**RESEARCH PERFORMANCE PROGRESS REPORT**

**U.S. Department of Energy National Energy Technology Laboratory**

**Cooperative Agreement: DE-FE0031558**

**Project Title: Partnership for Offshore Carbon Storage Resources and Technology Development in the Gulf of Mexico**


**Principal Investigator: Dr. Susan Hovorka**

**PH: 512-471-4863**
susan.hovorka@beg.utexas.edu

**Co-Principal Investigator: Dr. Tip Meckel**

**PH: 512-471-4306**
**tip.meckel@beg.utexas.edu**

**Co-Principal Investigator: Mr. Ramon Trevino**

**PH: 512-471-3362**

**ramon.trevino@beg.utexas.edu**


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**DUNS Number: 170230239**


**The University of Texas at Austin**
**Jackson School of Geosciences**
**Bureau of Economic Geology**
**University Station, Box X**
**Austin, Texas, 78713**


**Project Period: April 1, 2018 – March 31, 2023**

**Reporting Period End Date: March 31, 2020**

**Report Frequency: Quarterly**

**Signature Submitting Official:** ______________________________________________

# EXECUTIVE SUMMARY OF RESEARCH DEVELOPMENTS DURING THIS QUARTER

## Project Management

The due date for Milestone M5 was changed from 3/13/2020 to 12/31/2020 because, due to other commitments, the GCCC staff member who is going to work on the modeling and simulation for Milestone M5will be unable to begin working on the project until later this calendar year (probably fall). A revised PMP was submitted to the NETL project manager reflecting the milestone's due date change.

The second annual Joint GoMCarb/SECARB Offshore Partnership Meeting was originally planned as an onsite, in-person meeting. Because of the Covid-19 pandemic, the meeting was held remotely instead using the Cisco WebEx video conferencing platform. After the end of the technical presentations, the GoMCArb Advisory Committee conducted a remote meeting in which they discussed the technical presentations and submitted a summary report of recommendations and feedback. The entire report can be seen in subtask 6.3.

At the end of the two offshore Partnerships' annual meeting, the NETL Project Manager informed the group that no-cost extension (NCE) had been approved. The end of the first budget period was now December 31, 2020. The reason for the NCE request was a delay, due to schedule logistic, in the deployment of the high-resolution 3D (HR3D) seismic system (aka "P-Cable") to acquire the Partnership's first HR3D survey.

The subcontract with Aker Solutions progressed to the final review stage by the University of Texas Office of Sponsored Projects (OSP). At that point (in late March), OSP noticed that Aker's profile in the U.S. Government's System for Award Management (SAM), which is a contractual flow-down requirement for signing of the subcontract. Due to the Covid-19 pandemic and the collapse in oil prices and layoffs in the oil industry, the Aker staff person in charge of the SAM application was laid off before the application was approved. As of the end of the reporting quarter, the Aker PI was actively trying to secure the staff person's SAM login information in order to finalize Aker's application.

## Offshore Storage Resource Assessment

During the quarterly reporting period, the undergraduate research assistants continued to populate the Petra™ project with well curve raster images and digitized well log curves. The total number of wells with LAS curves digitized as of the end of the reporting period was 730. Also, wells were identified with (1) sonic and density logs and (2) check shot data in the OBS South area to enable preliminary calibration of seismic depths to well-log depths.

Work is ongoing to migrate historical interpretations from previous studies (e.g"TexLa") to the GomCarb study's interpretation software space. In addition, two relatively small surveys in federal OCS waters offshore Galveston Island were added to the seismic database during the reporting quarter. The surveys became publicly available via USGS' (U.S. Geological Survey's) NAMSS site (National Archive of Marine Seismic Surveys).

The MFS09 surface (top of the dedicated geological storage interval) was used to identify the largest 50 structural closures and associated fetch areas in the TexLa Merge 3D (Figure 2.1.1.1), Offshore OBS 3D (Figure 2.1.1.2.5), and Offshore OBS South 3D seismic dataset areas of coverage.

The USGS has focused on assessing one unit in the Gulf of Mexico, the middle- and lower-Lower

Miocene strata of the Gulf of Mexico shelf. For this effort, the reservoirs that produce from this unit were grouped, and their current hydrocarbon production was determined.

Attribute analysis of the Paleoscan spectral frequency volumes continued in the most recent reporting period with a focus on defining potential $CO_2$ Storage plays unique to the Chandeleur seismic area. Two distinct play types based on the seismic character were investigated, an upper Miocene stratigraphic play and Oligocene/Base Miocene slope fan play.

Risk Assessment

A peer-reviewed paper by Partners from Lawrence Berkeley National Lab (LBNL), "Major $CO_2$ blowouts from offshore wells are strongly attenuated in water deeper than 50 m," appeared in *Greenhouse Gases: Science and Technology*.

In addition from LBNL, the field evidence of multiscale and multipath channeling of $CO_2$ flow in the hierarchical Tuscaloosa (i.e., Cretaceous age Gulf of Mexico reservoir) fluvial reservoir at Cranfield, Mississippi was documented in a published article (Zhou et al., 2020) in the journal *Water Resources Research.* This interpretation of the CISB and flow channel network can guide future modeling and data inversion to best understand the effects of natural heterogeneity on $CO_2$ storage efficiency and residual trapping.

Geologic Modeling

Part II of a final report on Compressibility Effects on Viscous Instability Under Sealing and Partially Sealing Boundaries was submitted. See Appendix I.

Partners from Lawrence Livermore National Lab working with colleagues from Total at Stanford University have built an unstructured mesh honoring the faulted geometry at the High Island 24L site and have populated it with geostatistical properties honoring active seismic and well log date. They have run preliminary compositional simulations to confirm the model works well.

Monitoring, Verification, and Assessment (MVA)

In the CFD simulation reported last quarter by Lamar University (see previous quarterly report), 3 fluids were used: $CO_2$, water and air. In a subsequent CFD simulation run during the reporting quarter, the 3 fluids that were used included $CO_2$, water, and $HCO_3^-$. The simulation results showed that 58% of the $CO_2$ dissolved in water. Only, 20kg/s were released to the surface as a $CO_2$ gas. The dissolved $CO_2$ reacted and formed mostly, $HCO_3^-$.

Infrastructure, Operations and Permitting

During this quarter, Trimeric engaged Darrell Davis, an oil and gas industry expert, as a vendor to Trimeric to lead activities related to pipeline infrastructure re-use. Darrell completed "Phase 1" of his study during the first quarter for 2020, which focused on an initial screening of publicly available pipeline data in state and federal waters along the Texas and Louisiana coastline (i.e., the GoMCarb study region). Darrell's findings are summarized in a Power Point presentation titled "GoMCarb Pipeline Review February 2020, Y200202", which is included as Appendix II to this report. Following this initial phase of work, Darrell began a second phase of the study with a goal to develop a "workflow" to re-use specific lines that were identified as prospects by the Phase 1 screening. Goals of the workflow approach include identifying publicly available data on specific pipelines (and gaps in data), identifying key risks and analyses required to re-use specific lines, identifying regulatory, legal, and technical hurdles to re-use, and understand best practices (if any) used in the oil and gas industry that may be applicable for re-use for

$CO_2$ pipelines. The work for Phase 2 is currently underway and preliminary results are expected in Q2 of Calendar Year 2020.

Trimeric is working with UT BEG to query the Texas General Land Office (GLO) as a source for platform data in Texas state waters. Trimeric prepared a platform data request list to present to GLO, as the data do not appear to be readily available in a public online database. The project team sent a request for platform information on High Island 10L and 24L Fields

Knowledge Dissemination

This quarter, the stakeholder outreach research team (led by the UT Stan Richards School of Advertising and Public Relations) pre-tested different messages to include in the final stakeholder study. Based on insights from the survey done in the previous quarter, we chose the specific benefits and risks to include in potential outreach and informational messages (i.e., about CCS). Three unique messages were crafted to manipulate the different CCS message frames (one with three environmental CCS benefits, one with three economic CCS risks and one with three environmental CCS risks) and tested among a sample 140 people to determine if the message frames were adequately detected.

## ***Task 1.0 – Project Management, Planning, and Reporting***

The due date for Milestone M5 was changed from 3/13/2020 to 12/31/2020 because, due to other commitments, the GCCC staff member who is going to work on the modeling and simulation for Milestone M5will be unable to begin working on the project until later this calendar year (probably fall). A revised PMP was submitted to the NETL project manager reflecting the milestone's due date change.

The second annual Joint GoMCarb/SECARB Offshore Partnership Meeting was originally planned as an onsite, in-person meeting. Because of the Covid-19 pandemic, the meeting was held remotely instead using the Cisco WebEx video conferencing platform. As the meeting host this year, SECARB Offshore Partnership's prime organization, SSEB (Southern States Energy Board) was able to take advantage of their WebEx site license to host the meeting. Despite the inability of presenters to share their screens, and therefore their presentations, the meeting co-hosts (two from GCCC and one from SSEB) were able to share the presentation files, which they had previously received (as a contingency) from the presenters. Ultimately, the Partnership meeting successfully took place as scheduled.

The first day of the 2-day meeting took place on March 26. GoMCarb Partners presented status and progress reports in the morning through mid-afternoon. After the end of the technical presentations, the GoMCArb Advisory Committee conducted a remote meeting in which they discussed the technical presentations and submitted a summary report of recommendations and feedback. The entire report can be seen in subtask 6.3.

At the end of the two offshore Partnerships' annual meeting, the NETL Project Manager informed the group that no-cost extension (NCE) had been approved. The end of the first budget period was now December 31, 2020. The reason for the NCE request was a delay, due to schedule logistic, in the deployment of the high resolution 3D (HR3D) seismic system (aka "P-Cable") to acquire the Partnership's first HR3D survey.

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## ***Task 2.0 – Offshore Storage Resource Assessment***

### Subtask 2.1 – Database development:

Well Database

During the quarterly reporting period, the undergraduate research assistants continued to populate the Petra™ project with well curve raster images and digitized well log curves. They did this by loading raster images from available sources (e.g., Lexco OWL7) and digitizing log curves from the images, thus, generating digital LAS (Log ASCII Standard) curves. Primarily, SP (spontaneous potential) curves have been digitized because they are used to define log facies and correlate wells. The total number of wells with LAS curves as of the end of the reporting period was 730. Figure 2.1.1 illustrates the distribution of wells and the primary 3D seismic datasets within the project area and also shows lines of section for three regional well-log cross sections.

Also, during the quarterly reporting period, wells were identified with (1) sonic and density logs and (2) check shot data in the OBS South area to enable preliminary calibration of seismic depths to well-log depths (Fig. 2.1.2). These data provide the means to identify structural elements (primarily faults) in the constructed well-log cross sections within the area. Calibration of all wells in the OBS South area with the seismic data is currently in progress.

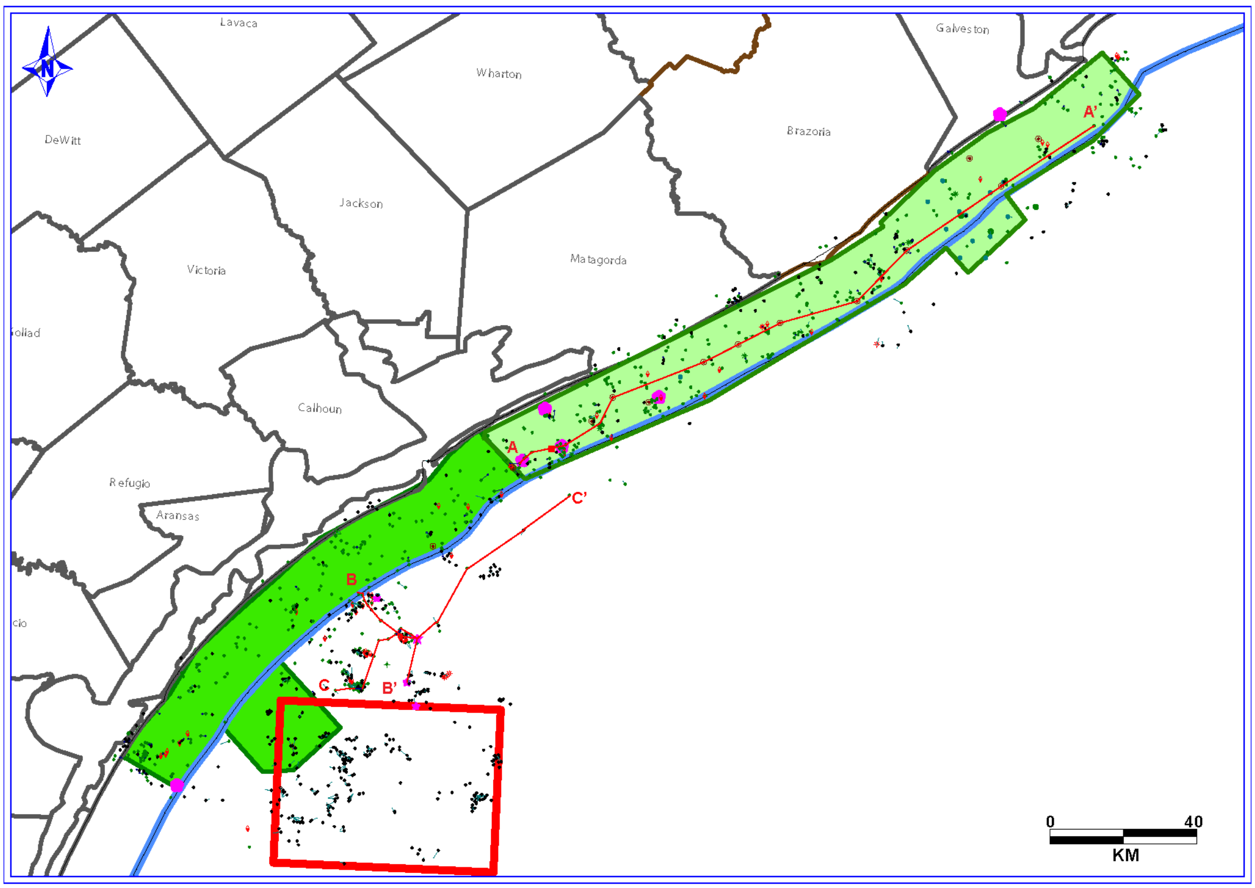


**Figure 2.1.1 –** Map of the study area from offshore Corpus Christi Bay to Galveston County showing the 3D seismic surveys (OBS - light green, OBS South - dark green) The state - federal waters boundary is demarcated by the blue line subparallel to the coast. There are 1446 wells in the study area, 1126 of which have wireline well log raster data only (black dots) and 730 of which have LAS SP curves (green dots). The line of sections of regional stratigraphic strike and structural dip cross-sections in Figures 2-4 are shown in red.

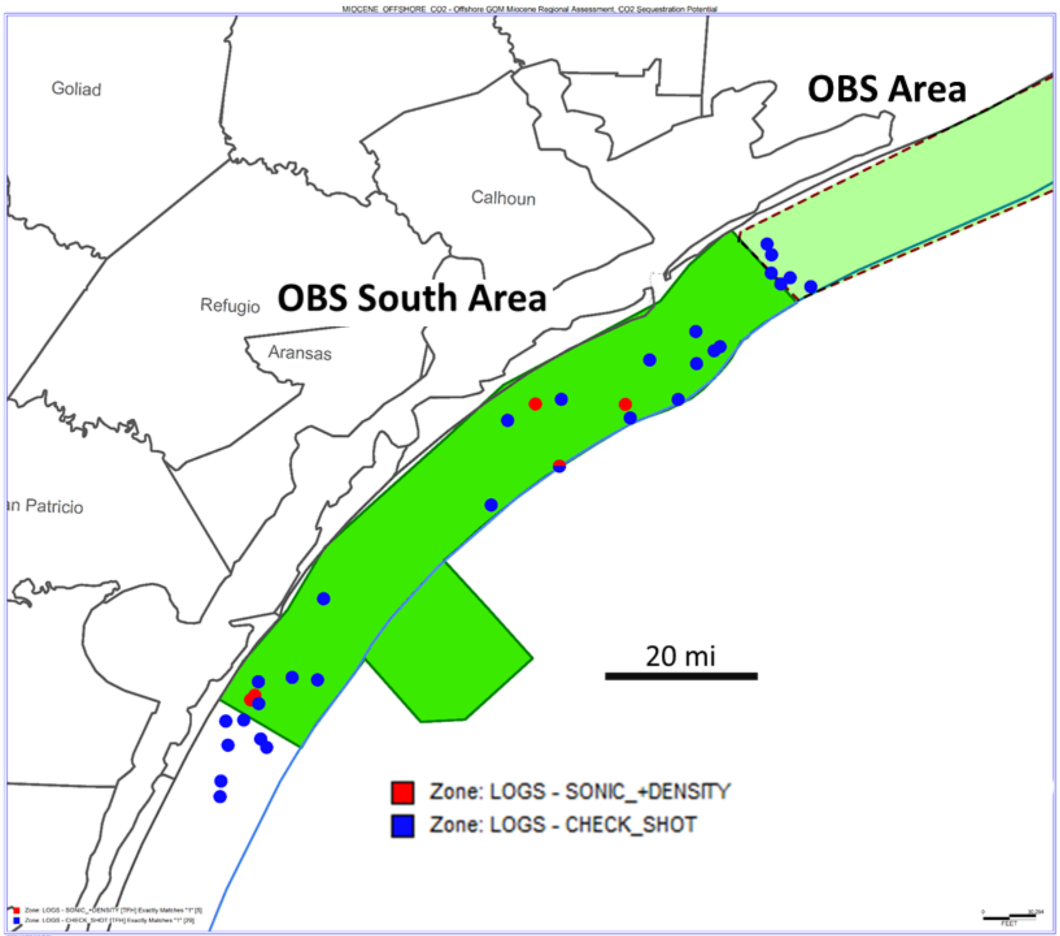


**Figure 2.1.2 –** All wells within the OBS South study area with sonic and density logs and those with check shot data.

<u>Seismic Database</u>

Work is ongoing to migrate historical interpretations from previous studies (e.g"TexLa") to the GomCarb study's interpretation software space. In addition, two relatively small surveys in federal OCS waters offshore Galveston Island were added to the seismic database during the reporting quarter. The surveys became publicly available via USGS' (U.S. Geological Survey's) NAMSS site (National Archive of Marine Seismic Surveys) (Figure 2.1.3).

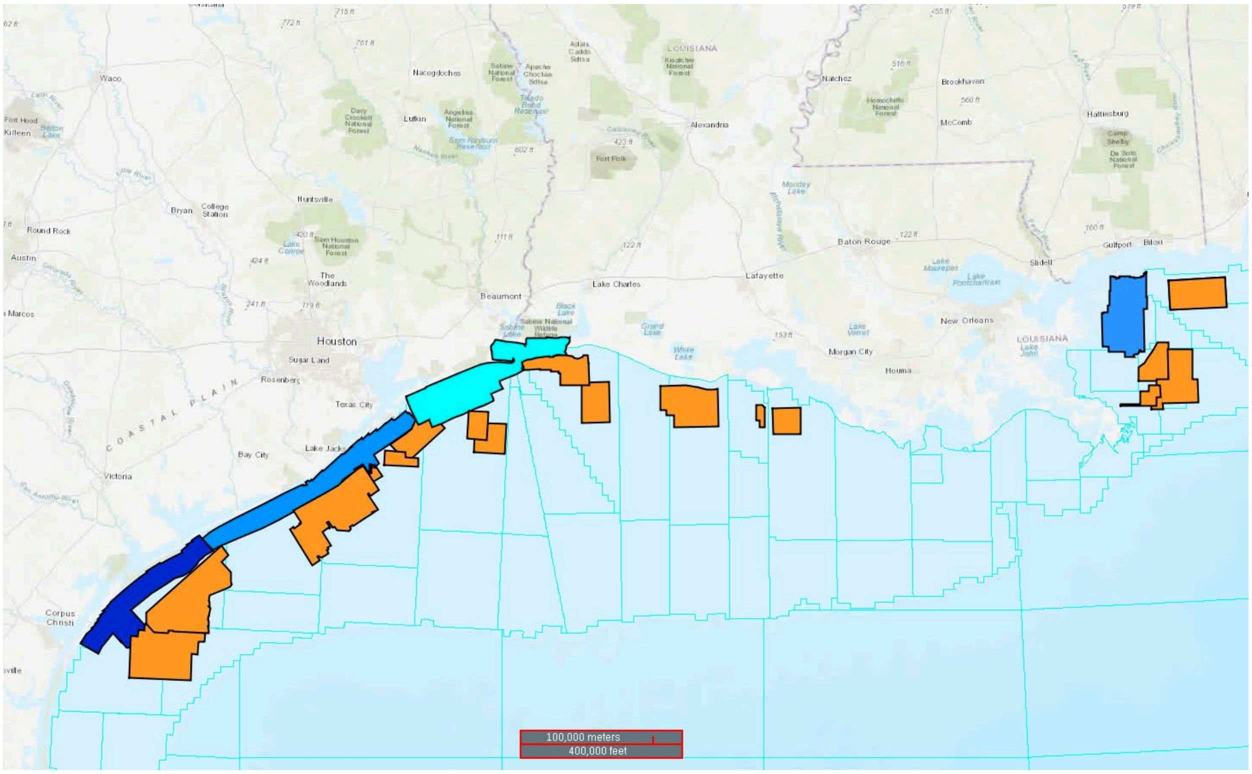


Figure 2.1.3 – Basemap of 3D seismic volumes in the GOMCarb seismic database. From left to right: Offshore OBS South 3D (Cobalt blue), Offshore OBS 3D (Cerulean blue), TXLA Merge (Turquoise blue), and Chandeleur Sound 3D (Cerulean blue), and publicly available NAMSS 3D seismic data sets (Orange). Note: two relatively small surveys in federal OCS waters offshore Galveston Island were added during the reporting quarter (i.e., adjacent to the northern portion of the Offshore OBS 3D (Cerulean blue polygon).

## ***Subtask 2.1.1 – Geographic Focus Area A - Lake Jackson, Lake Charles, and Lafayette (OCS) districts***

Subtask 2.1.1.1 Western Louisiana, Lafayette and Lake Charles Districts

The MFS09 surface (Figure 2.1.1.1.1), which is the top of the current prime candidate geological storage interval) was used to identify the largest structural closures and associated fetch areas in the TexLa Merge 3D seismic dataset areal coverage (Figure 2.1.1.1.2). Fetch are areas adjacent to zones in porous reservoirs from and through which buoyant fluids such as $CO_2$ may migrate to stratigraphically and lithologically connected structural closures or stratigraphic traps. The hypothesis is that fetch areas may provide additional, down-dip capacity via phase trapping of $CO_2$ during its migration from structurally lower injection points to the structurally higher traps.

Figure 2.1.1.1.1 - Seismic section showing key horizons mapped in the TexLa Merge 3D seismic survey. **(FIGURE REDACTED. PROPRIETARY DATA)**

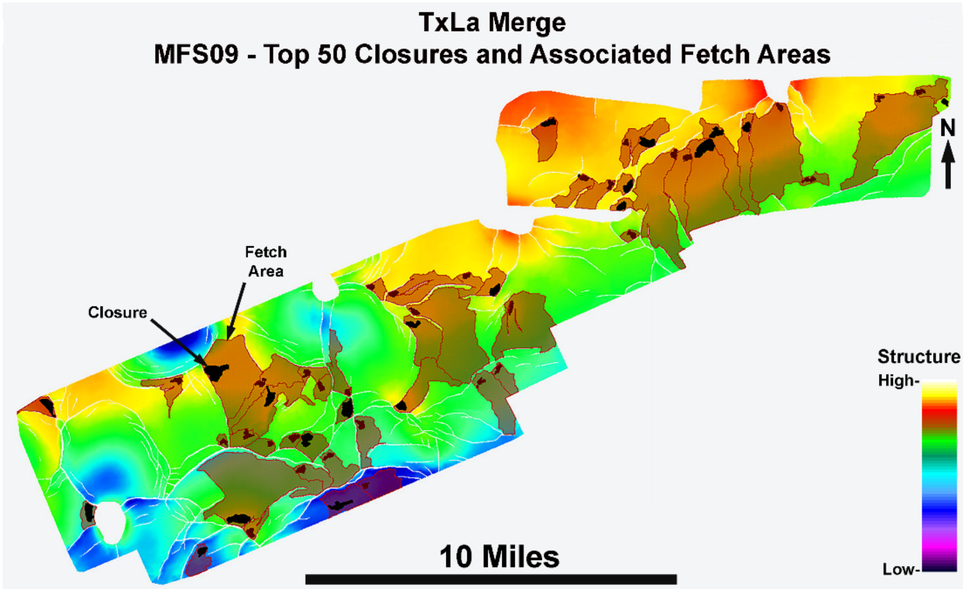


Figure 2.1.1.1.2 – TexLa Merge 3D - MFS09 structure map with top 50 closures and associated fetch areas.

Subtask 2.1.1.2 Mid-Texas coast offshore Houston to Corpus Christi

The upper depth limit for $CO_2$ injection is determined by the minimum temperature and pressure conditions at which CO2 is supercritical. In the northwestern GoM, the upper depth limit for supercritical $CO_2$ is about 3300 ft [1006 m] (Carr et al., 2017; Nicholson, 2012). The lower depth limit for $CO_2$ injection is determined by the depth at which the hydrostatic pressure in the subsurface significantly exceeds the expected pressure for a particular depth, also known as "overpressure." The top of overpressure shown on the cross sections in Figures 2.1.1.2.1 - 2.1.1.2.3 comes from a U.S. Geological Survey regional geopressure-gradient model of the pressure system spanning the onshore and offshore portions of Texas and Louisiana (Burke et al., 2012). The top to overpressure (dashed brown line) varies according to local conditions in the geologic section and can, and often does, cross time boundaries in the stratigraphy. The top of the overpressure becomes very shallow (4000-5000 ft) in the federal waters offshore Matagorda and Corpus Christi Bays. Therefore, the potential interval for CO2 storage below Amh B is limited.

A preliminary interpretation indicates that the primary reservoir targets along the middle Texas coast are Lower Miocene sandstone reservoirs between MFS 9 and MFS 10 (Figures 2.1.1.2.1 – 2.1.1.2.3) and the primary sealing unit is the regional transgressive shale unit associated with *Amphistegina B* ("Amph B") biochronozone. The cross section in Figure 2.1.1.2.1 is a stratigraphic cross section flattened on MFS9 (*Amphistegina B*). Note, the supercritical depth and top to overpressure (dashed lines), which vary stratigraphically as would be expected for a stratigraphic cross section. Currently, the primary candidate interval for $CO_2$ sequestration is the sandy section above the top of the overpressure between MFS 9 and MFS 10. Figure 2.1.1.2.2 is a dip-oriented structural cross-section. The top of the overpressure coincides roughly with the base of the Lower Miocene. In places the Amph B unit can reach a thickness of approximately 660 ft (200 m). The supercritical depth roughly coincides with MFS 6 and MFS7, and the depth of the overpressure is reached at (MFS 11 and MFS 12) the base of the Lower Miocene.

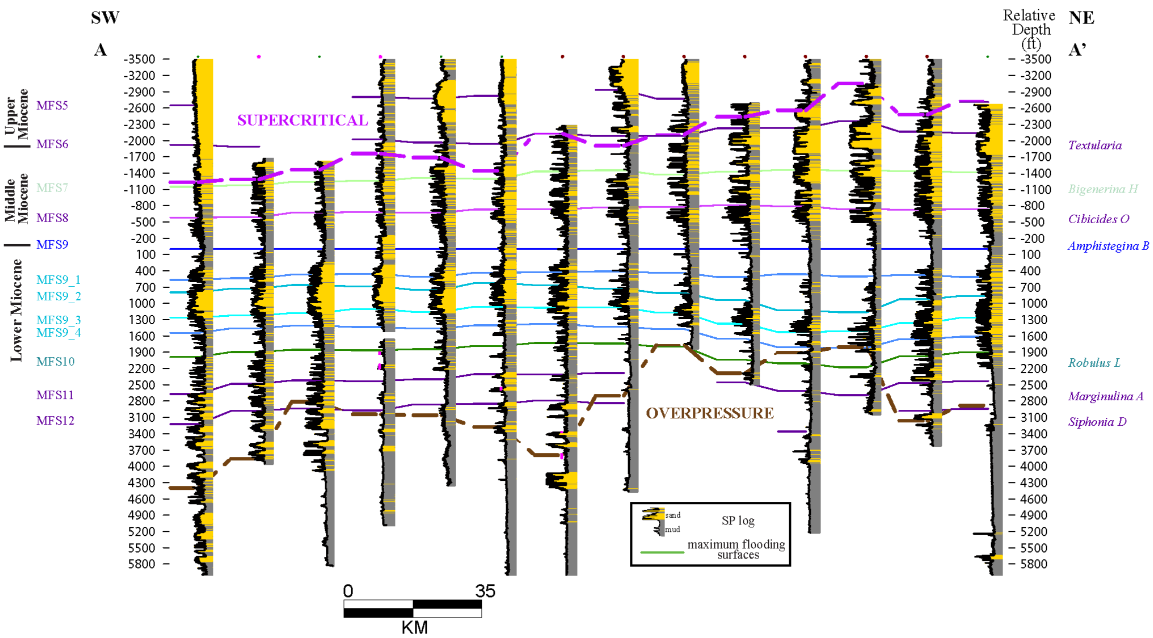


**Figure 2.1.1.2.1** – Strike-oriented stratigraphic cross-section, offshore Texas coast between Galveston and Matagorda Bay (AA' in Figure 2.1.1). The cross-section is flattened on MFS9 (*Amphistegina B*).

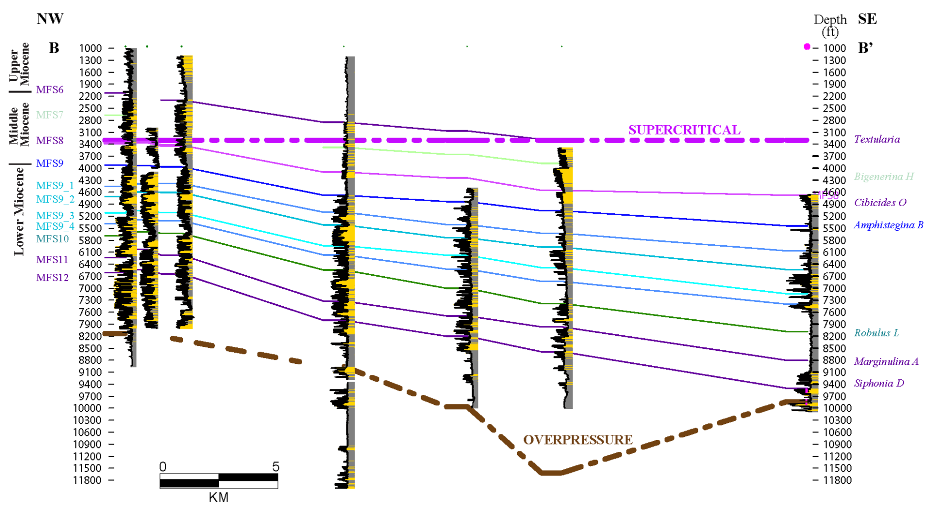


**Figure 2.1.1.2.2** – Dip-oriented structural cross-section, offshore Texas coast (BB' in Figure 2.1.1).

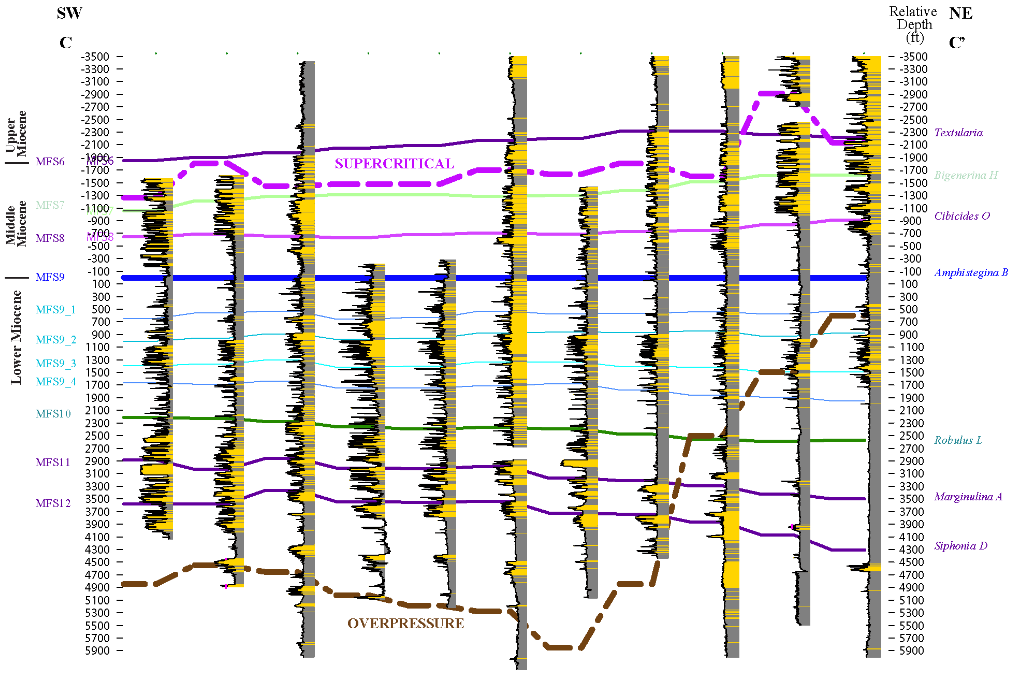


Figure 2.1.1.2.3 – Dip-oriented structural cross-section, offshore Texas coast (see Figure 2.1.1 for the line of section BB') The top of the overpressure coincides roughly with the base of the Lower Miocene. Note that the depth at which CO2 will remain in a supercritical state (dashed magenta line) is assumed to be approximately 100 meters (~3300 ft) throughout the area, and on a structural cross section, this is a horizontal line. Conversely, the top to overpressure (dashed brown line) varies according to local conditions in the geologic section.

We characterized the stratigraphic sections of the lower and middle Miocene strata in OBS South area (Fig. 2.1.1) within the context of systems tracts. At least five low-order sequences have been correlated within the study area, and they comprise lowstand incised-valley fill (LST:iv), transgressive (TST), and highstand (HST) systems tracts (Fig. 2.1.1.2.5). Lowstand incised valley fills are locally developed within most sequences and are interpreted to be potentially favorable reservoirs for $CO_2$ storage. One in particular, sequence 9 LST:iv (Fig. 2.1.1.2.5) is overlain by the Amph B flooding event, which forms a potential trap-forming shale that ranges from 200 to 700 ft (60 to 210 m) thick. The Amph B zone is generally thickest in the downdip parts of the section. The sequence 9 LST:iv ranges from 100 to 400 ft (30 to 120 m) thick and from 4,200 to 4,900 ft (1,280 to 1,495 m) deep.

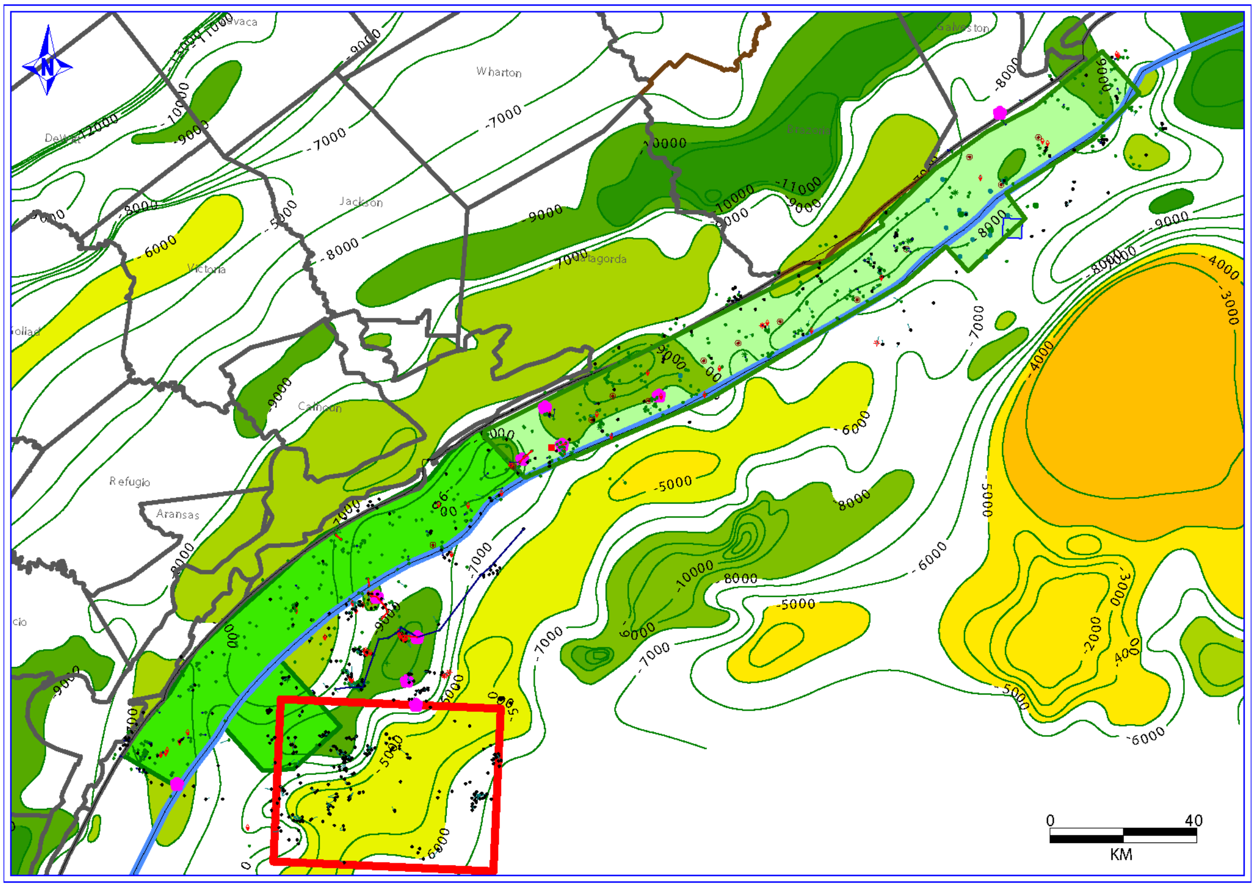


Figure 2.1.1.2.4– Map of the study area from Corpus Christi to Galveston Counties showing the 3D seismic surveys (highlighted in green and red). The map contours are from (Burke et al., 2012) top of overpressure grid. The state - federal waters boundary is demarcated by the blue line subparallel to the coast. The top of the overpressure is very shallow (4000-5000 ft) in the federal waters immediately southeast of the state waters offshore Matagorda and Corpus Christi Bays.

As mentioned in subtask 2.1.1.1 (above) and repeated here for the convenience of the reader, the MFS09 surface (top of the dedicated geological storage interval) was used to identify the largest 50 structural closures and associated fetch areas in the TexLa Merge 3D (Figure 2.1.1.1), Offshore OBS 3D (Figure 2.1.1.2.5), and Offshore OBS South 3D seismic dataset areas of coverage (Figure 2.1.1.2.6). Fetch are areas adjacent to zones in porous reservoirs from and through which buoyant fluids such as $CO_2$ may migrate to stratigraphically and lithologically connected structural closures or stratigraphic traps. The hypothesis is that fetch areas may provide additional, down-dip capacity via phase trapping of $CO_2$ during its migration from structurally lower injection points to the structurally higher traps.

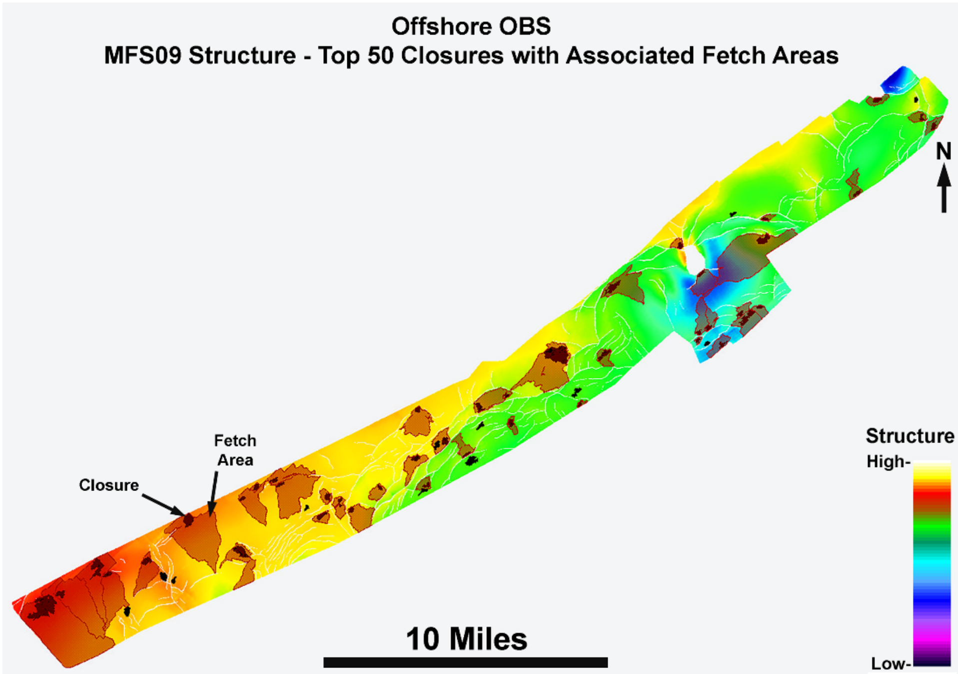

Figure 2.1.1.2.5 – Offshore OBS 3D - MFS09 structure map with top 50 closures and associated fetch areas.

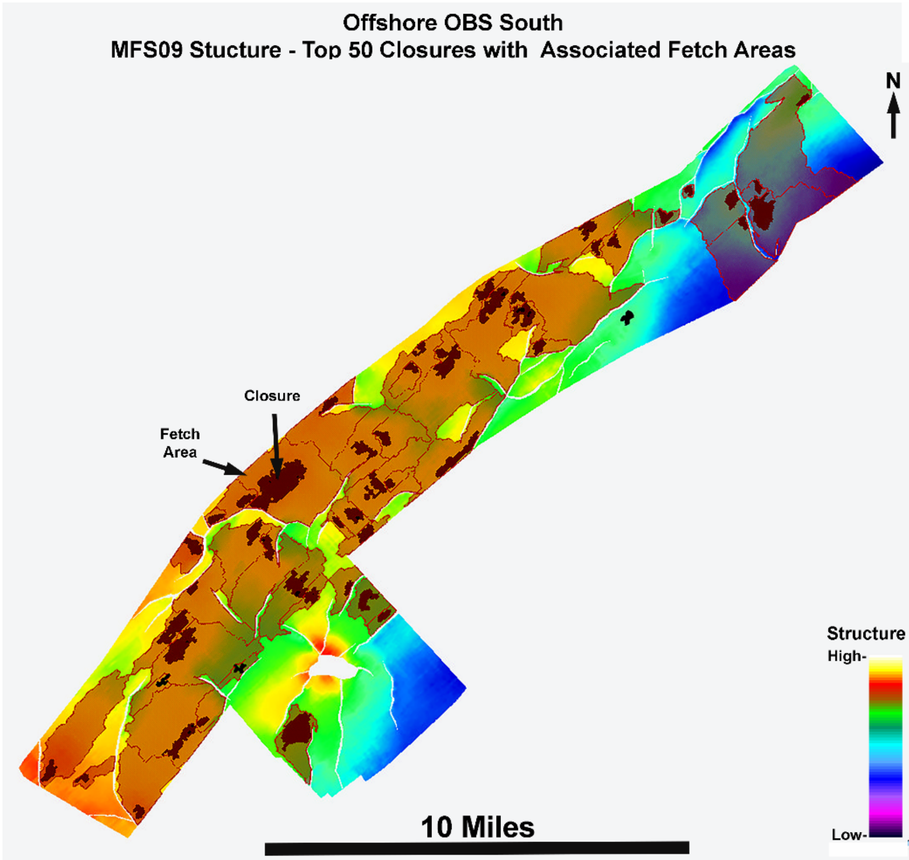


Figure 2.1.1.2.6. Offshore OBS South 3D - MFS09 structure map with top 50 closures and associated fetch areas.

A robust synthetic tie was established from a well (ST TR 632-L) in the Offshore South 3D survey that established a good time-to-depth correlation to begin mapping horizons (tops) identified from stratigraphic well interpretations (Figure 2.1.1.2.7) as well as quality control seismic derived velocity model. Horizon MFS10 will be mapped from this control point, throughout the Offshore South 3D and Offshore 3D surveys. This horizon (MFS10) will eventually be tied to the northern most TexLa 3D survey, allowing to determine first estimates of storage capacity (volumetric).

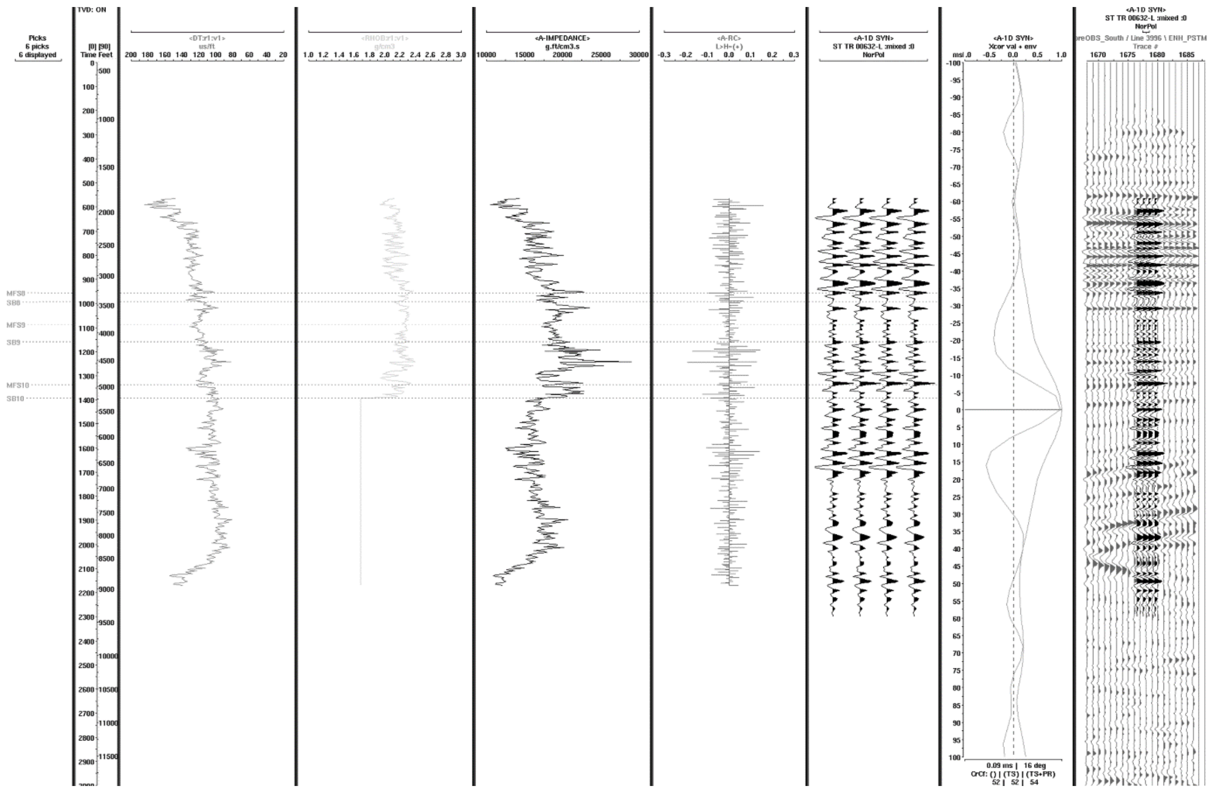

Figure 2.1.1.2.7 – Synthetic seismogram for time/depth correlation.

Subtask 2.1.1.3 Buoyant storage capacity

For this quarter the USGS has focused on assessing one unit in the Gulf of Mexico, the middle and lower Lower Miocene strata of the Gulf of Mexico shelf. For this effort, the reservoirs that produce from this unit were grouped, and their current hydrocarbon production was determined. The undiscovered hydrocarbons from this unit were gathered from the BOEM assessment (BOEM, 2017). The major work during this quarter was to build a probabilistic model for assessing buoyant storage. The hydrocarbon production and undiscovered volumes are given in oil, gas, and natural gas liquid amounts. These volumes are measured at surficial conditions and need to be adjusted to subsurface volumes. To determine the subsurface volumes formation volume factors from the USGS values of the onshore portion of this same assessment unit (U.S. Geological Survey Geologic Carbon Dioxide Storage Resources Assessment Team, 2013) were used to convert the surficial volumes. This conversion was handled probabilistically using distributions of the formation volume factors, and the known and undiscovered hydrocarbon volumes, and potential maximum pore volumes within traps. These volumes were then used to create a total available pore volume distribution for the assessment unit. The total buoyant pore volume distribution, combined with the buoyant storage efficiency distribution from the USGS assessment (Blondes, et al., 2013) and a $CO_2$ density distribution based on the pressure and temperature of hydrocarbon reservoirs in the assessment unit, were used to probabilistically estimate the total mass of $CO_2$ that could be stored buoyantly within the assessment unit. The results of the model were presented at the joint GoMCARB and SECARB-Offshore virtual meeting held on March 26 and 27th of 2020. The results are preliminary as the maximum buoyant storage values are not yet determined, and the most likely buoyant storage values are still being modified. However, getting the probabilistic model in place and tested was the significant effort for the quarter.

Subtask 2.1.1.4 Fluid inclusion stratigraphy

No activity this quarter

## ***Subtask 2.1.2 – Geologic Characterization of Chandeleur Sound, LA***

Seismic Interpretation

Attribute analysis of the Paleoscan spectral frequency volumes continued in the most recent reporting period with a focus on defining potential $CO_2$ Storage plays unique to the Chandeleur seismic area. Two distinct play types based on the seismic character were investigated, an upper Miocene stratigraphic play and Oligocene/Base Miocene slope fan play. Using the Paleoscan spectral frequency stratal slices, we investigated slices from top-overpressure (Below Base Miocene) to above Top Miocene (Figure 2.1.2.1). 15Hz, 30Hz, and 45Hz as well as Root-Mean-Squared (RMS), Seismic Relief, and coherency attributes were generated. The stratal slices revealed Upper Miocene-age sediments hosting shelf elongate (E-W trending) faults that bound areas of channelization and high seismic response (Fig. 2). These stratigraphic relationships show promise in perturbing fluid flow up-dip across fault boundaries. Additional fault mapping and log/facies correlation is ongoing.

Figure 2.1.2.1 - N-S Seismic line illustrating the location of stratigraphic storage potential relative to top-overpressure. **(FIGURE REDACTED. PROPRIETARY DATA)**

Figure 2.1.2.1 - Late Miocene-age 30Hz frequency stratal slice showing a high-amplitude disconformance at seismically imaged faults intersected by a S-N seismic section **(FIGURE REDACTED. PROPRIETARY DATA)**

In stratigraphically older sediments, numerous stratal slices highlight a zone of mass wasting above the lower Paleogene. The mass-transport and slump deposits sit above and distally from the Paleogene shelf edge. The seismic section shows an overall chaotic seismic facies and seismically visible head scarps (Figure 2.1.2.3). As previously reported, shelf edge incised valleys linked to up-dip channels are visible and may source some of the shelf-edge failures in lower Miocene-age sediments. The Mass-transport Deposits (MTDs) appear to overlie areas of high seismic amplitude downslope of the Paleogene shelf edge. The areas of high amplitude are stratigraphically adjacent to a dense network of slope gullies and suggest that the amplitudes could be the result of shelf-edge sediment gravity flows. Furthermore, more distal basin-floor high amplitude, laterally continuous reflectors are visible (Figure 2.1.2.4). One hypothesis under consideration is that the toe-of-slope turbidities and slope deposits were deposited prior to a period of transgression and more intense mass wasting. The more proximal slope deposits exist above the calculated top-overpressure. Evaluation of BOEM distal seismic data and more detailed seismic interpretation is ongoing to better characterize the seismic facies.

Figure 2.1.2.2 - Upper Paleogene-age stratal slice with intersection seismic section. The Lower Miocene section is characterized by a chaotic seismic facies typically diagnostic of Mass wasting processes. **(FIGURE REDACTED. PROPRIETARY DATA)**

Figure 2.1.2.3 - Late Paleogene-age stratal slice highlighting numerous high seismic amplitudes along the slope within dip-elongate gullies and basin floor fans as well as on the shelf in shoreline parallel delineated seismic facies. **(FIGURE REDACTED. PROPRIETARY DATA)**

Search for storage potential opportunities is currently focused within the identified debris flows, especially within the Middle Miocene, south of the shelf break and above the top of overpressure (Figure 2.1.2.5).

Figure 2.1.2.4 - 3-D cube view facing East of Chandeleur Sound area. Stratigraphic layers shown are the top Miocene, top Middle Miocene and Base Miocene. Also shown is the intersection of the Top of Overpressure with the base of Miocene. The red shaded box indicates where debris flow and fan deposits have been identified and is currently the primary focus for storage potential. **(FIGURE REDACTED. PROPRIETARY DATA)**

**Investigation of shale seal efficacy**

All available logs from the Chandeleur SA are being examined for shales. To date, of the 170 wells drilled in the area, 121 have wireline logs available for shale evaluation. Current efforts are working to cross-reference the logs with the seismic and narrow down which logs cover our interval(s) of interest. Shales will be identified and evaluated for seal efficacy (thickness, purity, etc.).

#### ***Subtask 2.1.3 – Geologic Characterization of High Island, TX***

See subtask 2.1.1 for overlapping activities.

### Subtask 2.2 – Data Gap Assessment

#### ***Subtask 2.2.1: Data gap assessments will focus on regionally relevant analog settings***

No activity this quarter

### Subtask 2.3 – Offshore and reservoir storage Enhanced Oil Recovery (EOR) Potential

No activity this quarter

#### ***Subtask 2.3.1 Texas (High Island area of Lake Jackson district) and Louisiana (Lake Charles and Lafayette districts)***

No activity this quarter

## *Task 3.0 – Risk Assessment, Simulation and Modeling*

**Subtask 3.1 – Risk Assessment and Mitigation Strategies**

### *Subtask 3.1.1 Assess the adaptation of existing tools to offshore settings*

No activity this quarter.

### *Subtask 3.1.2 Extend geomechanical assessment to additional areas of the basin*

No activity this quarter.

### *Subtask 3.1.3 Dissolution and bubbling in water column*

**LBNL**

Our paper, "Major $CO_2$ blowouts from offshore wells are strongly attenuated in water deeper than 50 m," appeared in *Greenhouse Gases: Science and Technology*.

Oldenburg, C.M., and L. Pan, Major $CO_2$ blowouts from offshore wells are strongly attenuated in water deeper than 50 m, Greenhouse Gases: Science and Technology, 10, 15-31, 2020. DOI: 10.1002/ghg.1943

### *Subtask 3.1.4 Numerical modeling of heterogeneous reservoirs*

The field evidence of multiscale and multipath channeling of $CO_2$ flow in the hierarchical fluvial reservoir at Cranfield, Mississippi (Figure 3.1.4.1) was documented in a published article (Zhou et al., 2020) in the journal *Water Resources Research* (see section "3. Products" of this report). The dynamic channeling, invasion, spreading, and breakthrough (CISB) with small-scale $CO_2$-flow channels in the F1-F2-F3 cross section (F1, F2, and F3 are one injection and two monitoring wells) was imaged by daily electrical resistance tomography (ERT) and time-lapse crosswell seismic surveys. One, three, and four $CO_2$ flow channels logged at F1, F2, and F3, respectively, were dynamically connected with strong temporal variations in $CO_2$ saturation during 221 days of drainage with injection rate doubling twice and 81 days of imbibition. Three intermediate-scale $CO_2$ flow channels (with highest $CO_2$ saturation) normal to the cross section were ERT-imaged during late-time drainage. A large-scale, sinuous fluvial $CO_2$ flow channel was imaged by repeat surface seismic survey at the end of the imbibition. The fluvial sandstone channel sinuously bypasses the F1-F2-F3 cross section in a point bar, but the channel is connected to the cross section through an intermediate-scale sandstone channel, forming a complicated flow channel network. The multiscale flow channel network (in the fluvial channel-point bar system) revealed from the observed CISB enables us to consistently interpret the hydrological monitoring data of three tracer tests, each conducted during an injection rate step, and preinjection hydraulic-thermal-tracer tests. This interpretation of the CISB and flow channel network can guide future modeling and data inversion to best understand the effects of natural heterogeneity on $CO_2$ storage efficiency and residual trapping.

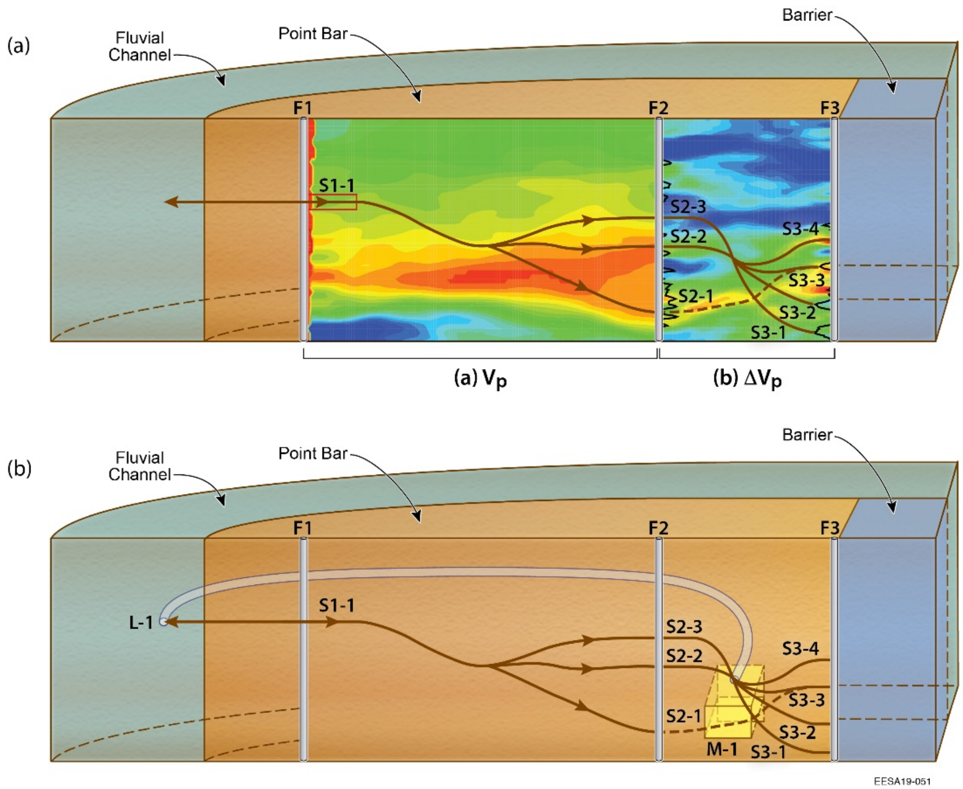


*Figure* 3.1.4.1 *Diagram of the fluvial-channel-point-bar system at the DAS site with (a) small-scale flow channels imaged during the early $CO_2$-plume development and (b) the network of large-, intermediate-, and small-scale flow channels imaged during the late-time plume development*

## Subtask 3.2 – Geologic Modeling

Part II of a final report on Compressibility Effects on Viscous Instability Under Sealing and Partially Sealing Boundaries was submitted. See Appendix I.

Partners from Lawrence Livermore National Lab working with colleagues from Total at Stanford University have built an unstructured mesh honoring the faulted geometry at the High Island 24L site and have populated it with geostatistical properties honoring active seismic and well log date. They have run preliminary compositional simulations to confirm the model works well. They are working on constraining fault transmissibility properties to appropriately represent sealing and non-sealing sections of the faults, using a shale gauge ratio approach and fault offset data.

### ***Subtask 3.2.1 – Reservoir modeling***

No activity during this quarter.

### ***Subtask 3.2.2 Sub-basinal scale modeling***

No activity during this quarter.

### ***Subtask 3.2.3 History matching experiment via modeling***

No activity during this quarter.

### ***Subtask 3.2.4 Economic modeling***

No activity during this quarter.

## ***TASK 4.0: Monitoring, Verification, and Assessment (MVA)***

**Subtask 4.1: MVA Technologies and Methodologies**

No activity during this quarter.

### ***Subtask 4.1.1 Geochemical Monitoring of Seabed Sediments***

No activity during this quarter.

### ***Subtask 4.1.2 Geochemical Monitoring of Seawater Column***

No activity during this quarter.

### ***Subtask 4.1.3 UHR3D Seismic***

No activity during this quarter.

### ***Subtask 4.1.4 Distributed Acoustic Sensors***

See figure Figure 6.2.1, photo of poster presented at the STEMM-CCS Open Science Meeting in Bergen, Norway February 11-13, 2020. Components of the poster included research from the DAS (distributed acoustic sensors) subtask.

### ***Subtask 4.1.5 Pipeline MVA***

In the CFD simulation reported last quarter by Lamar University (see previous quarterly report), 3 fluids were used: $CO_2$, water and air. In a subsequent CFD simulation run during the reporting quarter, the 3 fluids that were used included $CO_2$, water, and $HCO_3^-$. Table 4.1 summarizes the inputs used in the simulation. The volumetric mass transfer of $CO_2$ to seawater at pH 8 was calculated using the following equation 4.1.5.1 [6],

$$kLa= [31.59-(VL*R*T/QG*H)]^{-1} \qquad (4.1.5.1)$$

Where, VL= liquid volume in the reactor (L), R = gas constant ((atm L/ mol K)), T = temperature (K), QG = aeration rate (L/s) and H = Henry's coefficient ((atm L / mol))

Table 4.1Fluent Inputs

| Input | Value |
|---|---|
| Model | Volume of Fluid |
| Fluids | 3 |
| Unidirectional Mass Transfer Constant (1/s) | 0.032 |
| CO2 Flow(kg/s), Close to Choke Conditions | 50 |
| CO2 Phase | gas |
| Pressure(psig) | 1218.72 |
| Temperature (F) | 97.2 |

The simulation results showed that 58% of the $CO_2$ dissolved in water, Figure 4.1.5.1. Only, 20kg/s were release to the surface as a $CO_2$ gas, Figure 4.1.5.2. The dissolved $CO_2$ reacted and formed mostly, $HCO_3^-$, Figure 4.1.5.3.

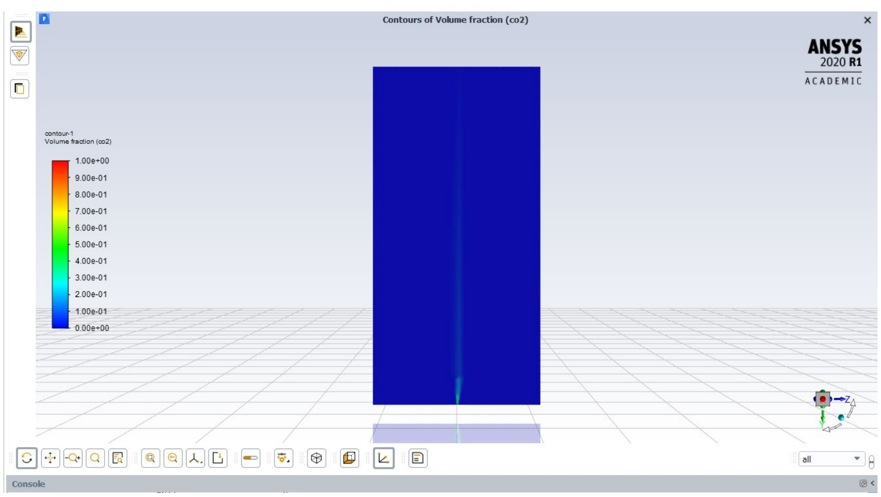

Figure 4.1.5.1 $CO_2$ Simulation Leak from High Island 10L Injection Well

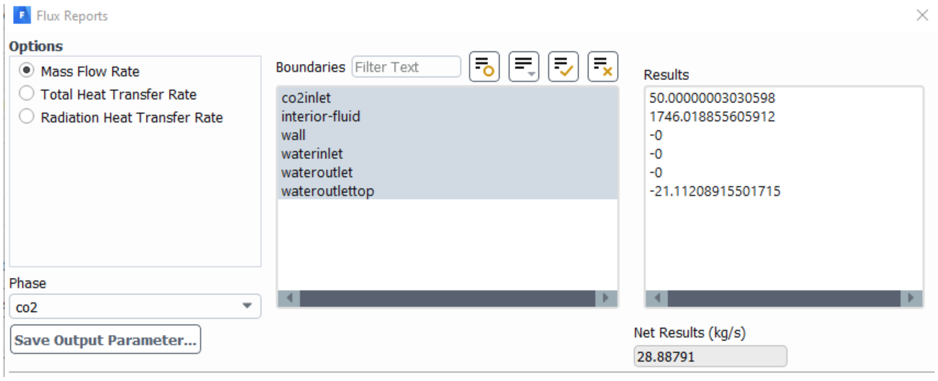


Figure 4.1.5.2 CO2 Mass Balance

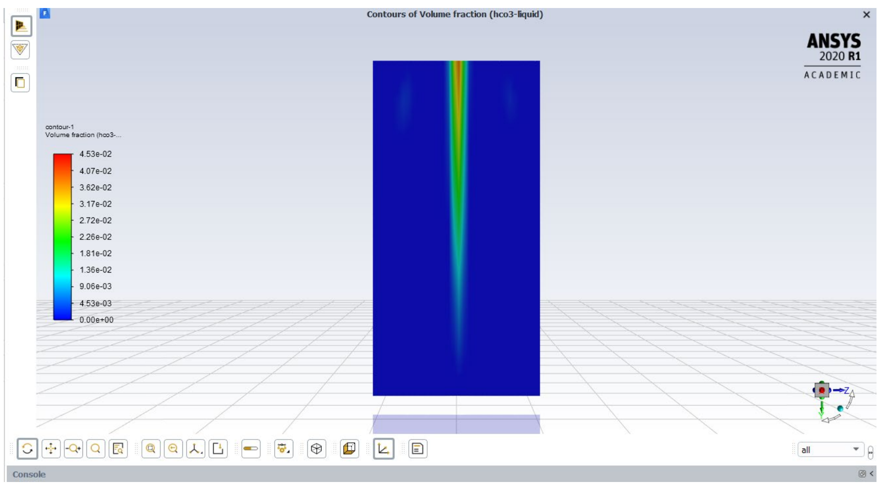


Figure 4.1.5.3 $CO_2$ Mass Transfer and Reaction.

Reference cited

[6] Kordac, M., and V. Linek. "Dynamic measurement of carbon dioxide volumetric mass transfer coefficient in a well-mixed reactor using a pH probe: analysis of the salt and supersaturation effects." *Industrial & engineering chemistry research* 47.4 (2008): 1310-1317.

## Subtask 4.2: Plans for Testing of MVA Technologies

### ***Subtask 4.2.1 Priority list for MVA Technologies and testing methods***

No activity during this quarter.

## ***TASK 5.0: Infrastructure, Operations and Permitting***

A key component of Trimeric's effort under Task 5 includes the assessment of existing infrastructure for re-use in $CO_2$ transport and storage applications. The objective of Subtask 5.1 ($CO_2$ Transport and Delivery) is to define what is known about infrastructure re-use and identify data gaps. The intent is to develop screening tools/methods that can be used to assess the potential of infrastructure assets (such as wells, platforms, and pipelines) for reuse. Trimeric is then applying these infrastructure screening criteria to specific assets (e.g., assets in the High Island (HI) Large Block 10L region) as a way to validate and refine criteria. In this way, a more detailed and practical understanding of the infrastructure reuse will be developed for the context of an overall $CO_2$ capture, transport, and storage project.

### Subtask 5.1: $CO_2$ Transport and Delivery

The work accomplished by Trimeric in support of Subtask 5.1 is described herein.

**Pipelines**

- During this quarter, Trimeric engaged Darrell Davis, an oil and gas industry expert, as a vendor to Trimeric to lead activities related to pipeline infrastructure re-use. Darrell completed "Phase 1" of his study during the first quarter for 2020, which focused on an initial screening of publicly available pipeline data in state and federal waters along the Texas and Louisiana coastline (i.e., the GoMCarb study region). Darrell's findings are summarized in a Power Point presentation titled "GoMCarb Pipeline Review February 2020, Y200202", which is included as Appendix II to this report. Key findings from the report include (but are not limited to) the following:
    - A spreadsheet database was developed to allow rapid filtering and sorting of publicly available data in the regions of focus.
    - By using initial high-level screening criteria on the pipeline data for federal waters (most complete part of the dataset) such as size, operating pressure, length, water depth, service status, age, and access/connectivity to the shoreline, the pipeline dataset was quickly reduced to < 20 lines that met the initial screening criteria and merited further evaluation (see Phase 2 study below).
    - Mapping and summary of the subset of high priority lines (< 20 lines) identified in Phase 1 are also summarized in the report.
    - State water pipeline data for Texas were also included in the spreadsheet tool and specific lines were identified using similar screening data as previously discussed.
    - State water pipeline data from Louisiana were also reviewed, although the data available online for Louisiana was more limited and the screening procedure was more manual than in the Federal and Texas state waters.
    - The report highlights next steps for data gathering and provides a basis for the second phase of work (outlined below).
- Following this initial phase of work, Darrell began a second phase of the study with a goal to develop a "workflow" to re-use specific lines that were identified as prospects by the Phase 1 screening. Goals of the workflow approach include identifying publicly available data on specific pipelines (and gaps in data), identifying key risks and analyses required to re-use specific lines,

identifying regulatory, legal, and technical hurdles to re-use, and understand best practices (if any) used in the oil and gas industry that may be applicable for re-use for $CO_2$ pipelines. The work for Phase 2 is currently underway and preliminary results are expected in Q2 of Calendar Year 2020.

**Platforms**

- Trimeric is working with UT BEG to query the Texas General Land Office (GLO) as a source for platform data in Texas state waters. Trimeric prepared a platform data request list to present to GLO, as the data do not appear to be readily available in a public online database. The project team sent a request for platform information on High Island 10L and 24L Fields including the following:
  - Location of platform (GIS coordinates)
  - Construction date of platform
  - Platform status (producing, auxiliary, idle, decommissioned)
  - Platform type (fixed or floating)
  - Platform construction materials (concrete, steel type, etc.)
- After additional engagement with GLO, including a review of some limited data in response to the above request, the following was determined:
  - The data available from GLO are limited and are not intended to be used for evaluation of platform status.
  - The GLO contact offered that it may be reasonable to assume (based on active leases) that most platforms are not operational.
  - All platforms in state waters are fixed platforms made of steel.

**Wells**

- Well tasks in Q1 2020 included significant contributions from and collaboration with UT BEG staff (Margaret Murakami).
- UT engaged the Texas Railroad Commission (TX RRC) to obtain information on wells in High Island Block 24-L to understand the type of data publicly available for well-reuse evaluation.
- The well spreadsheet database for HI-10L and HI-24L was expanded to include data (e.g., well status) from proprietary databases accessible by UT BEG.
- Well data for HI-10L and HI-24L were plotted to screen and quickly assess the general status of wells in these lease blocks. This plotting activity will serve as the basis for identifying the scale of the opportunity in this region, but more importantly, to further develop the approach and method for broad screening across the GoMCarb region. Figures 5.1.1 and 5.1.2 represent examples of the well data plotting effort. Figure 5.1.1 presents well completion dates and well status (active vs. inactive/abandoned) in HI-10L to facilitate high-level screening of wells. Figure 5.1.2 presents the well integrity data that are publicly available for individual wells. Well integrity data availability affects the potential to further screen specific wells, the potential risk/cost associated

with assessing wells starting with publicly available data, and the potential to identify data gaps in the publicly available data.

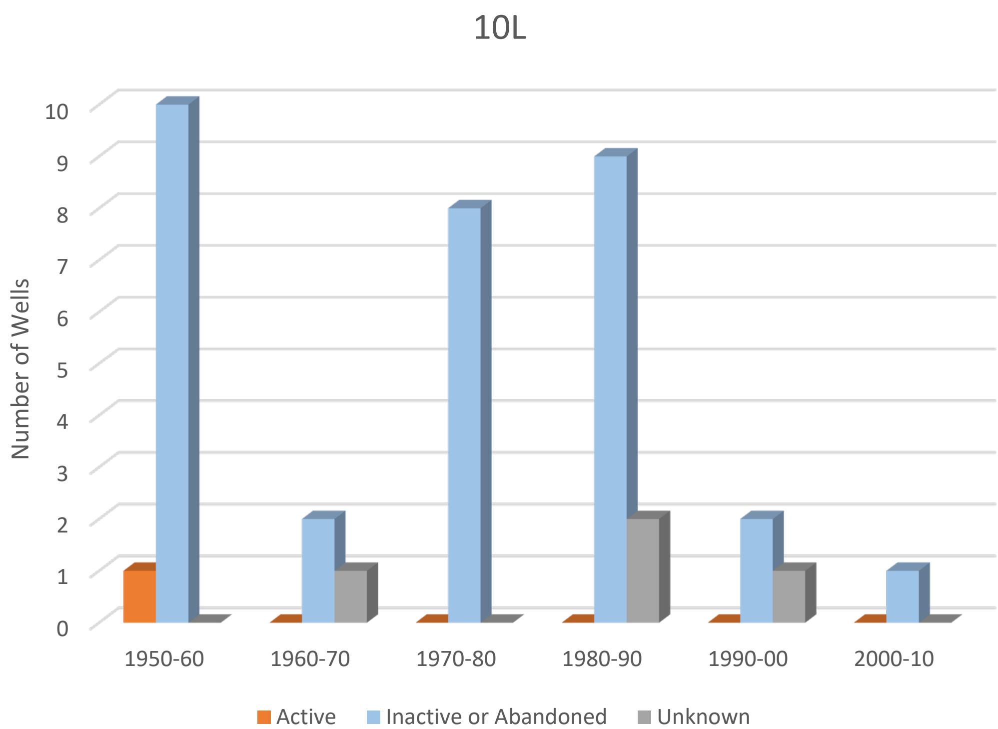


**Figure 5.1.1: HI-10L Well Status Summary as a Function of Completion**

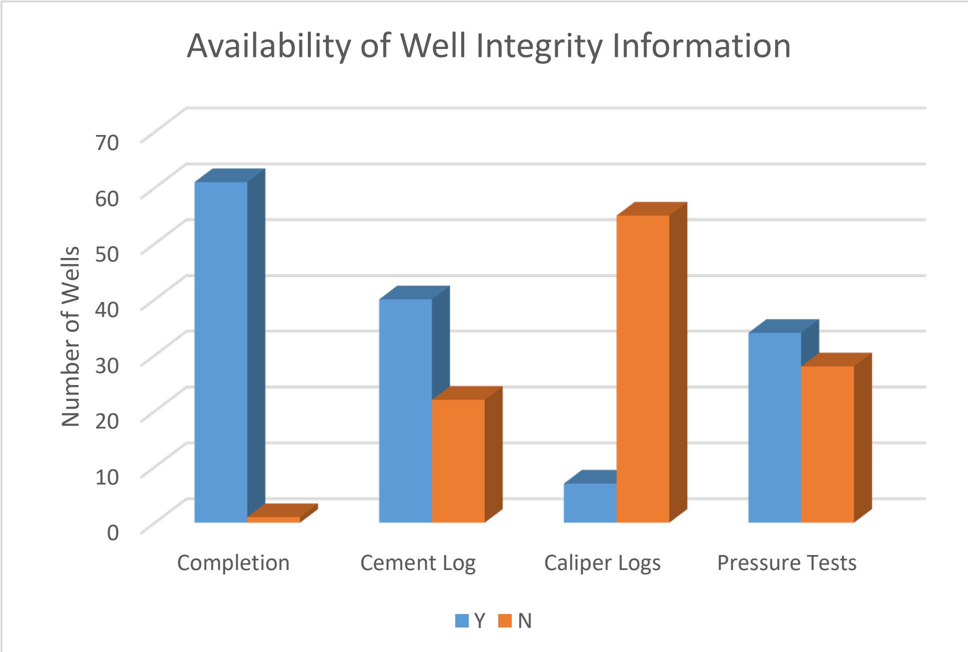


**Figure 5.1.2: HI-24L Well Integrity Data Availability**

Several similar plots have been developed for HI-10L and HI-24L and are being further refined for summary in a report or similar document.

***Subtask 5.1.2 Evaluate feasibility of subsea template in GoM***

(See Task 1, note on Aker Solutions.)

***Subtask 5.1.3 Preliminary Risk Assessment of CO2 Release from Truck/Barge Transfer Operations***

No activity this quarter.

***Subtask 5.1.4 Site Leasing***

No activity this quarter.

**Subtask 5.2: Scenario Optimization**

Lamar University

In this report, four different Petroleum Refineries in Southeast Texas have been analyzed for

$CO_2$ output.

a) Valero Refinery (Port Arthur, TX)
b) Total Petrochemicals & Refining USA, Inc. (Port Arthur, TX)
c) ExxonMobil Beaumont Refinery (Beaumont, TX) (Beaumont, TX)
d) Motiva Enterprises, LLC (Port Arthur, TX)

**REPORT**

1. **Refinery Capacity in Thousand Barrels per Day (Mbbl/d)**

The refinery capacity data (Fig. 5.1) for each of the refineries was obtained from archives of the Refinery Capacity Report published by the US Energy Information Administration[1] and the Crude Throughput Capacity Utilization percentage from the quarterly and the annual reports of each of the refineries[2,3,4]. The major increase in refinery capacity for Motiva Enterprises is due to a major facility upgrade (~$2 billion) that was completed in 2012.

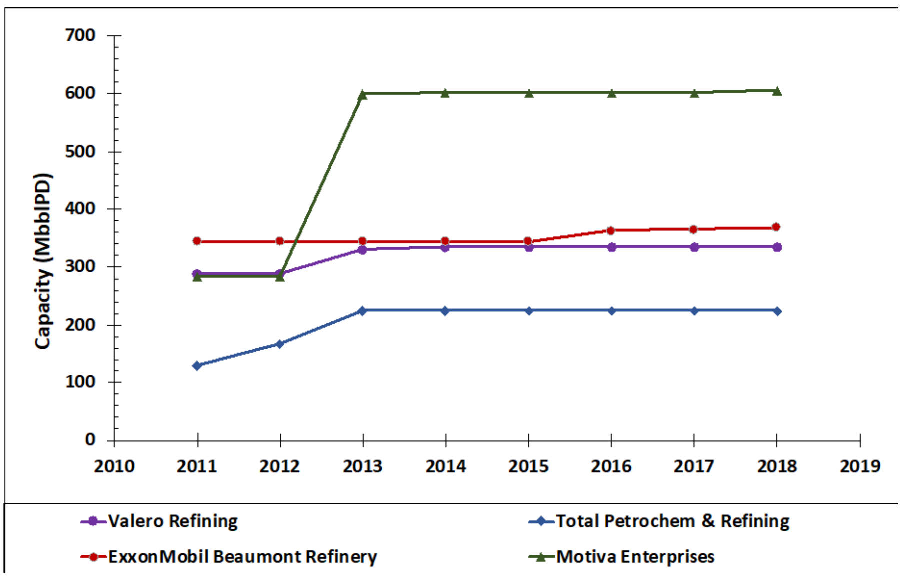


*Figure 5.5. Refinery Capacity in Thousand Barrels per Day (Mbbl/d)*

2. **Crude Throughput (Mbbl/d)**

While refinery total capacities were presented in Fig. 5.1, this does not necessarily reflect the actual throughput of the refineries. In general, chemical facilities have scheduled downtimes, usually called turnarounds, for cleaning, repairing, and replacement of equipment. Ultimately, our work seeks to normalize CO2 production based upon crude oil throughput. Quarterly and annual corporate reports, where available, were used to develop Fig. 5.2. It is important to mention that

a) Valero had the quarterly Average utilization report for each quarter between 2018 and 2015 but only reported an annual average utilization rate for the years preceding 2015[2].
b) The Average utilization Values for Total Petrochemicals was based on an overall global value[3].
c) ExxonMobil reported its Crude Throughput Capacity Utilization for Crude in their annual report[4].
d) The average utilization values for Motiva Enterprises wasn't available online; hence, an average Crude Throughput Capacity utilization of 89%. was used.

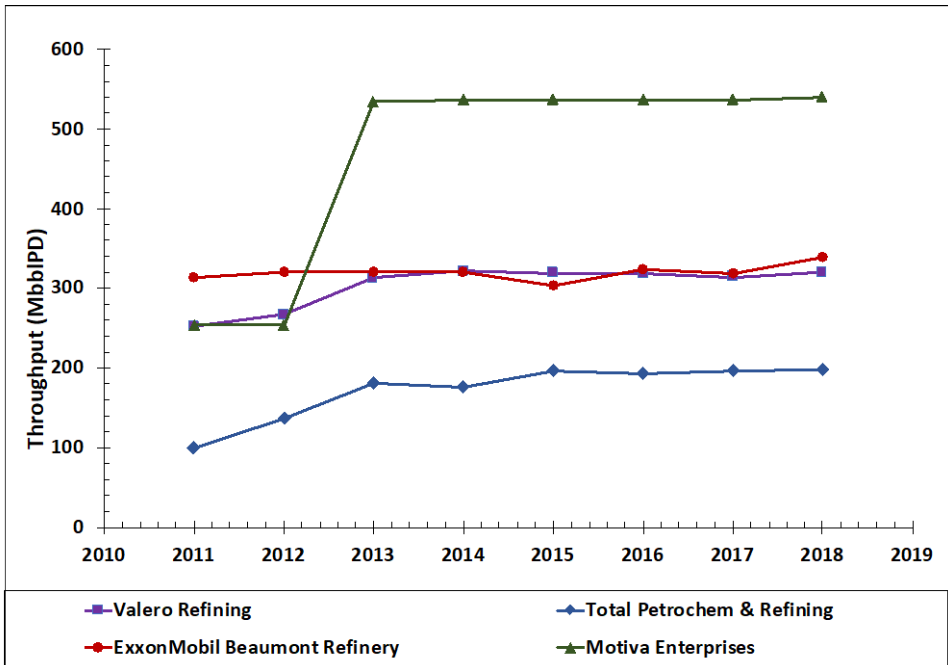


*Figure 5.6. Crude Throughput (Mbbl/d)*

3. ***Overall Analysis of Annual $CO_2$ Emissions from each refinery***

The $CO_2$ emission data was determined from the U. S. EPA website using the Facility Level Information on Green House gases Tool (FLIGHT)[5]. Figure 5.3 shows the annual CO2 production, and the daily production values are shown in Fig. 5.4.

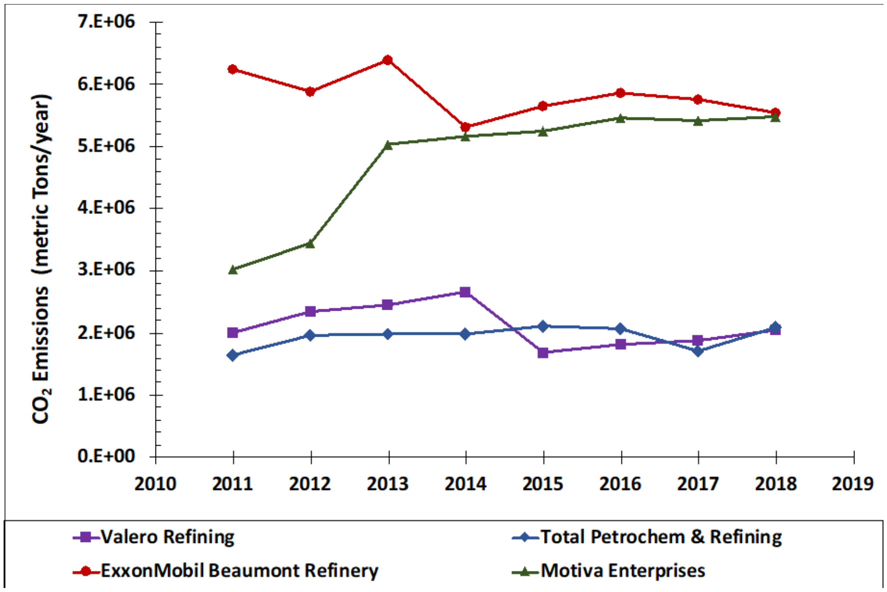


*Figure 5.7. Annual $CO_2$ Emissions in MMTons per year*

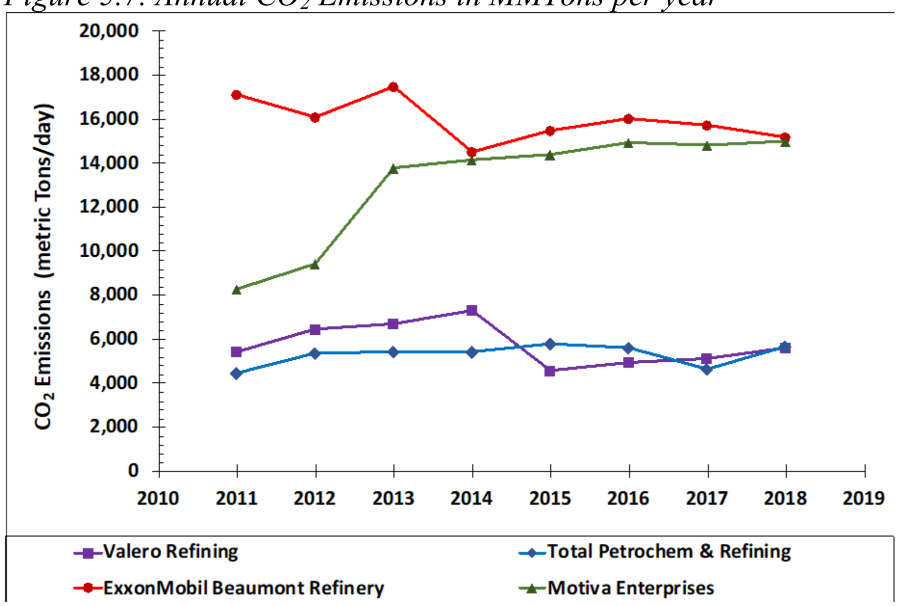


*Figure. 5.4. Daily $CO_2$ emissions in MMTons/day*

Since the capacity of each of the refinery is different, the refineries were compared by calculating the total $CO_2$ emissions caused for refining one barrel of crude oil. This value was obtained by dividing the $CO_2$ emissions (metricTons/D) with Crude Throughput (Mbbl/d) or with Capacity (Mbbl/d).

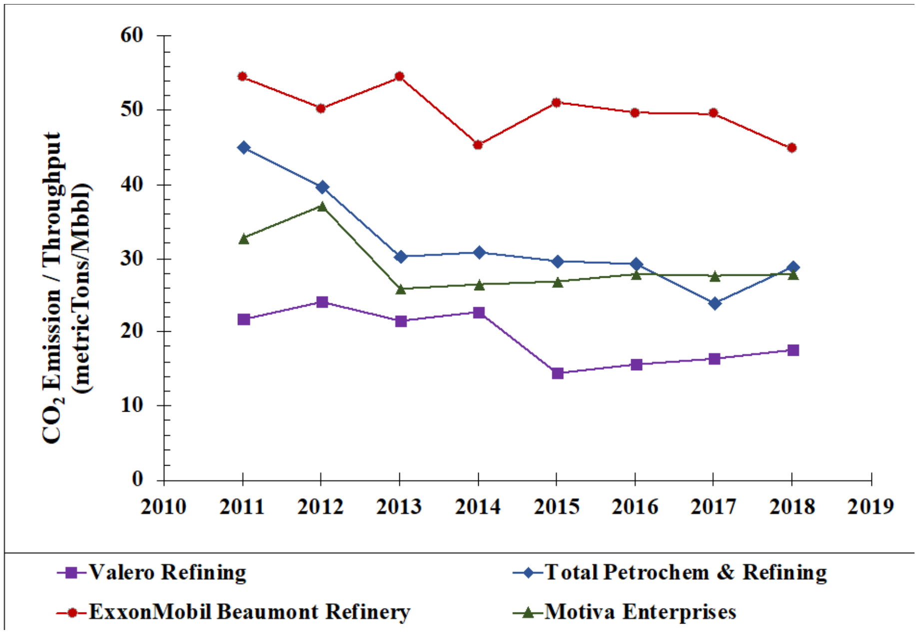

*Figure 5.5. $CO_2$ Emissions/Capacity (metric Tons/Mbbl)*

The overall $CO_2$ emissions at Valero Refining steadily increased from 2 x $10^6$ metric tons in 2011 to 2.7 x $10^6$ metric tons in 2014 at an overall rate of 8.4% per year. Afterwards, there was a sharp decline in the $CO_2$ emissions being reported. In 2015, the reported $CO_2$ emissions was ~1.68 x$10^6$ metric tons of $CO_2$ (i.e. ~37 % less than the previously reported value). The cause for the decrease is suspected to be due to a process turnaround in that plant, as the number of $CO_2$ emission sources being reported changed in 2015. In addition, the naming of many if the process equipment differed, suggesting that older equipment had been replaced by newer, more efficient ones.

The $CO_2$ emissions from Total Petrochemicals in Port Arthur has been steady and flatlined 2013 - 2018, except in 2017 where the $CO_2$ emissions dipped by about 17%. This could be because a few of the Stationary Fuel Combustion equipment were taken offline after being affected by Hurricane Harvey and had remained offline till mid-2018. Total also increased in capacity from 167 Mbbl/day in 2012 to 226 Mbbl/day in 2013.

The ExxonMobil Beaumont Refinery has also had flatlined $CO_2$ emissions from 2011 through 2018. The overall rate of change of $CO_2$ emissions has been 1.4 % per year. It may be interesting to note that since 2014, ExxonMobil has been reporting a gradual increase in its refining capacity, perhaps due to consistent facility and processing optimizations.

Motiva Enterprises completed the expansion of its capacity in the second quarter of 2012 from 285 Mbbl/day to 600 Mbbl/day, which increased the annual $CO_2$ emissions by ~ 49 % in 2013 and has been steadily increasing from 5.03x$10^6$ metric tons in 2013 to 5.48x$10^6$ in 2018 at an overall rate of 1.7% per year.

4. **Types of $CO_2$ Emission Sources**

The 6 types of reported $CO_2$ emission sources are a) Stationary Fuel Combustion Sources, b) Flares, c) Catalytic Cracking and Reforming Units, d) Sulfur Recovery Units, e) Electricity Generators, and f) Process Vents (Table 5.1). Daily CO2 emission values for each refinery from Stationary Fuel Combustion sources can be seen in Fig. 5.6. Details for individual equipment Stationary Fuel Combustion sources for each of the refineries studied can be seen in Table 5.2.

Table 5.1. Typical percentages of CO2 produced by specific refinery sources

| **Unit Type** | **% of $CO_2$ Produced** |
|---|---|
| Stationary Fuel Combustion Sources | 55 - 60 |
| Catalytic Cracking & Reforming | 25 |
| Sulfur Recovery | 7 - 10 |
| Flares | minimal |
| Electric Power Generators | [a] |
| Process Vents | [a] |

[a]Only reported for ExxonMobil and appear to have no correlation to production capacity

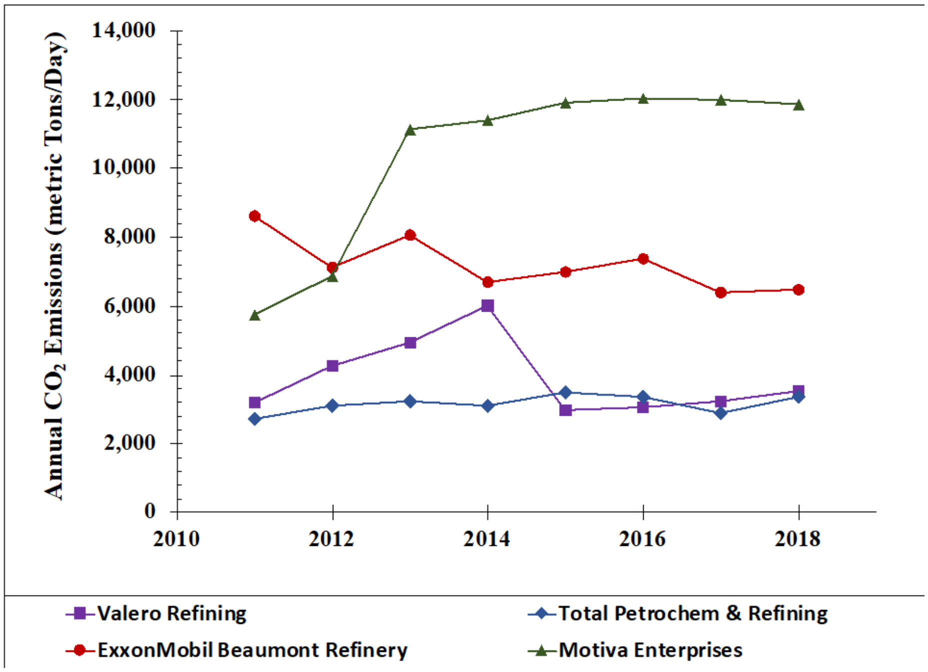


*Figure 5.6. Daily $CO_2$ Emissions from Stationary Fuel Combustion sources*

Table 5.2. Annual $CO_2$ Emissions for Stationary Fuel Combustion (By Equipment Type)

| Refinery Name | Equipment Type | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|
| Valero Refinery (Port Arthur, TX) | PRH (Process Heater) | 689729 | 947054 | 1216409 | 1163353 | 687246 | 694925 | 769253 | 834356 |
| | PFB (Boiler, pressurized fluidized bed) | 0 | 0 | 0 | 0 | 84282 | 74420 | 85178 | 94066 |
| | OCS (Other combustion source) | 348375 | 516934 | 512517 | 951982 | 315785 | 349499 | 326105 | 351075 |
| | ICI (Incinerator, commercial and industrial) | 45416 | 67439 | 74242 | 76930 | 0 | 0 | 0 | 3639 |
| | CCCT (CC (Turbine, combined cycle)) | 81574 | 23265 | 497 | 3195 | 0 | 0 | 0 | 0 |
| Total Petrochemicals & Refining USA, Inc. (Port Arthur, TX) | TODF (Thermal oxidizer, direct fired, no heat recovery) | 34072 | 35346 | 33946 | 32184 | 34226 | 36479 | 33783 | 35653 |
| | PRH (Process Heater) | 881008 | 980207 | 999452 | 970531 | 1107110 | 1073379 | 918034 | 1071170 |
| | OCS (Other combustion source) | 165 | 166 | 2149 | 2106 | 2321 | 2196 | 1750 | 1834 |
| | OB (Boiler, other) | 75647 | 109943 | 136697 | 128844 | 122971 | 110673 | 107519 | 112380 |
| ExxonMobil Beaumont Refinery (Beaumont, TX) | OCS (Other combustion source) | 3151144 | 2598887 | 2940582 | 2443597 | 2552647 | 2696421 | 2334621 | 2368228 |
| Motiva Enterprises, LLC (Port Arthur, TX) | TODF (Thermal oxidizer, direct fired, no heat recovery) | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 |
| | RCO (Regenerative catalytic oxidizer) | 340 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | PRH (Process Heater) | 1142970 | 1425631 | 2126618 | 2196875 | 2412730 | 2411519 | 2440294 | 2416797 |
| | OCS (Other combustion source) | 17363 | 47914 | 55225 | 66627 | 61773 | 64365 | 66959 | 71496 |
| | OB (Boiler, other) | 938455 | 1029619 | 1891280 | 1901663 | 1877583 | 1913887 | 1865006 | 1851389 |

Key takeaways for Stationary Fuel Combustion Equipment are:

- These types of combustion sources make for up to 55 – 60% of the $CO_2$ emissions in a refinery. These include all the process heaters, incinerators, boilers, pressurized fluidized bed reactors, thermal oxidizers and other miscellaneous combustion sources.
- Of the different sources of $CO_2$ emissions from Stationary Fuel Combustions, Process Heaters and Other combustion sources make up for about 99% of the Stationary fuel combustion sources.
- Valero has reported around 28-30 equipment between 2011 and 2014, it reduced the number of $CO_2$ emission sources to around 14 and 15 in the subsequent years.

- Total Petrochemicals has been reporting 47 stationary fuel combustion sources every year.
- ExxonMobil has been reporting anywhere between 12 and 17 equipment of $CO_2$ emissions from stationary fuel combustion sources.
- Motiva Enterprises, LLC (Port Arthur, TX) has been reporting around 83-88 equipment since its expansion.
- Upon finding the average $CO_2$ emissions per Day/Equipment for each refinery, it was found that the emissions due to fuel combustion at Valero is increasing at a steady rate, while that of Total Petrochemicals and Motiva Enterprises has been constant. ExxonMobil has been drastically reducing its carbon dioxide emissions due to combustion sources since 2011 but is still higher than the rest of the refineries. This alludes that the average Carbon Dioxide emissions from each of the equipment is fairly constant.
- The correlation between the $CO_2$ produced from stationary fuel combustion is at a much better correlation with the throughput of crude utilization than the overall $CO_2$ emissions from the refinery. Hence, it can be safely said that fuel combustion emissions of $CO_2$ in a refinery is in direct correlation with the number of barrels refined.

References

1) Refinery Capacity Report, US Energy Information Administration, https://www.eia.gov/petroleum/refinerycapacity/
2) Valero Earnings, http://www.investorvalero.com/financial-information/quarterly-results
3) Total Reports and Publications, https://www.total.com/en/investors/publications-and-regulated-information/reports-and-publications
4) Annual Meeting of Shareholders, ExxonMobil https://corporate.exxonmobil.com/Investors/Investor-relations/Annual-meeting-materials#2019AnnualMeetingOfShareholders
5) FLIGHT Tool, GHGRP, EPA, https://ghgdata.epa.gov/ghgp/main.do#

### ***Subtask 5.2.1 Analog Site Optimization***

No activity during this quarter

### Subtask 5.3: Communication

No activity during this quarter

## ***TASK 6.0: Knowledge Dissemination***

### Subtask 6.1: Stakeholder Outreach

This quarter, the stakeholder outreach research team (led by the UT Stan Richards School of Advertising and Public Relations) pre-tested different messages to include in the final stakeholder study. Based on insights from the survey done in the previous quarter, we chose the specific benefits and risks to include in potential outreach and informational messages (i.e., about CCS). Three unique messages were crafted to manipulate the different CCS message frames (one with three environmental CCS benefits, one with three economic CCS risks and one with three environmental CCS risks) and tested among a sample 140 people to determine if the message frames were adequately detected. Analysis of the pretest data indicated the benefit messages and risk messages were evaluated as significantly different from each other in terms of perceived benefits and risks, confirming that our message manipulations were successful.

The research team led by Dr. Lucy Atkinson and post-doctoral scholar Dr. Rachel Lim developed the findings from the qualitative data collected in summer and fall 2019 into a manuscript to be submitted to a relevant conference in April.

Additionally, Dr. Lim attended two research symposia where she presented our in-progress findings. In January, she attended the 5th University of Texas Conference on Carbon Capture and Storage (UTCCS-5) held at the J.J. Pickle Research Campus. In March, she attended the virtual SECARB Offshore and GoMCarb Joint Partnership Meeting that was originally slated to be held in New Orleans but was transitioned to a virtual meeting due to COVID-19 travel restrictions.

### Subtask 6.2: Technical Outreach

1) LBNL staff's planned trip to present a poster at the STEMM-CCS Open Science Meeting in Bergen, Norway February 11-13, 2020 was not approved by DOE on January 31, 2019. The staff printed the poster remotely in Bergen and arranged for colleagues to pin it up for the poster session at which it reportedly received attention despite the staff's absence. This poster presented both the $CO_2$ blowout work (Subtask 3.1.3) and a summary of the DAS monitoring work (Subtask 4.1.4) in a single poster (Figure 6.2.1).

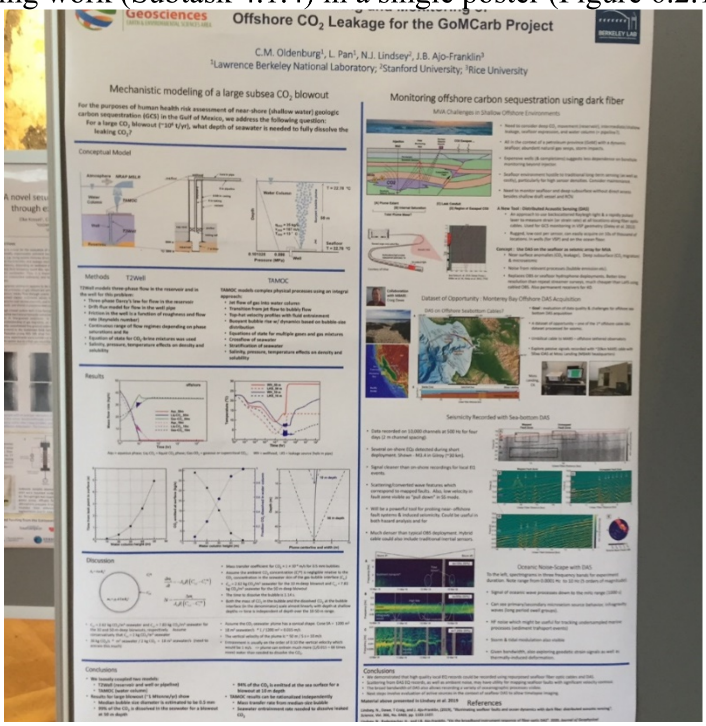


*Figure 6.2.1. Poster as presented at the STEMM-CCS meeting in Bergen, Norway.*

LBNL presented an invited talk on March 23, 2020 on $CO_2$ blowout attenuation in the water column via Zoom @ Texas A&M University:

Oldenburg, C.M., Mechanistic modeling of CO2 leakage into the water column from off-shore CO2 wells or pipelines, Water Resources, Environmental, and Coastal Engineering Division, Civil and Environmental Engineering Department, Texas A&M University, March 23, 2020 (via Zoom).

2) **UTCCS-5**: Trimeric presented the material titled "Overview of $CO_2$ capture, transport, and infrastructure in the Gulf of Mexico: Opportunities & Challenges" (Appendix III) at the UTCCS-5 meeting in Austin, Texas in January of 2020. UTCCS (University of Texas Conference on Carbon Capture and Storage) is a regular conference hosted by the University of Texas that brings together academia, industry, and other stakeholders actively engaged in CCS research.

3) Updates on the Geologic characterization and $CO_2$ storage potential of the Chandeleur 3D Seismic Survey Area were presented at the Annual GBDS (Gulf Basin Depositional Synthesis) consortium Sponsor Meeting on January 16$^{th}$.

## Subtask 6.3: Advisory Committee

As part of the annual GoMCarb Partnership meeting, the Advisory Committee met remotely (due to the Covid-19 pandemic) via the WebEx video conferencing software and provided the following report:

**GoMCarb Advisory Committee Feedback**
**26 March 2020**

**Overall**

- The project is commended for a good diversity of leading researchers and a great team
- The project is moving forward with a good program
- A good foundation is being laid for future demonstration project(s).
- The key topics are being addressed by the leading expertise in the areas

**Task 2 Offshore Storage Resource Assessment**

- Offshore capacity mapping work is good
- Net sandstone, reservoir architecture work needs to be better explained- are those structures really valley fill in the south? Very important to the overall geometry of the storage complex. The background work by Tucker Hentz is important and should be brought out more.
- Can you say more on the criteria for caprock selection? Faults are well mapped but how will you assess their potential to transmit CO2?
- Top seal Amph B cross section shows some sand. What is net to gross across the interval? Are there areas where you should not view it as a seal?
- Sandwich of the Amph B and top of overpressure – seems thinner on the Texas side. Compare and contrast between the South TX and LA ends of the shore-parallel trend
- Is there potential to go deeper in Texas with respect to top geopressure? Is there normally-pressured sand in the overpressured shales? Does that expand the storage capacity if you look at those?
- If deeper reservoirs are isolated by overpressured zones - is that a physical boundary, or an engineering one e.g. because you can't or don't want to drill through overpressured zones?

**Task 3 Risk Assessment and Modelling**

- Well blowout simulation work of Curt Oldenburg is informative and covers all the variability, we like the combination of the two models. What is the overlap from Daniel Chen's work to Curt's?
- Is Curt's work going to include the NRAP tool for atmospheric release within this project?

- Sahar's model of dissolution of CO2 in the brine - can she look at the factors that affect brine dissolution kinetics?

**Task 4 MVA**

- Jonathan's integration of two seismic methods for offshore application is good
- Tip's plans for P-cable surveys of leaky hydrocarbon sites will be interesting

**Task 5 Infrastructure**

- Trimeric screening approach to arrive at small number of examples is good.
- What is the lifetime of corrosion inhibitors in pipelines?
- How could the way in which termination (hardware remaining at endpoints) of out-of-service or abandoned pipelines affect cost? How are the chosen examples terminated?
- For the Tracy Benson work, can you add screening to identify high purity CO2 sources in the region/refineries.
- Are you talking with the owners of those identified refineries?

**Task 6 Knowledge Dissemination**

- Rachel's work – the ordering of benefits first then risks in the surveys was appreciated.
- Be aware of the broad interest that may arise from the first offshore project - national and even international players may be interested so you need a plan for stakeholders other than local.
- Alex's summary of the Offshore Workshop was appreciated.
- Develop concise publications that can be used to inform policy-makers in the USA, including on the benefits of offshore storage. Recommend on an annual basis, not just at end of project.

**Integration of Tasks**

- Task 4 MVA should look at and use the outputs of Task 3 Risk and Modelling.
- At these annual meetings, create a panel of the experts from different Tasks for cross cutting discussion among tasks.
- Task 4 MVA and Task 5 Infrastructure should work together to assess 'monitorability' of the different locations identified in Task 2, i.e. some may have difficult access. The team have good and unique experience already from Tomakomai, apply this to GoM and share through this project.

**Suggestions on next steps**

- Need peer reviewed pubs that round up the state of knowledge on real prospects of offshore storage for regulators. (CSIRO/CarbonNet and STEMM-CCS are aiming for a special offshore storage and monitoring issues of IJGGC)

- This project can help to de-risk storage and infrastructure offshore by informing relevant stakeholders and policy-makers. Suggest communicate with brief publications. These short summaries (maybe multiple topics such as a piece on the advantages of offshore storage; state of research accompanied by recommendations; pertinent summaries for project developers ) should be largely non- or light-technical, for public education—project developers and industry, public policymakers, ENGOs, and affected communities.
- These information publications should include that CCS applies to industrial sources such as steel and cement, not just to power.

Tim Dixon, Bruce Hill, Anastasia Ilgen, Gary Teletzke, Kari-Lise Rørvik, Rob Finley, Chris Walker, Nick Hoffman, Jun Kita

## PLANS FOR THE NEXT PROJECT QUARTER

***Task 1***

- Monitor the status of the Aker SAM application and finalize the subcontract.
- Kick-off Aker's technical study and integrate them with pertinent Partners (e.g., Trimeric).

***Task 2***

Subtask 2.1:

- Evaluate BOEM distal seismic data for more detailed seismic interpretation to better characterize seismic facies of Chandeleur Sound.
- **2.1.1.3** - The next steps will be to work with the collaborators at the Texas Bureau of Economic Geology on getting structural maps of relevant horizons in the lower Miocene, and to determine how the high-resolution data can be employed as analogues. These data will be used to define a distribution, which can then be run through the USGS buoyant storage methodology to estimate the buoyant $CO_2$ storage resource of the lower Miocene shelf region of the state waters of Texas and Louisiana, and the federal waters of Texas and western Louisiana.

***Task 3*** Risk Assessment, Simulation and Modeling

Subtask 3.1:

- Subtask 3.1.3 - Investigate options for modeling atmospheric dispersion of $CO_2$ that breaches the sea surface in blowout scenarios.
- Subtask 3.1.4 - Check on the status of the BEG geological model with hydrofacies distributions.

3.2 – LLNL will start running simple poromechanical simulations, gradually increasing the complexity of the geomechanical physics (elasticity to elastoplasticity to elastoplasticity with fault slip).

***Task 4*** Monitoring Verification and Assessment

- Subtask 4.1.4 - Develop subcontract from LBNL to Rice University to allow Jonathan to continue working on this subtask.

***Task 5*** Infrastructure, Operations and Permitting

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- Subtask 5.1: Broader data assessment of wells across the GoMCarb region.
- Subtask 5.1: Develop a workflow for pipeline infrastructure re-use, engage feedback from industry experts and key stakeholders.
- Subtask 5.2: Continued development of $CO_2$ source list along the Texas and Louisiana coast, including outreach and education of industry in the region.
- Subtask 5.2: Develop first draft of an LNG Case study for presentation to the broader project team and regional stakeholders.

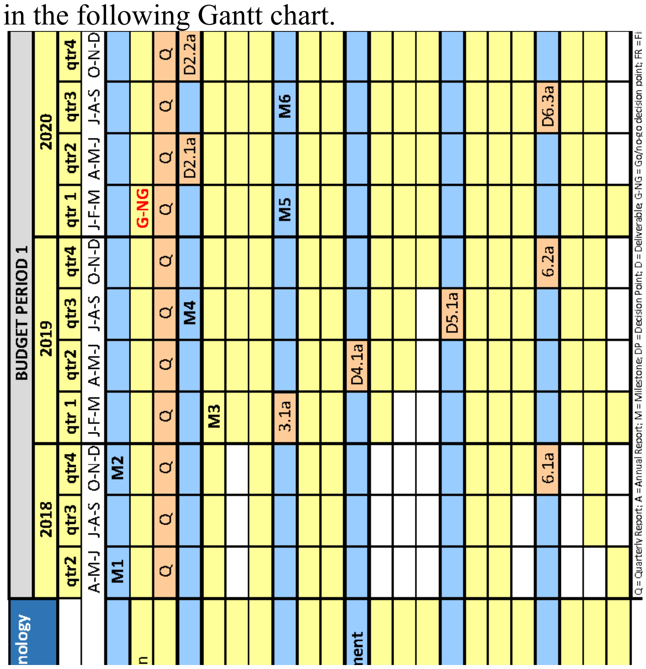
***Task 6***

- This coming quarter we will refine the messages and carry out the final testing among our representative sample of participants in the Gulf Coast area of Texas.
- A remote presentation on CCS, geo-sequestration and current activities in the northwest Gulf of Mexico is scheduled for technical session of the Texas A&M-Kingsville Department of Physics and Geosciences Technical Session on Earth Day, April 22, 2020.
- Present topics in CCS to audiences of opportunity.

## STATUS OF PROJECT SCHEDULE AND MAJOR GOALS/MILESTONES OF PROJECT

Schedule/Timeline

The project schedule/timeline is shown in the following Gantt chart.



**MAJOR GOALS / MILESTONES**

| Task/ Subtask | Milestone Number and Title | *Planned* Completion *Date* | Verification method |
|---|---|---|---|
| 1 | M1: Attend Kickoff meeting | 4/30/2018 | Submit Presentation File |
| 1 | M2-1: Partnership Fact Sheet | 8/31/2018 | Fact Sheet file |
| 2 | M3: Data submitted to NETL-EDX | 1/31/2019 | List of data submitted |
| 2 | M4: Identification of geologic storage prospects & data gaps | 11/1/2019 | Summary Report |
| 3 | M5: Risk assessment, simulation and modeling of prospects | *12/31/2020* | Summary Report |
| 3 | M6: Modified risk assessment, simulation and modeling of prospects | *9/30/2020* | Summary Report |
| 4 | M7: Modified MVA technologies and testing plan identified for prospects | *2/26/2021* | Summary Report |
| 2 | M8: Refinement of geologic storage prospects & data gaps | *9/30/2021* | Summary Report |
| 6 | M9: Summary of Advisory Committee recommendations | *3/31/2022* | Letter Report |
| 6 | M10: Outcomes of public acceptance studies | *9/30/2022* | Letter Report |
| 1 | M11: Upload results to EDX | *3/3/2023* | Summary Report |

## ***3. PRODUCTS***

Publications, conference papers, and presentations.

Water Resources Research

TECHNICAL REPORTS: DATA
10.1029/2019WR025688

This article is a companion to Zhou et al. (2020) https://doi.org/10.1029/2019WR025695

**Key Points:**
- A comprehensive conceptual model of $CO_2$ channeling, invasion, spreading, and breakthrough (CISB) in heterogeneous reservoirs is proposed
- A multiscale network of $CO_2$ flow channels with dynamic CISB imaged in the hierarchical fluvial reservoir at Cranfield, MS, United States, is presented
- The evident channel network makes the hydrological-geophysical monitoring data self-consistent, allowing future joint inversion of all data

**Supporting Information:**
- Table S1

**Correspondence to:**
Q. Zhou,
qzhou@lbl.gov

**Citation:**
Zhou, Q., Yang, X., Zhang, R., Hosseini, S. A., Ajo-Franklin, J. B., Freifeld, B. M., et al. (2020). Dynamic Processes of $CO_2$ Storage in the Field: 1. Multiscale and Multipath Channeling of $CO_2$ Flow in the Hierarchical Fluvial Reservoir at Cranfield, Mississippi. *Water Resources Research*, *56*, e2019EF001360. https://doi.org/10.1029/2019WR025688

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# Dynamic Processes of $CO_2$ Storage in the Field: 1. Multiscale and Multipath Channeling of $CO_2$ Flow in the Hierarchical Fluvial Reservoir at Cranfield, Mississippi

**Quanlin Zhou[1], Xianjin Yang[2], Rui Zhang[3], Seyyed A. Hosseini[4], Jonathan B. Ajo-Franklin[1,5], Barry M. Freifeld[1], Thomas M. Daley[1], and Susan D. Hovorka[4]**

[1]Energy Geosciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA, USA, [2]Lawrence Livermore National Laboratory, Livermore, CA, USA, [3]School of Geosciences, University of Louisiana, Lafayette, LA, USA, [4]Bureau of Economic Geology, University of Texas at Austin, Austin, TX, USA, [5]Department of Earth, Environmental, and Planetary Sciences, Rice University, Houston, TX, USA

**Abstract** A consistent picture of dynamic channeling, invasion, spreading, and breakthrough (CISB) of supercritical $CO_2$ in the hierarchical fluvial reservoir at Cranfield, Mississippi is presented after 10 years of integration and analysis of complementary field monitoring and characterization data. The dynamic CISB with *small-scale $CO_2$-flow channels* in the F1-F2-F3 cross section (F1, F2, and F3 are one injection and two monitoring wells) was imaged by daily electrical resistance tomography (ERT) and time-lapse crosswell seismic surveys. One, three, and four $CO_2$ flow channels logged at F1, F2, and F3, respectively, were dynamically connected with strong temporal variations in $CO_2$ saturation during 221 days of drainage with injection rate doubling twice and 81 days of imbibition. Three *intermediate-scale $CO_2$ flow channels* (with highest $CO_2$ saturation) normal to the cross section were ERT-imaged during late-time drainage. A *large-scale, sinuous fluvial $CO_2$ flow channel* was imaged by repeat surface seismic survey at the end of the imbibition. The fluvial sandstone channel sinuously bypasses the F1-F2-F3 cross section in a point bar, but the channel is connected to the cross section through an intermediate-scale sandstone channel, forming a complicated flow channel network. The multiscale flow channel network (in the fluvial channel-point bar system) revealed from the observed CISB enables us to consistently interpret the hydrological monitoring data of three tracer tests, each conducted during an injection rate step, and preinjection hydraulic-thermal-tracer tests. This interpretation of the CISB and flow channel network can guide future modeling and data inversion to best understand the effects of natural heterogeneity on $CO_2$ storage efficiency and residual trapping.

## 1. Introduction

### 1.1. Preface

Geological carbon storage (GCS) has been investigated for three decades as a mitigation measure for climate change (Steinberg, 1992; van der Meer, 1992; also see Klara et al., 2003; Riemer, 1996). The understanding of GCS-related processes has been improved significantly through analytical modeling, numerical simulations, and laboratory experiments. The processes include propagation of injection-induced pressure buildup (e.g., Szulczewski et al., 2014; Zhou et al., 2008), evolution of supercritical $CO_2$ plumes under viscous, capillary, and gravitational forces (Zhou et al., 2010), convection of dissolved $CO_2$ (MacMinn et al., 2012; Pau et al., 2010), and reaction of dissolved $CO_2$ with minerals of resident brine and rocks (Matter et al., 2016). Some of these processes in idealized, homogeneous storage formations are well captured by numerous analytical solutions (Cihan et al., 2011; MacMinn et al., 2011; Nordbotten & Celia, 2006) and reduced-dimensional models (Gasda et al., 2011; Guo et al., 2014) that have been developed in support of GCS and have advanced subsurface hydrology in general. The complexity of these processes in heterogeneous storage formations has been demonstrated by laboratory experiments conducted at centimeter scale (Zhang et al., 2011) through meter scale (Agartan et al., 2015; Trevisan et al., 2017).

Websites

http://www.beg.utexas.edu/gccc/research/gomcarb

Technologies or techniques

None generated to date.

Inventions, patent applications, and/or licenses

None generated to date.

Other products

None to date.

## *4. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS*

## The University of Texas at Austin

**Bureau of Economic Geology, GCCC (Gulf Coast Carbon Center)**

Name: Susan Hovorka, PhD
Project Role: Principal Investigator
Nearest person month worked: 1
Contribution to Project: Leadership in planning and negotiating

Name: Tip Meckel, PhD
Project Role: Co-Principal Investigator
Nearest person month worked: 1
Contribution to Project: Dr. Meckel oversaw geologic interpretation work

Name: Ramón Treviño
Project Role: Co-Principal Investigator (project manager)
Nearest person month worked: 1
Contribution to Project: Mr. Treviño provided project management and project reporting; he acted at the primary contact for the NETL project manager and contracting specialist.

Name: Michael DeAngelo
Project Role: Researcher (geophysicist seismic interpreter)
Nearest person month worked: 1
Contribution to Project: Mr. DeAngelo conducted structural interpretation of the "TexLa Merge," "Texas OBS" and "Chandeleur Sound" regional 3D seismic datasets.

Name: Iulia Olariu, PhD
Project Role: sedimentologist
Nearest person month worked: 1
Contribution to Project: Interpretation of subsurface geology; supervisor of undergraduate

research assistants.

Name: Dallas Dunlap
Project Role: seismic interpreter,
Nearest person month worked: 1
Contribution to Project: worked with Dr. Purkey-Phillips to interpret seismic in the Chandeleur Sound area.

**UT Institute for Geophysics, GBDS (Gulf Basin Depositional Synthesis) Industrial Associates Program**

Name: Marcie Purkey-Phillips, PhD
Project Role: Biostratigrapher
Nearest person month worked: 1
Contribution to Project: Dr. Purkey-Phillips contributed expertise in biostratigraphy and integrated well and seismic data in the Chandeleur Sound 3D survey area.

### Fugro Marine Geoservices, Inc.

### Lamar University

### Louisiana Geological Survey

### Trimeric Corp.

### Lawrence Berkeley National Laboratory

### Lawrence Livermore National Laboratory

### TDI-Brooks, Inc.

### Texas A&M University GERG (Geochemical & Environmental Research Group)

### U.S. Geological Survey (USGS)

## *5. IMPACT:*

## ***6. CHANGES/PROBLEMS***

Changes in approach and reasons for change: **None**

Actual or anticipated problems or delays and actions or plans to resolve them:

> A no-cost extension (NCE) of budget period 1 from March 31, 2020 to December 31, 2020 was granted by NETL. The NCE was requested in order to accomplish the acquisition of a high-resolution 3D seismic survey, which was anticipated to occur in late 2020. Acquiring a survey will depend on the ongoing Covid-19 pandemic and whether or not it will be safe for staffing a survey vessel, which involves close quarters for staff and ship's crew.

Changes that have a significant impact on expenditures: **None**

Change of primary performance site location from that originally proposed: **None**.

## ***7. SPECIAL REPORTING REQUIREMENTS***

Respond to any special reporting requirements specified in the award terms and conditions, as well as any award specific requirements. **None**

## 8. BUDGETARY INFORMATION

**Cost Plan Status Report**

## References Cited


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Carr, D. L., Wallace, K. J., Nicholson, A. J., & Yang, C. (2017). Chapter 5: Regional CO2 Static Capacity Estimate, Offshore Miocene Saline Aquifers, Texas State Waters. In R. H. Trevino & T. A. Meckel (Eds.), *Geological CO2 Sequestration Atlas for Miocene Strata Offshore Texas State Waters* (Vol. 283, pp. 37-46): The University of Texas at Austin, Bureau of Economic Geology.

Nicholson, A. J. (2012). *Empirical Analysis of Fault Seal Capacity for CO2 Sequestration, Lower Miocene, Texas Gulf Coast*. Unpublished Masters Thesis. Unpublished Masters Thesis. Geoscience. The University of Texas at Austin.

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# **Appendix I**

Compressibility Effects on Viscous Instability Under Sealing and Partially Sealing Boundaries
Part II: Fluid Flow

## **Appendix II**

GoMCarb Pipeline Review February 2020 Y200202
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## **Appendix III**

Overview of $CO_2$ capture, transport, and infrastructure in the Gulf of Mexico:
Opportunities & Challenges
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