, c)
- Lamar: Paul Latiolais, Tracy Benson
- UT: Hilary Olson, Victoria Osborne

Notes: Paul and Hilary gave Ana Pereda some more detail on the CarbonSAFE program.

Travis mentioned that Coastal Caverns – Darrell Hall, plant manager – is interested in talking to someone about storage in salt domes/salt caverns. Coastal Caverns is much bigger than Valero. This is the aggregate industry's storage. They are currently storing H to sell later. Travis told him about the International Offshore Storage Conference. Japanese group bought Coastal Caverns.

Recommendation: Need to get a meeting with Valero and Air Products to find out about the driving and motivating factors. Air Products said during the June field trip, "Yes, given the subsidies, we would do this again." Travis has a contact in Barbara Phillips at Valero, and she is also on the Port Arthur Chamber of Commerce board. Main switchboard number: 985-1000. **Hilary will follow up with Travis, after talking to Tip and Sue, about setting up a meeting with Valero and AirProducts.**

Jim Davis with Chevron, Air Quality Manager – Travis will talk to him. **Hilary will follow up with Travis to see if we should meet with Jim Davis.**

Travis will call Rocky Howe – over maintenance at Valero. He will ask him about their general interest in CO2. **Hilary will follow up with Travis to see what information he finds out.**

Travis suggested BHP Billiton – as an offshore company to partner with.

Travis and Ana recommended we talk to Judge Jeff Branick – Commissioner's Judge. He represents Jefferson County and is a Jefferson County Judge. He runs the coastal restoration project (several plants are involved, like Cheniere) to look at coastal erosion from Hurricane Rita and Ike. [Note below: Doug Head at McFadden Wildlife Refuge knows Judge Branick and works with him on these types of projects.] **Hilary will get contact info from Paul as he knows Judge Branick, and she will follow up with him.**

There was a lot of talk about capturing CO2 and creating a commercial product.

Ana described an upcoming event the Beaumont Chamber of Commerce is involved with. They are bringing about 150 legislators and their aids to Beaumont in April. The event is called "Navigating the Neches: Legislative Tour". This will be the first event of this type. Normally they plan a Golden Triangle Days in Austin every other year when the legislature is in session. Recommendation: Ana and Paul suggest we put together the legislative flyer and get it in front of the state legislators at this meeting. It could be passed out and then Paul could answer any questions about the project. **Victoria will work with Paul and Hilary to create this legislative handout.**

3:00pm Drive to Port Arthur

PORT ARTHUR CHAMBER OF COMMERCE

3:30pm Meeting: **Port Arthur Chamber of Commerce** (409-963-1107)

501 Procter Street, Suite 300, Port Arthur, TX 77640

- **Bill McCoy**, President* (409-527-0889, c)
- UT: Hilary Olson, Victoria Osborne

Notes: We gave Bill McCoy a copy of the public and the industry flyers and a brief overview of the project.

He is aware of the project, but doesn't seem to understand it is a storage project. He seems to think it is capturing CO2 and utilizing it for a commercial product. He pre-empted the discussion about CarbonSAFE by telling us that he is a fiscal conservative and he doesn't much like federal subsidies, believes there's a lot of regulatory over-reach, and likes to see thinks happen through a business model. He referenced that the Air Products/ Valero endeavor had received subsidies.

We talked to Bill about the Legislative Meeting in April in Beaumont and the flyer idea. He said, yes, we should pass out a brochure at the Legislative Meeting. These are state people. Show:

The importance of this area to the entire nation (1/3 of all jet fuel produced here; deepening of ship channel – got to 50+ ft – federal dollars); importance to national security – Coast Guard; 600,000 bbls of oil / day processed at Motiva refinery; 3 plants that will export LNG between now and 2020 (Cheniere already).

The Legislative Meeting will also be talking about health care. Orange doesn't have a hospital left – they have all closed – because of changes in the hospital industry. St. Mary's in Port Arthur, a Christus hospital, they are basically closed because they are going to outpatient clinics.

Bill thinks we should try to get the state regulatory agencies at the Legislative Event. He suggested we talk to Paul – get on a committee and say we will talk to regulatory agencies and invite them to come. Bill also asked should some of the Texas Regents be invited to the Legislative Tour.

Erosion topics: Coastal marsh areas protect their environment. Judge Jeff Branick – talk to him. We could go on the environmental tour of the Legislative Tour (find out what day this is), or we could go on the Industrial tour – have a captured audience (find out what day this is). It isn't clear to us that we can invite ourselves on this tour. **Hilary will discuss Legislative Tour attendance with Paul L and Tip.**

Ship channel, refineries and rail topics: These are the primary reasons why this city is here. 69 ends at the ocean (Wordsworth Street). Taylor Bayou mouth – needed an inland port. Pleasure Island built from spoils of ship channel. Then sea wall was built.

January 24th Port Arthur Chamber of Commerce Dinner and Program, 6pm – reception

Keynote – Dan Romasko – President and CEO, Motiva Enterprises, LLC

Citizen of the Year award – Paul Beard, Sabine Neches Navigation District

Bill recommened we go look at the jewel of the city - Lamar State College. Parker Center – meetings there. (Civic Center had 3 ft. of water during Harvey).

4:30pm Travel to Lamar University

LAMAR UNIVERSITY AND UT AUSTIN WRAP-UP

5:00-6:00pm Meeting and Wrap-Up for Day: Lamar University, CICE Bldg

- Lamar: Paul Latiolais, Tracy Benson
- UT: Hilary Olson, Victoria Osborne

Notes: Discussion about how to properly motivate the business/industry community on a storage project. Wrap-up of action items listed above. Discussion of history of Port Arthur and Beaumont development.

Met a few other Lamar folks who were in the building.

<u>Tuesday Nov 7</u>

<u>SEA RIM STATE PARK (TX PARKS & WILDLIFE)</u>

8:30am Meeting: **Sea Rim State Park** (TX Parks & Wildlife)

19335 State Hwy 87, Sabine Pass, TX 77655

- Sea Rim: **Kimberly Bingham**, Park Assistant (Nathan Londenberg, Park Superintendent arranged – he is out of town this week) (park: 409-971-2559)
- UT: Hilary Olson, Victoria Osborne

Notes: We gave Kimberly Bingham a copy of the public and the technical flyers (to pass on to Nathan Londenberg, Park Superintendent) and a brief overview of the project. She was not aware of the project.

She talked to us about the different facilities in the park: the camping, kayaking, birding and other activities. She mentioned how Hurricane Rita had wiped out their nice visitor center and museum many years ago. Now they have a fairly modest building for the visitors center. Kimberly had worked at H&R Block and then worked her way into the job at the park. She lives in Sabine Pass and her daughter goes to the school there.

Phone conf 11/1 Phone Conference: **Sea Rim State Park (TX Parks & Wildlife)**

- **Nathan Londenberg**, Superintendent (409-749-0171, c)
- UT: Hilary Olson

Notes: Nathan said he is out of town next week but set up meetings with two rangers, Glenda and Kimberly. He also gave Hilary the contacts at Murphree Wildlife Management Area (TX) and McFadden Wildlife Refuge (U.S.). He would like to visit another time. He did not seem aware of the project.

<u>MCFADDEN NATIONAL WILDLIFE REFUGE (US FISH & WILDLIFE)</u>

9:30am Meeting: **McFadden National Wildlife Refuge** (US Fish & Wildlife)

7950 S Gulfway Dr, Sabine Pass, TX 77655

- McFadden: **Doug Head**, Refuge Manager (409-284-1360, c)
- UT: Hilary Olson, Victoria Osborne
- Notes: text him ahead of time that morning and he will meet us – especially if we can't find him as he will be overseeing hunting activities; Willow Slough – largest freshwater marsh in Texas

Notes: We gave Doug Head a copy of the public and the technical flyers and a brief overview of the project. He was not aware of the CarbonSAFE project.

Doug had set out multiple maps of the refuge, produced by their GIS specialist. He was very hospitable and offered us root beers. Victoria took high-res photos of all the maps. He went through the maps to tell us about the various features of the refuge.

Willow Slough is the largest freshwater marsh in Texas. Mottled duck have a year-round habitat in Willow Slough. Because of the mottled duck, the area is protected. There is no hunting or visiting the area by the public.

Oilfield is in the wildlife refuge: OLEUM is operator now – the operator is from Pennsylvania. The name of the field is Clam Lake Field. Seems to be a peaceful coexistence between the operator and the wildlife refuge.

Refuges (McFadden and Texas Point) - founded in 1980s. A new refuge is coming onboard soon - Sabine Ranch (a migratory bird conservancy purchased the area and has been operating it – then will grant it over to US Fish and Wildlife).

Stats for the refuge:

150,000 visitors/year of which: 5,000 hunters, 50,000 fishing (blue crab) - no commercial crab traps, and the rest is tourism.

We discussed storm surge and coastal erosion problem. Big coastal erosion problem in this refuge. The sandy beach pretty much stops at the boundary between Sea Rim State Park and McFadden Wildlife Refuge. All the road was washed out during Hurricane Rita. He would like to see a new coastal highway done right – with a good levee. It would be a benefit in that it would help the refuge w saltwater incursion. He mentioned that they are short on sand input – one reason is the intercoastal waterway steals the sand as it moves toward the coast.

His house was flooded during Hurricane Harvey and he was supposed to have gal bladder removed. He Did get the surgery several weeks later – but sure was tough, plus with his house damaged. He is currently living with his 2 sisters and their kids in a sister's house. He said it is very energetic!

He is from High Island so is working his dream job.

TEXAS POINT NATIONAL WILDLIFE REFUGE (US FISH & WILDLIFE)

9:30am Dropped off material: **Texas Point National Wildlife Refuge** (US Fish & Wildlife)

7950 S Gulfway Dr, Sabine Pass, TX 77655

- Texas Point: **Ernie Crenwelge**, Refuge Manager (409-971-2909)
- UT: Hilary Olson, Victoria Osborne
- Notes: It appears he in same office as Doug Head; coastal marsh habitat; called number on website but no answer or voicemail on Fri afternoon; will drop by and see if he is there when we visit Doug Head

Notes: Ernie Crenwelge is in the same office as Doug Head. Ernie and Doug were swapping out between the office and the hunting areas in the refuges that morning. Doug offered to give Ernie a set of flyers when Ernie was back in the office and tell him about the project. We gave Doug a copy of the public and the technical flyers for Ernie. We do not believe that Ernie was aware of the project either.

US FISH & WILDLIFE

9:30am Dropped off material: **US Fish & Wildlife**

- US Fish & Wildlife: **Jena Moon**, Zone Biologist
- UT: Hilary Olson, Victoria Osborne
- Notes: Jena oversees biology at multiple refuges - 13 in TX and LA

Notes: Doug Head will give a copy of the public and the technical flyers and a brief overview of the project to Jena Moon (Zone Biologist). Doug does not believe Jena is aware of the project.

COASTAL FISHERIES (TX PARKS & WILDLIFE)

10:45am Meeting: **Coastal Fisheries Field Office** (TX Parks & Wildlife)

601 Channelview Drive, Port Arthur, TX 77640

- **Carey Gelpi, PhD**, Sabine Lake Ecosystem Leader (409-983-1104 x222)
- UT: Hilary Olson, Victoria Osborne
- Left messages back and forth with Carey. He is going to be out doing fish surveys around the area.

Notes: We were just going to drop off material for Carey Gelpi but we ended up running into him at Sabine Pass, not far from Port Authority, where he was doing his fishing survey. It was a slow morning so he had plenty of time to talk to us and we had a lengthy visit.

We gave Carey a copy of the public and the technical flyers and told him a little bit about the CarbonSAFE project. He was unaware of the project. However, he is aware of carbon storage because he worked on a project offshore Monterey – looking at it for a potential storage site – when he was in school at LSU. He said he was doing an assessment of that offshore area: picking copepods, etc. He said that was in about 2004-2005 and it was a DOE-funded project.

We asked him about the health of the offshore area, Sabine Lake, fish and shellfish in general. We asked him if people were concerned about any potential impacts from climate change on the fish in the area. He said that unfortunately not that many people believe in science, and that it is always a challenge to show cause and effect, so that most people don't believe there is a link.

He explained that in the 1980s, 90s, to 2000s there was overfishing of blue crab. There has been some recovery. They implemented programs like buy back of fishing licenses (fishermen could sell them to each other, but once the licenses were sold back to the state they were then out of circulation), enlarging the escape hole size in the crab pot, limitations on catching female crabs.

Some of the patterns they have seen in the female crab spawning – they are not present in the area where they usually see them. So the question is, did they move offshore more. We think he said that the crabs need like 20 to 25 parts per mil salinity. They've also seen a decrease in the ratio of female crabs to male crabs. Carey said there are some crabbers who are catching female crabs and then shipping them out, so there's a tendency to over fish the female population. He mentioned things like She Crab Soup and also that some cultures just particularly like the flavor of female crabs more. This has led to a reduction in female population.

He was talking about Sabine Lake and he mentioned Sabine Oyster Reef as very unique because it hasn't really been fished. It's not because there are any restrictions on it, it just sounds like it's because it's situated in the middle of a bunch of industrial development that people haven't really tried to fish it yet. But sounds like there might be some worry that Louisiana fisheries might start fishing there.

We asked him if anybody was worried about shrimp and reduction of translucency of their shells as a result of ocean acidification. He said nobody's really been paying attention or concerned about it. He said for shrimping they're sort of an up-and-down cycle but didn't sound like it was a big problem with overfishing.

There is one commercial fisherman that fishes black drum in Sabine lake, but other than that no real commercial fishing there that he is aware of. Coastal Fisheries asks commercial fishermen to measure size of any fish they catch from Sabine Lake for their research, and no one tells them they have caught any fish there. He isn't sure if that's because they aren't catching anything or because they aren't telling him.

He also mentioned an interesting dynamic between the estuary where sometimes you'll have a lot of rain upstream in the Mississippi and that will bring tons of fresh water into the ocean environment that will bleed over into the ocean environment here but then you might have a heavy drought so than Sabine Lake becomes more saline because of the evaporation so you actually have a situation where the estuary is more saline then the proximal ocean water.

Carey has been in his job as coastal fisheries division Sabine lake ecosystem leader for the past two years.

J.D. MURPHREE WILDLIFE MANAGEMENT AREA (TX PARKS & WILDLIFE)

12:00pm Meeting: **J.D. Murphree Wildlife Management Area** (TX Parks & Wildlife)

10 Parks and Wildlife Drive, Port Arthur, TX 77640

- **Mike Rezsutek, PhD**, Program Leader for Wildlife Management area in SE Texas, waterfowl program (409-736-2551 x22)
- UT: Hilary Olson, Victoria Osborne
- Note: talked to him 11/3: come by but he may be in and out; in fact we were able to catch him in the office when we visited

Notes: We gave Mike Rezsutek a copy of the public and the technical flyers and a brief overview of the project. He was not aware of the CarbonSAFE project.

He told us a little bit about Murphree Wildlife Management Area. They have about 4,000 hunters per year. Hunting is increasing and may become congested. There are a lot of young people working good jobs who have money to spend on hunting – so there has been an increase in the sport. Also, there is a lot of fishing - they don't know numbers because the recreational fishermen don't have to check in with them. Some of Murphree originally was part of Sea Rim State Park and then they did a swap to gain part of Sea Rim State Park for Murphree and then gave some wildlife management area land in another part of the state over to the state park system and created another park in Texas. Murphree was created in early 60s. Doing marsh restoration now. The intercoastal waterway divides the wildlife management area.

Mike is from rural PA - couple hours from PSU.

JBS PACKING CO.

1:45pm Meeting: **JBS Packing Co.** (Shrimp)

101 Houston Avenue, Port Arthur, TX 77640

- **Trey Pearson**, General Manager (409-719-7090, c)
- UT: Hilary Olson, Victoria Osborne

Notes: We gave Trey Pearson a copy of the public and the technical flyers and a brief overview of the project. He was not aware of the CarbonSAFE project. He asked questions about what would happen if the CO2 leaked into the ocean. We talked a little about research on natural CO2 seeps in Italy. **Hilary will follow up via Katherine Romanak.** He also said that he knows Bart Owens and we referred him to talk to Bart about the project as well.

We were maybe going to go by in the late morning, but he has a surprise inspection from the state of Texas. He said that was a typical event and he passed with flying colors.

JBS processes tens of millions of pounds of shrimp per year. Almost all of the fleet are of Vietnamese background. They came here after the Vietnam war. So most of the Vietnamese shrimpers got small business loans from the government - sounds like in the late 1990s or so. And then it sounds like there was a big collapse in the market around 2003 or so because of imports of shrimp. He also mentioned that their catch was down about 45% from this time last year. We told him we had eaten lunch at Sartins in Nederland and he said that shrimp is likely sourced from overseas. JBS mostly sells to groceries – they have a big contract with HEB. Really made a mark for them to get that HEB business it sounds like. We recognize their brands – Captain Jack (named after the founder of JBS – Jack, who is Trey's grandfather in law). He thinks the shrimping business is hard and isn't looking to have his kids do it. He was a bit nostalgic that there isn't going to be anybody to carry on this type of work because no young people are going into the shrimping business or the shrimp processing/distribution business.

Shrimp come from all over the Gulf of Mexico and their trucks here to this processing plants. He talked about a problem with the aging of the shrimping fleet as well as the aging of people that are in the processing and distribution side of the business. He said that 30% of the shrimp they process comes from the dock here in Port Arthur. He said that there were about 42 vessels in the fleet and that of those about 38 of them are Vietnamese run. He agreed with Terry Looney that we probably don't need to visit with most of the fleet owners. The important thing to do is to talk to the processing and distribution folks.

He is really into high school and college football. He told us to look for Raschon Johnson to play quarterback next year at UT – said every major college tried to sign Raschon when he was a sophomore. Trey is very excited about Raschon and UT. Trey's son plays football – sounds like he is in 8th or 9th grade. Trey himself played college football.

PORT ARTHUR INTERNATIONAL SEAFARERS ASSOCIATION/CENTER

2:45pm Drop By: **Port Arthur International Seafarers Association/Center**

1500 Jefferson Dr., Port Arthur, Texas 77642

- **Fr. Sinclair Oubre**, Executive Director (409-749-0171, c) – unavailable at this time but I spoke to him on the phone the week prior
- **Tammy Domain**, Volunteer Coordinator
- UT: Hilary Olson and Victoria Osborne

Note: [See entry from conversation with Fr. Sinclair related to Texas Shrimp Association.] We dropped by and visited with Tammy Domain, a volunteer coordinator. She told us a little bit about their work assisting seafarers. Not as much volunteerism as before – not as many young people volunteering. They have been in this building since 2005. Before that, they were in a trailer at the port. The building is very nice and they have a meeting room that looks like it could hold about 40 people with round tables. This Seafarers Association serves about 20-30 ports from LA to Beaumont. We introduced the CarbonSAFE project and gave her a public and technical flyer. She was not aware of the project.

GOLDEN TRIANGLE EMPOWERMENT CENTER (GTEC)

3:15-5:30pm Meeting: **Golden Triangle Empowerment Center (GTEC)**

617 Procter Street, Port Arthur, TX 77640

- **Caroline Brandon**, Activity Coordinator (832-816-0808, c)
- **Matt Boudreaux**, GTEC Instructor

- UT: Hilary Olson, Victoria Osborne

Notes: Caroline Brandon and Matt Boudreaux spoke about the GTEC current program.

Each group of about 25 students goes through a 10 weeks program, mostly sponsored by companies and other grants.

2 weeks @ CICE - Life Skills, Critical Thinking

8 weeks @ GTEC - Introductory Craft Skills (NCCER curriculum - National Center for Construction Education and Research). Matt Boudreaux is an instructor who has been teaching in 2017. His background is Safety Management. He is from Port Arthur (born Baton Rouge).

Caroline and Matt showed us one of the groups currently in class, then took us into the adjacent office to discuss the program. Later Matt took us to the 'lab', which is a giant workshop in an old brick store – has had leaks from Hurricane Harvey so some of the lab space is under repair.

Equal mix men and women in the classes. Accommodations are often made to assist students, for example, allowing their children to come with them when they don't have childcare as long as the children are well-behaved.

Levels in plants are typically Laborer (starting), Level 1 Helper, Level 2 Helper. The participants at GTEC are training for Level 2 Helper. They gain classroom knowledge and lab skills (intro to welding, pipe fitting, power tools, rigging, scaffolding work) so they can have some specialization as needed. We toured the GTEC lab – it's a giant workshop – sort of a maker space. Matt likes Bethel for placement of his students because they treat their employees well and give them a lot of free training.

Matt helps his students get important cards they need in their jobs. TWIC card - Transportation Worker Identification Credential - some of the companies will help the employs get this GTEC tries to help the students get funding for the card. It allows them access to ships and ports. Then there is also a safety card they need to get into the refinery. Often GTEC will help them with funds to get these cards.

Caroline told us GTEC had been running 2007-2012. Then hiatus when a lot of the block grants dried up. They were back up and running in 2017. ~35 cohorts of 25 students in first 5 yrs. Right now they are on their 6, 7 and 8th groups in 2017. Participant sessions run 9-12pm, 1-4pm, 6:30-9:30pm each day – one cohort meets during each session.

We gave Caroline copies of the public and technical flyers. She did not seem to be aware of the project. She was hosting us I response to our request from Melvin White, the President of GTEC.

COASTAL CONSERVATION ASSOCIATION, GOLDEN TRIANGLE CHAPTER

6:15pm Meeting Scheduled – Could only drop off flyer: **Coastal Conservation Association, Golden Triangle Chapter**

- **Drew Adams**, President
- **Jason Kuchera**, Vice President (903.780.8618)

Classic Chevrolet, Buick, GMC 9-4pm

3855 Eastex Freeway, Beaumont, TX

- UT: Hilary Olson, Victoria Osborne
- Note: Hilary talked to Jason 11/3; he is also a fishing guide; we will stop by his 'real job' at the Classic dealership on Monday

Notes: Hilary previously e-mailed and left vm for Drew Adams. Drew returned e-mail and we will visit later. Arrangements were made to visit with Jason Kuchera. Hilary and Victoria dropped off public flyer with Tyler (from Redwood City, CA) at Classic Chevrolet, Buick, GMC for Jason and will call him to follow up. Jason had already left for the day. He is in the service department.

Phone Conferences Ahead of Trip – visit with these people / groups on next visit

TEXAS SHRIMP ASSOCIATION IN PORT ARTHUR

Phone conf 11/2 Phone Conference: **Texas Shrimp Association in Port Arthur**

- **Fr. Sinclair Oubre**, Treasurer (409-749-0171, c)
- UT: Hilary Olson

Notes: Fr. Sinclair suggested calling Terry Looney, Secretary of TX Shrimp Association and would like to meet with us next time we are down. He is out of pocket the two days of our visit.

Phone conf 11/2 Phone Conference: **Texas Shrimp Association in Port Arthur**

- **Terry Looney**, Secretary (409-656-0559, c)
- UT: Hilary Olson

Notes: Terry is retired from Texas Sea Grant. She suggested talking to processing plants and wholesaler/distributors rather than the actual shrimping fleet operators. She thinks the wholesalers/distributors have more at stake with public opinion so will want to know how to explain the CarbonSAFE potential project and any effects on the environment. She suggested JBS Packing, Trey Pearson, in Port Arthur.

HAYES REAL ESTATE, PORT ARTHUR

Phone conf 11/3 Phone Conference: **Hayes Real Estate**

- **Jeff Hayes**, President (409-728-6464, c)
- UT: Hilary Olson

Notes: talked to him on the phone 11/3/2017

Christus Hospital Group (presence in SE TX) is donating an outpatient center (app. 80,000 ft2 and 18.3 acres) to Aurora (a non-profit center). Jeff's son-in-law, Paul Trevino, works with Christus so Jeff has stepped back. Melvin White and Travis Woods are on the board of Aurora. Evidently, there is talk about giving CarbonSAFE an office in the Aurora complex.

Jeff suggests we have a good CarbonSAFE presence at the Jan 25, 2018 Port Arthur Chamber of Commerce dinner/presentation. Probably around 6pm. The President of Motiva (now 100% Saudi Aramco owned) is going to present at the meeting. Jeff says Motiva has talked about donating $12B to Port Arthur, but Jeff has heard rumors it's more like $36B. Jeff suggests I talk to Verna Rutherford (Public Relations for Motiva). Motiva's refinery (was Texaco's) in Port Arthur is the largest in North America.

Fishing and Shrimping - Commercial/Wholesale/Processing: Jeff says there is a processing plant at the corner of Shreveport and 7th street. He thinks they process blue crabs from Sabine Lake. This processing plant send daily refrigerated trucks of blue crab to Bush Intercontinental Airport to be shipped to Baltimore – evidently they have a shortage of crab there. This processing plant may be Vietnamese owned and a good connection to the Vietnamese shell-fishing community. Jeff says there is also a processing plant at the end of Pleasure Island on Hwy 82 right before you get to Louisiana. He suggests looking in the Texas Almanac for a list of processing plants. Jeff confirmed we should be talking to JBS Packing, Trey Pearson.

Jeff mentioned connecting with Bart Owens (I said Tip was doing that). He also mentioned that we should connect with Russell Buss, a retired chemical engineer with a masters who is interested in the project.

He also mentioned the Seafarer Center that Fr. Sinclair Oubre is part of – we could maybe drop by there and check it out.

Graduate Research Assistant, Peter Tutton, presented an oral talk on some of his research. Tutton's hypothesis (Figure 4.3.1) proposes that a stochastic solution that allows for more dynamic (versatile) matching of sources and sinks is superior to a deterministic solution because of uncertainties that will cause CO_2 source volumes and injection volumes to vary through time.

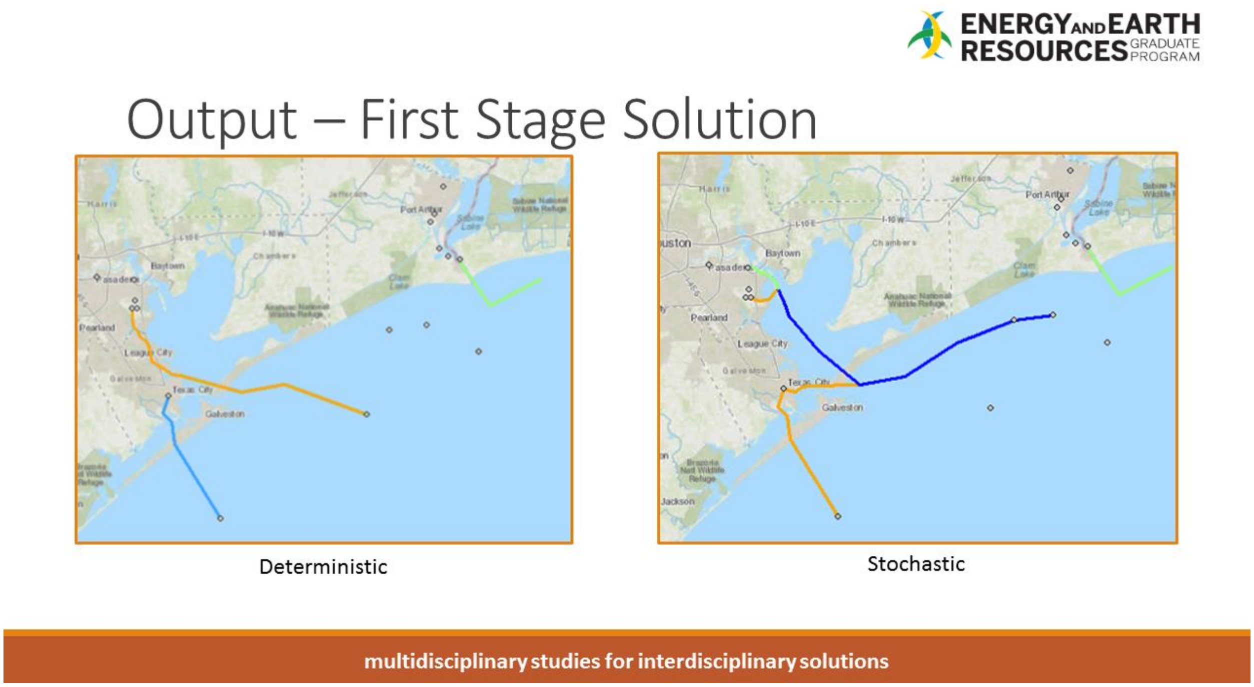


Figure 4.3.1 – Slide from Tutton presentation showing the difference in infrastructure design when a 'perfect information' scenario (left) is compared to uncertainty of future demand (right) (i.e., a deterministic (left) vs. stochastic (right) solution for initial development of a source – transportation (pipeline) – sink matching CO_2 sequestration network). The colored lines indicate pipelines. The small circles denote actual oil and gas fields that are currently under consideration as possible CO_2 sinks.

Industrial Outreach Surveys

As reported in the last quarterly report, industrial surveys including telephone and e-mail surveys were conducted by Lamar Chemical Engineering seniors Daniel Perales and Bryan Wright. They contacted 61 individuals at various petroleum/petrochemical companies located from Houston to Beaumont. Among these pool of industrial contacts, 4 responses were received.

STATUS OF PROJECT SCHEDULE AND MAJOR GOALS/MILESTONES OF PROJECT

Reports fulfilling Deliverables 2 (letter report of initial estimate of the area of review) and 3 (Quick look report of IAM (NRAP validation)) of the project SOPO (Statement of Project Objectives) were submitted on September 26 and 27, 2018, respectively.

A comprehensive report fulfilling Deliverables 4 (summarize the results of Task 3) and 5 (summarize the site development plan) was submitted on October 24, 2018.

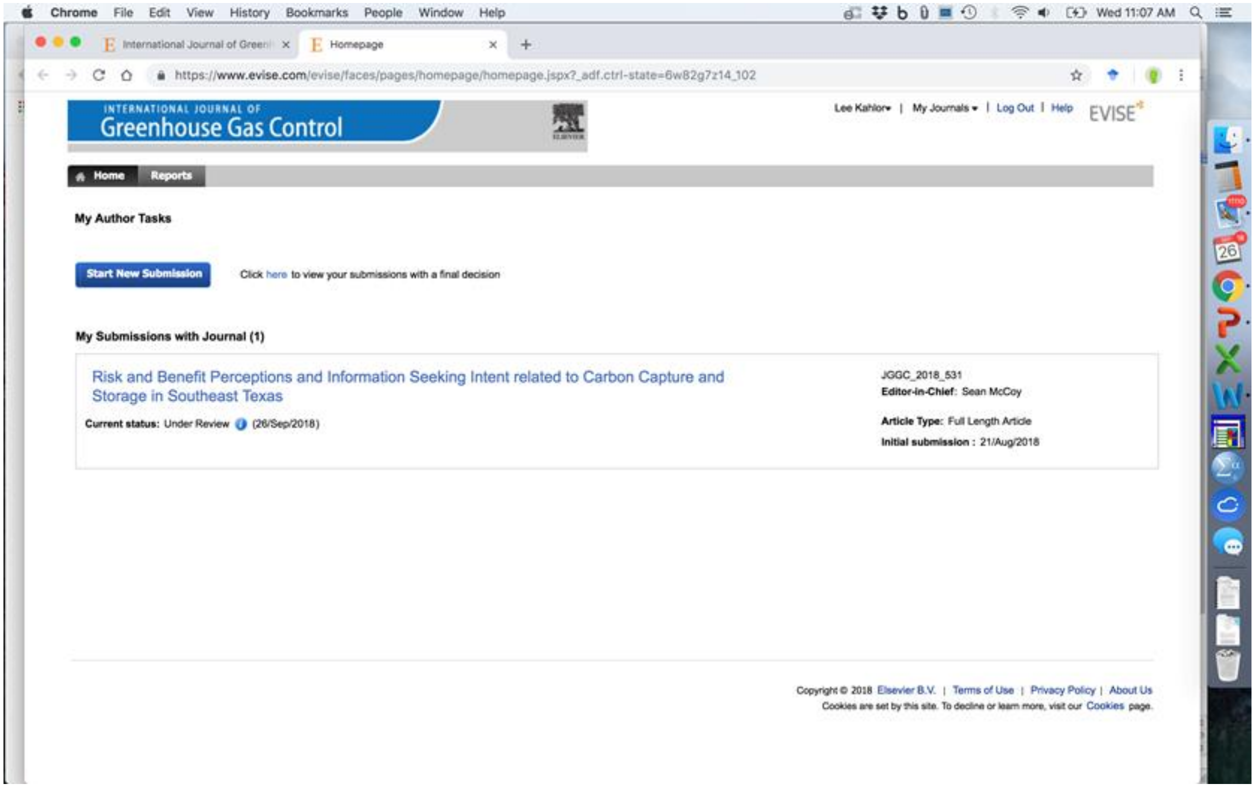
MAJOR GOALS / MILESTONES

Task	Milestone Title	Planned Completion Date	Verification method
1	M1: Project Kickoff Meeting	3/14/2017 (Completed)	Attendance at meeting; Presentation file
3	M2: Letter report documenting data used for geologic study	3/29/2017 (Completed)	Submit letter report to DOE documenting data used for geologic study
2	M3: Convene 1st Coordination Team meeting	6/15/2017 (Completed)	Submit to DOE letter report of Coordination Team members & meeting attendees
2	M4: Identify technical challenges for continued project development	10/14/2017 (Completed)	Quick look report summarizing findings of the CCS Coordination Team.
4	M5: Summarize outreach activity conducted in Year 1 and planned for remainder	10/19/2017 (Completed)	Submit to DOE letter report listing the outreach activities
2	M6: Identify non-technical challenges	12/31/2017 (Completed)	Submit to DOE letter report containing identified non-technical challenges for continued project development
3	M7: Detailed plan for additional characterization	12/31/2017 (Completed)	Submit to DOE letter report of a detailed plan for additional characterization of the storage complex and specific site(s)
2	M8: Convene 2nd Coordination Team meeting	3/12/2018 (Completed)	Submit to DOE letter report of Coordination Team members & meeting attendees

3. PRODUCTS

Publications, conference papers, and presentations.

The following manuscript was submitted on August 21, 2018 to the International Journal of Greenhouse Gas Control



Risk and Benefit Perceptions and Information Seeking Intent related to Carbon Capture and Storage in Southeast Texas

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Abstract:

The public remains relatively unaware of the risks and benefits associated with carbon capture and storage (CCS) technology, including the role of CCS in combating CO_2 emissions as a means to address climate change. This study explores risk and benefit perceptions and information seeking intent related to CCS in a southeast region of Texas that has seen growth in the application of CCS technology. Our goal is to determine factors that might help build awareness and knowledge of CCS so that citizens can make informed decisions about CCS expansion in the future. We surveyed 970 general population adults residing in eight counties in southeast Texas. Consistent with prior research, results indicate that most respondents were not aware of CCS or the risks and benefits associated with it. To explore CCS-related information seeking intent, we sought guidance from the planned risk information seeking model (Kahlor, 2010) which identifies factors that contribute to intentions to seek information about risk-related topics. The majority of the hypothesized relationships were supported, and the model accounted for more than 60% of the variance in intent to seek information about CCS risks and benefits. Implications for better engaging the public with the topic of CCS are discussed.

Running head: Public Perception and Risk Information Seeking

Keywords: carbon capture and storage (CCS), risk information seeking, information seeking behavior, environmental risks

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

The University of Texas, Bureau of Economic Geology

Name: Tip Meckel, PhD
Project Role: Principal Investigator
Contribution to Project: Dr. Meckel provided leadership to the project team. He also interacted with local stakeholders.

Name: Susan Hovorka, PhD
Project Role: co-Principal Investigator
Contribution to Project: Presented project overview at project kickoff meeting. Acted as the point person for efforts by LLNL,

Name: Ramón Treviño
Project Role: co-Principal Investigator
Contribution to Project: Mr. Treviño provided project management, and submitted milestone and quarterly reports.

Name: Dallas Dunlap
Project Role: Researcher (geophysicist - seismic interpreter / seismic database manager)
Contribution to Project: Mr. Dunlap maintained the seismic database on the Halliburton Landmark OpenWorks platform.

Name: Michael DeAngelo
Project Role: Researcher (geophysicist seismic interpreter)
Contribution to Project: Mr. DeAngelo conducted structural interpretation of the "TexLa Merge" and "Texas OBS" regional 3D seismic datasets.

Name: Mariana Iulia Olariu, PhD
Project Role: Researcher (geologist – well interpreter / well database manager)
Contribution to Project: Established and maintained the well-related database on the IHS Petra geological interpretation software package and correlated regional well logs. She estimated regional static capacity in the portions of the study area.

Name: Ramon Gil-Egui
Project Role: Researcher (Economist)
Nearest person month worked: 2
Contribution to Project: Mr. Gil evaluated the economic feasibility of a proposed storage complex.

Name: Reynaldy Fifariz
Project Role: Graduate Research Assistant (PhD candidate)
Contribution to Project: Moved his area of focus to a site in the "TexLa Merge" 3D seismic dataset in the northeast portion of the study area under the direction of Dr. Meckel and Mr. Trevino.

Name: Peter Tutton
Project Role: Graduate Research Assistant
Contribution to Project: Analyzed the distribution of CO_2 hubs working closely with Trimeric Corporation engineers and under the direction of Dr. Hovorka.

Name: Sarah Prentice
Project Role: Graduate Research Assistant
Contribution to Project: Studied feasibility of EOR in near offshore

Name: Izaak Ruiz
Project Role: Graduate Research Assistant
Contribution to Project: Interpreted "TexLa Merge" 3D seismic dataset in the northeast portion of the study area under the direction of Dr. Meckel.

Name: Omar Ramirez Garcia
Project Role: Graduate Research Assistant
Contribution to Project: Assisted Mr. Fifariz in analyzing some of the field sites.

Name: Maryam Rasti
Project Role: Undergraduate Research Assistant
Contribution to Project: Uploaded project data to EDX.

Other Collaborating Organizations:

The University of Texas:
Dept. of Petroleum and Geosystems Engineering
Stan Richards School of Advertising and Public Relations
Lamar University
Trimeric Corp.
Lawrence Livermore National Laboratory

5. IMPACT & CONCLUSIONS

The GoM has a long tradition of global leadership in research, technological development and specialized human resources in the oil, gas and petrochemical sectors that have impacted not only the local and national economy but also the world economy. These sectors are in unprecedented capacity expansion based on the "tight oil" and "shale gas" boom generating wealth and jobs. But it is predictable that this concentrated capacity expansion will impact total emissions, increasing its national share when the total trend was expected to keep decreasing or at least steady in the predicable future.

The sustainability of GoM energy ecosystem is tied to its de-carbonization through the CCS ready-to-go technology. Highly concentrated industrial clusters with large amounts of high purity CO_2 sources, extended oil and gas operations and financial infrastructure, the availability of a highly trained workforce and the unequaled proximity to the vast offshore storage capacity provided by the GoM make this region the privileged environment for CCS commercial deployments.

Additionally, for more than a decade the state of Texas has been developing an extensive set of laws, guidelines, regulations and incentives that demonstrate the mature status and substantial preparation for the commercial scaling of the CCS in the region.

The study demonstrates that industrial source clusters connected to a transport hub delivering CO_2 to a nearby storage complex is the most cost-effective and improved way to de-carbonize industrial activities, particularly, in an expected low-carbon and increasing carbon price environmental. The feasibility of the new business models should be based on the best use of the existing infrastructure and strategically build on new supporting infrastructure to drive down the costs of large-scale CCS deployment. Assessing the pre-feasibility of the commercial implementation of a CCS cluster and hub in the GoM energy ecosystem, our study links these elements successfully through an optimized combination (minimum cost) of CO2 sources on land with offshore storage.

Offshore storage achieves two major objectives for the US commercial large scale CCS deployment:

3. Adding large capacity to serve local regional, and potentially broader objectives
4. Lowering risk by providing storage with one public owner, away from population, with no conflict with water resources and reduced concern about induced seismicity.

The 10-L Field was assessed in somewhat more detail than other examined oil and gas fields in the study area in order to look at some specifics about how first projects might be accomplished in a favorable area of the US in the GoM and expand the sites to a larger set to experiment with matching all the possible sources to sinks. The 10-L site is large enough to accept CO2 from multiple sinks; the expanded sinks are estimated to be large enough to accept all the CO2 from the region plus some from outside the region.

A number of uncertainties were identified. The largest and most consequential uncertainty is the cost of offshore pipelines in study setting, which impacts the conditions where CO2 transport would be by ship versus the cases where pipeline would be preferred. Ships are preferred for small volumes and short durations; pipelines for larger volumes and long duration. Additional work is needed to advance the maturity of multiple sinks available, to continue outreach to industries and the public, and to develop realistic source opportunities. Contact with NET Power has engaged a potentially new source of anthropogenic CO_2 that will use an innovative power generation technique (a.k.a., the Allam Cycle) that could greatly reduce the cost of CO_2 captured from power generated by fossil fuels.

Through the Coordination Team, the project has made stakeholders in southeast Texas aware of the possibility of a future CCS industry developing in their region.