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

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

Reporting Period End Date: June 30, 2019

Report Frequency: Quarterly

Signature Submitting Official: ____

EXECUTIVE SUMMARY OF RESEARCH DEVELOPMENTS DURING THIS QUARTER

A subcontract was established with new Partner, Texas A&M University GERG (Geochemical & Environmental Research Group).

Work progressed on establishing a subcontract with Aker Solutions.

In addition to additional publicly available 3D seismic data, the project's privately owned inventory included leasing another significant portion (863.6 square miles) of the "Texas Offshore OBS" dataset from SEI, Inc. (i.e., along the middle Texas coast from near Matagorda Bay to near Corpus Christi Bay). The dataset is located offshore from the coastal barrier islands.

The project management team continued discussions with a senior BEG (Bureau of Economic Geology) research scientist associate, Tucker Hentz, about the possibility his characterizing the geology of the middle Texas coast. Hentz is a staff member of the STARR (State of Texas Advanced Resource Recovery) project at BEG. STARR is a state of Texas funded program whose goal is to increase revenue from Texas state lands and state waters. Hentz' work would continue to be funded by STARR, but he would work closely and in conjunction with GoMCarb, as GoMCarb's and STARR's interests overlap in Texas state waters.

LBNL (Lawrence Berkeley National Laboratory) reports that because the Sintef water-column transport code identified in Q2FY19 could not be shared with the GoMCarb project, LBNL searched for water-column CO_2 modeling capability and found an open-source code called TAMOC, the Texas A&M Oilspill Calculator. LBNL downloaded, installed and ran TAMOC on test problems. LBNL ran the code for various cases to understand how it works and interacted with TAMOC developer and expert, Scott Socolofsky and Jonas Gros, respectively, who answered questions and assisted with preliminary runs. LBNL carried out an additional blowout simulation with T2Well for a water column depth of 10 m. The CO_2 blowout emission transitions from a jet to a buoyant plume during its rise through the water column and we are in the process of understanding whether this transition will occur in the shallow (10 m water depth) near-offshore region at the 24L and 10L locations.

Research in the MVA effort continued to evaluate the potential of marine DAS (distributed acoustic sensing) for GCS (geological carbon sequestration) monitoring. The lead researcher in the effort left LBNL (co-PI) to take a position in Rice University. Some of the funding for this effort will remain at LBNL to support a graduate research assistant, and some will go to Rice University for the co-PI.

Lamar University compiled results from literature surveys of CO_2 pipeline design and monitoring technologies for large-scale CO_2 storage projects.

As reported previously, at a high level, there appears to be an alignment of interests and incentives to re-use existing oil and gas infrastructure in applications such as CO_2 storage offshore. Trimeric has not yet identified a database that addresses production platform infrastructure in High Island-10L Field area, the area currently considered as an analog for potential future development.

Task 1.0 – Project Management, Planning, and Reporting

A subcontract was established with new Partner, Texas A&M University GERG (Geochemical & Environmental Research Group).

Work progressed on establishing a subcontract with Aker Solutions.

LBNL coordinated transfer of a Graduate Student Research Assistant (GSRA, Nate Lindsey) supervisorial responsibility from Jonathan Ajo-Franklin to Curt Oldenburg in response to Jonathan's move to Rice University starting in July 2019. Part of the MVA project funding will stay at LBNL to support Nate's work on this project and the engineering design, equipment, and processing as needed. The current plan is that LBNL will set up a subcontract to Rice U. for $230k for three years of support (~$76.5k per year) assuming $67k subcontract for FY21 (Fall of 2020), FY22, FY23) ($67k per year assumes $50k student effort, $10k equipment, and $7k travel). By this plan, LBNL retains ~$120k for support of the GSRA and for equipment and fabrication costs.

A significant regional 3D seismic dataset was leased from SEI, Inc. See Subtask 2.1 (below).

The project management team continued discussions with a senior BEG (Bureau of Economic Geology) research scientist associate, Tucker Hentz, about the possibility his characterizing the geology of the middle Texas coast. Hentz is a staff member of the STARR (State of Texas Advanced Resource Recovery) project at BEG. STARR is a state of Texas funded program whose goal is to increase revenue from Texas state lands and state waters. Hentz' work would continue to be funded by STARR, but he would work closely and in conjunction with GoMCarb, as GoMCarb's and STARR's interests overlap in Texas state waters.

Delivery of the items (below), previously ordered from Geometrics, Inc., the HR3D system's manufacturer, was delayed due to previously un-recognized but required adjustments for equipment compatibility with the existing system.

ITEM 1: DEPTH SENSOR/REPEATER MODULE (57558-15SP)
QUANTITY: 5
UNIT PRICE: $12000.00
TOTAL: $60000.00
CHARGE ACCOUNT: Hovorka, Sue [(26-0839-03) DOE – NETL – GOMCarb].

ITEM 2: STREAMER TOW CABLE, SINGLE WET-END (57516-21SP)
QUANTITY: 4
UNIT PRICE: $11300.00
TOTAL: $45200.00
CHARGE ACCOUNT: Hovorka, Sue [(26-0839-03) DOE – NETL – GOMCarb].

ITEM 3: GPS TAIL MODULE GPS POWER SUPPLY (57750-50SP)
QUANTITY: 4
UNIT PRICE: $8200.00
TOTAL: $32800.00
CHARGE ACCOUNT: Hovorka, Sue [(26-0839-03) DOE – NETL – GOMCarb].

ITEM 4: COLLAPSIBLE PACKING CASE FOR ACTIVE SECTIONS AND CABLE (14-416-000, 14- 416-001)
QUANTITY: 1
UNIT PRICE: $600.00
TOTAL: $600.00
CHARGE ACCOUNT: Hovorka, Sue [(26-0839-03) DOE – NETL – GOMCarb].

ITEM 5: P-CABLE BACK DECK NETWORK BOX -- 4 STREAMER (810-00118-01)
QUANTITY: 1
UNIT PRICE: $15000.00
TOTAL: $15000.00
CHARGE ACCOUNT: Hovorka, Sue [(26-0839-03) DOE - NETL - GOMCarb].
TOTAL AMOUNTS: $153,600.00

Task 2.0 – Offshore Storage Resource Assessment

Subtask 2.1 – Database development:

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

Seismic Database

New datasets along the upper and middle Texas coast were loaded during the reporting quarter. These include the BOEM Galveston/Brazos 3D dataset (Figure 2.1.1 – green polygon) and Mustang Island 3D dataset (Figure 2.1.1 – dark blue polygon). Although the BOEM datasets are of older vintage, they contain relatively high signal-to-noise quality within the zone of interest (i.e., upper 3 seconds).

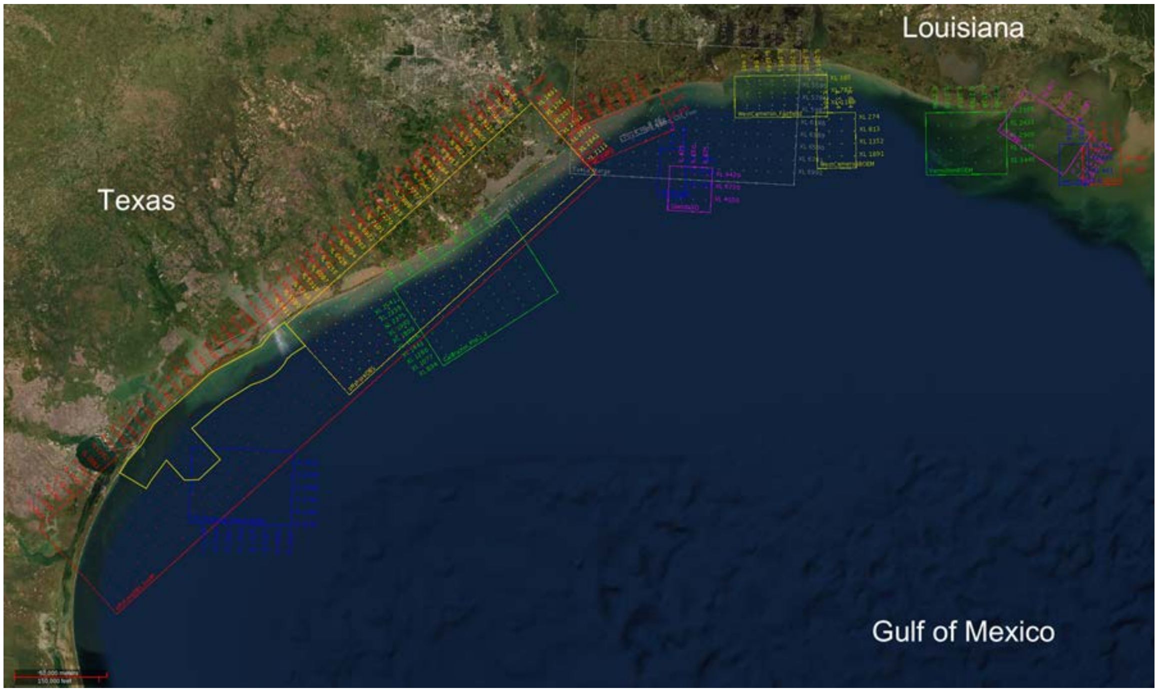

Figure 2.1.1.1 - Texas / Louisiana 3D Seismic Inventory

In addition to publicly available data, an addition to our privately owned inventory included leasing a portion of the "Texas Offshore OBS" dataset from SEI, Inc. (i.e., along middle Texas coast from near Matagorda Bay to near Corpus Christi Bay, Figure 2.1.1.1 - Yellow polygon) adjacent to and south of the previously leased northern segment, thereof. The dataset was processed and binned the same as that of the project's pre-existing northern extent of the "Texas Offshore OBS" making future attribute analyses and time/depth calibration compatible. The recently leased mid-Texas coast portion included a portion extending into federal OCS waters with the intent to partly overlap the newly loaded Mustang Island 3D dataset in federal waters. The rest of the leased Texas Offshore OBS dataset is within Texas state water.

In addition to 3D seismic-reflection data, the leased Texas Offshore OBS data package included the velocity (PSTM) stacking velocities for both the newly acquired mid-Texas coast portion and the previously acquired (2011) northern portion, thereof. The time/velocity data will be used to generate a contiguous velocity model capable of converting seismic and well interpretations between domains dynamically and consistently across the Texas-Western LA shelf zones. An initial velocity model was produced for the recently leased middle-Texas coast portion (Figure 2.1.2). Once fully verified, the velocity model will be used to convert the seismic and derivative attributes to depth for calibration with well-based models. The existing 2011 upper Texas SEI 3D dataset will be generated in early Q3.

Proprietary Data Redacted

Figure 2.1.1.2 – Seismic transect A-A' (see inset map for line of section) through the initial velocity model of the recently leased portion of the mid-Texas coast portion of the "Texas Offshore OBS" 3D seismic dataset.

<u>Integrated Database</u>

An effort to consolidate geo-referenced GIS data continued during the reporting period with the collection of various Shape and GeoTIFF files in a central-shared repository for collective use by all users. This included up-to-date cultural data, map imagery, and purchased, geo-rectified map data. Testing of an integrated GIS server with remote access began in order to facilitate real-time cultural data delivery to both Linux and Windows platform interpreters.

Subtask 2.1.1.1 Western Louisiana, Lafayette and Lake Charles Districts

No activity this quarter

Subtask 2.1.1.2 Mid-Texas coast offshore Houston to Corpus Christi

Previous results from the regional seismic studies, Offshore OBS 3D, TexLA Merge 3D, and Chandeleur Sound 3D (Figure 2.1.1.2.1) were augmented by a new seismic data volume, Offshore OBS South 3D. The seismic dataset consists of approximately 690 mi^2 of 3D seismic data acquired in Texas state waters and adjacent federal waters.

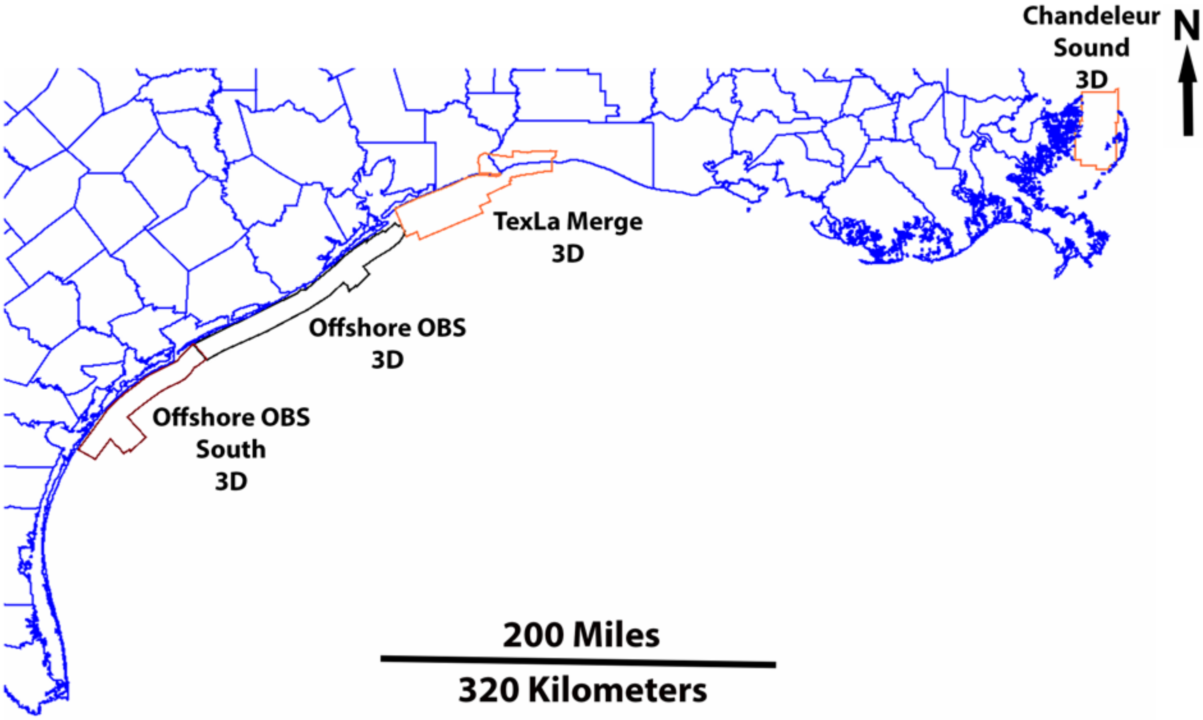

Figure 2.1.1.2.1 - Basemap of GOMCarb 3D seismic volumes.

Structural interpretation

Initial structural interpretation occurred as geologic faults were first mapped in the Offshore OBS South 3D volume on the basis of seismic expression in section and horizontal slice views. Uncorrelated fault segments were picked methodically throughout the 3D seismic volume. Semblance horizontal slices (Figure 2.1.1.2.2) were used in the initial structural interpretation phase because this technology allows a mathematical assessment of the seismic data without being biased by previous interpretation. Semblance calculations compare waveform similarity between adjacent traces. Traces within a specified time window (40 ms) are cross-correlated with neighboring traces. The lowest correlation coefficient calculated will be assigned to the central sample.

Semblance values range from +100 to -100. A value of +100 indicates a perfect match between adjacent traces. Semblance values near +100 indicate no lateral variations in stratigraphy or structure, indicating zones of rock homogeneity. A value of -100 indicates significant trace similarity if the phase of one of the waveforms is inverted. This condition could be an indicator of offset (faulting) within the reference window. In addition, low semblance values (negative) may indicate significant lateral changes in rock type, pore fluid content, facies, fracturing, or any geologic parameter that can affect seismic reflection wave shapes. Fault segments are more pronounced on semblance horizontal slices (Figure 2.1.1.2.2) relative to conventional amplitude horizontal slices (Figure 2.1.1.2.3). Horizontal slices of the semblance volume, starting at 0 ms, were generated at 4 ms intervals for the entire 3D seismic volume. Fault segments were identified and mapped across horizontal slices at 100 ms intervals. The finer detailed horizontal slices (4 ms) were occasionally utilized to constrain fault plane correlations in more complex areas.

Proprietary Data Redacted

Figure 2.1.1.2.2 - Semblance attribute horizontal slice at 1300 ms.

Proprietary Data Redacted

Figure 2.1.1.2.3 - Amplitude attribute horizontal slice at 1300 ms.

Subtask 2.1.1.3 Buoyant storage capacity

No activity this quarter

Subtask 2.1.1.4 Fluid inclusion stratigraphy

No activity this quarter

<u>Subtask 2.1.2 – Geologic Characterization of Chandeleur Sound, LA</u>

Completed picking all faults, and a second iteration of stratigraphic interpretation and surface gridding was undertaken in order to adjust some observed inconsistencies. Research on reported and pertinent foraminifera species (i.e., amoeboid protists commonly used to age-date sedimentary rocks and extrapolate environments of deposition) was begun in order to better understand the depositional environment in this area.

Subtask 2.1.3 Geologic Characterization of High Island, TX

General progress on re-processing and improving the utility of HR3D surveys

(The following work to improve HR3D surveys was conducted in conjunction with DE-FE0026083. The, results, thereof, will be available to the GoMCarb Partnership.) The Partnership has access to three HR3D (high-resolution 3D) survey datasets within the greater High Island area of interest (Figure 2.1.3.1). Internally, the datasets are informally named GOM2012, GOM2013, and GOM2014 because they were acquired in the Gulf of Mexico (GOM) in 2012, 2013 and 2014, respectively.

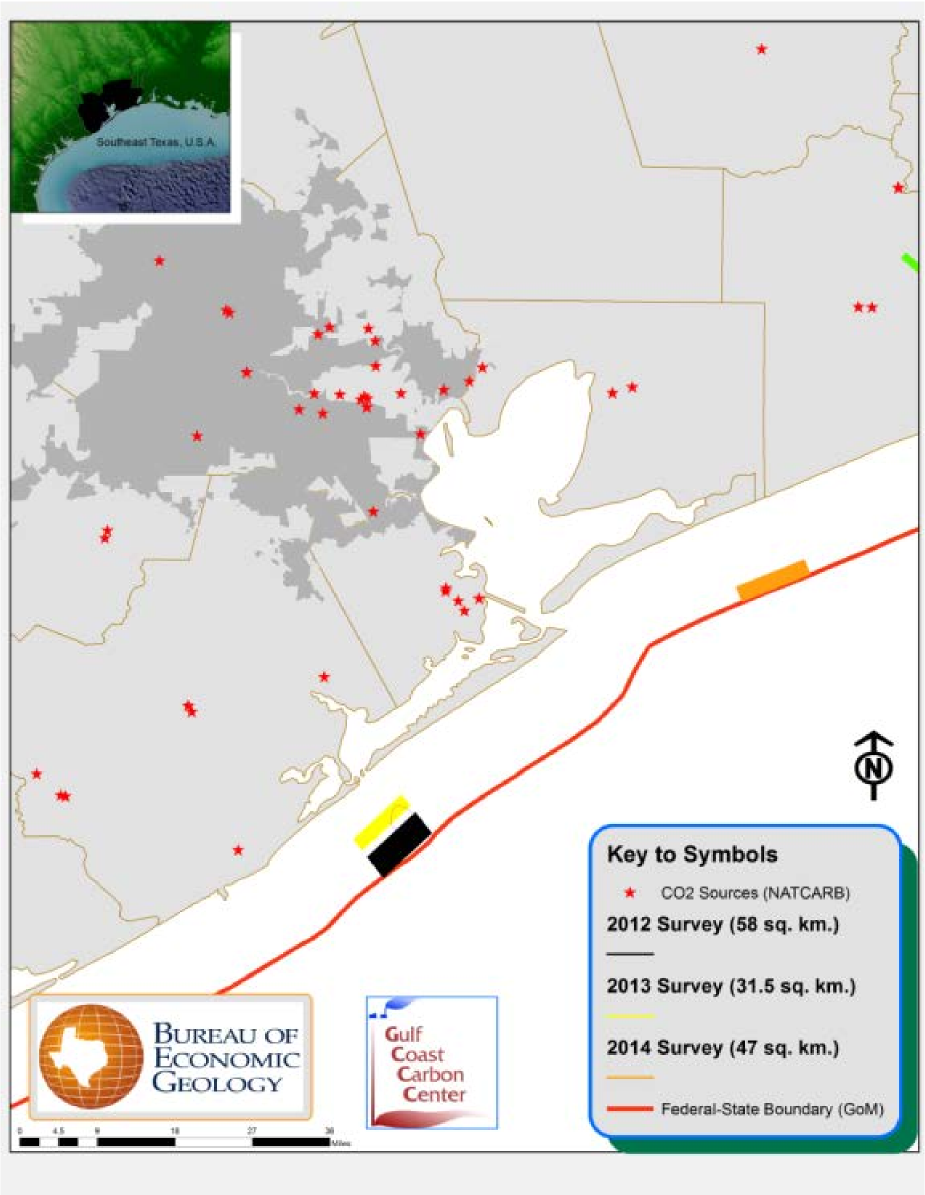

Figure 2.1.3.1 - Map of the southeast Texas coastal region showing the locations of three HR3D (P-Cable) surveys within the study area. The outline of the 2012 survey is shown in black, the 2013 survey in yellow and the 2014 survey in orange. Note the outline of the city of Houston in dark gray and the boundary (red line) between State and Federal waters.

Problems Resolved

Errors in geometry which caused missing values were fixed by changing some header values that were incorrect and re-applying the geometry. The "Shot-Receiver Relationship" was corrected using this method

Shots containing all zeros and -inf (negative infinity) values, were edited or replaced with the correct data. Some processes may have caused the data values to be distorted

Reviewed the SEGD raw data for all three surveys; also checked for missing values. GOM2013 and GOM2014 were reloaded from SEGD in preparation for final re-processing.

Noise patterns

A pattern of noise, which occurred every 11th shot as a series for spikes was discovered in the GOM2013 dataset; work is ongoing to either remove or minimize its effects on the survey.

New Techniques

There are four major innovations which produced improved results for GOM2012; some of the same techniques may be helpful for GOM2013 and GOM2104, but the latter two surveys did not have the heavy 60Hz noise (and harmonics) as GOM2012. These innovations applied to GOM2012 in steps:

1. Weiner type 60, 120 and 180Hz notch filters
2. Phase shifting filters for noise reduction
3. Positional corrections based on linear refractor and offset corrections
4. Stationary noise and minimum phase equivalent transfer function from precursor noise

Applying Weiner notch filters (Step 1) was also a new idea developed for this dataset. Ordinary notch filters function like a band pass filter except that they filter a very small range of frequencies (e.g., 60 HZ) such as was in the power systems during survey acquisition. Improperly grounded generators on an iron boat will generate a great deal of 60 Hz noise in the data. Figures 2.1.3.2 (before) and 2.1.3.3 (after) and Figures 2.1.3.4 (before) and 2.1.3.5 (after) demonstrate some of the improvements in data quality.

Weiner notch filters not only remove specific noise frequencies but also improve the "shape" of the signal. Mathematically the results should be similar for both Weiner notch and regular notch filters. But they aren't; this can be seen in time slices of the data (Figures 2.1.3.6 & 2.1.3.7).

A unique noise suppression (Step 2, phase shifting) filter was also applied. This new technique involves applying the Peacock filter [1] a numerical implementation of the integral followed by a numerical derivative, which, theoretically, restores the data to their original state. However, immediate benefits included phase changes, spectrum enhancement and random noise reductions. This is under study in a separate project but was useful in improving the GOM2012 data. Tests on GOM2013 and GOM2014 will determine if the method can be more generally applicable to HR3D data.

Trace positional uncertainties (Step 3) were further reduced using alignment of offsets with known water velocity and the survey's bottom refractor. Steps 1 and 2 were applied first to enhance the first arrivals' amplitudes for automatic picking. This is a new application of static corrections making several simple assumptions about the offset error as a static.

After the picking was successfully applied to correct the positional uncertainty, the stationary noise removal and minimum phasing (step 4) was completed. Typically, this method uses the signal recorded as input data to the algorithm for creating a minimum phase equivalent[2]. We use the precursor noise recorded prior to the air gun firing. Of course the Weiner filtering transforms the noise (60Hz etc.) to a spike near T = 0, which is not used in this technique.

Methods 1, 2 and 4 produce a better shaped spectrum, which is preferable for visually improving the data because without strong lows (near 0 Hz) the stacking, statics and velocities are much more accurate. Without the high frequency noise everything looks clearer. Compare figures 2.1.3.4 and 2.1.3.5.

3D balancing and statics were applied to GOM2012 but need further work. 3D FXY deconvolution greatly improved the quality of the data. Figure 2.1.3.7 is an example of the improved time slice; compare with figure 2.1.3.6 which also lacks the four methods described here.

A pre-stack time migration will be compared to post stack time migration. The better of these will be sent to the interpretation system and a final post stack dip steering computation will be run to see if fault/channel enhancement occurs. This volume will also be loaded to the interpretation system.

Status

GOM2012 will be finished by the end of July.

GOM2013 and GOM2014 are prepped and reloaded with geometry and quality tested. Experiments have begun to see if the same or similar techniques used in GOM2012 will produce good results in these datasets. Once the parameters are optimized the same steps will quickly follow GOM2012 to completion within the August time frame.

	Data QC	Positional Corrections	Signal Processing	3D Statics and Balancing	Migration
GOM2012	Done	Done	Done	In Progress	In Progress
GOM2013	Done	Testing	Testing		
GOM2014	Done	Testing	Testing		

GOM2012 Images

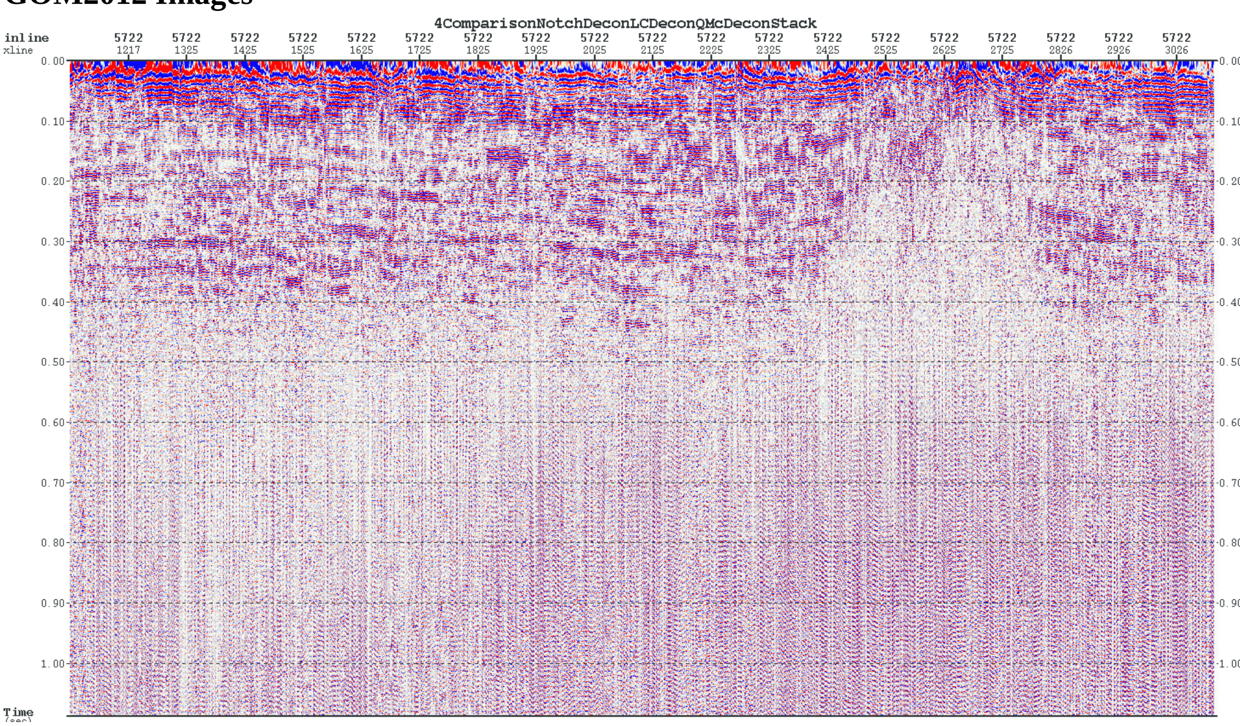

Figure 2.1.3.2- GOM2012 Inline 5722 before positional corrections or phase shifting filters (i.e., using

only notch filters and shot signature derived from the whole shot). Other processing is the same as for the data in Figure 2.1.3.3.

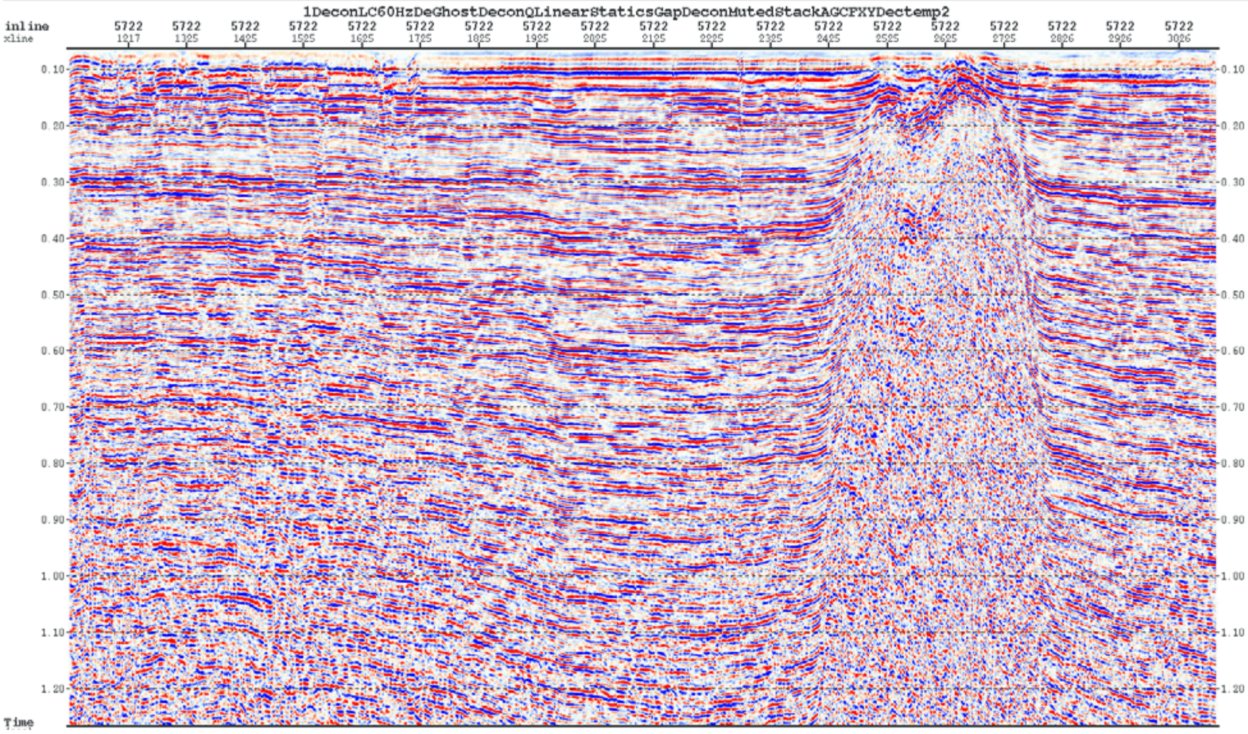

Figure 2.1.3.3- Gom2012 Inline 5722 showing increased resolution with depth, sharpened faults and salt sediment boundaries. Depth of interpretable reflections is about 1.25 seconds

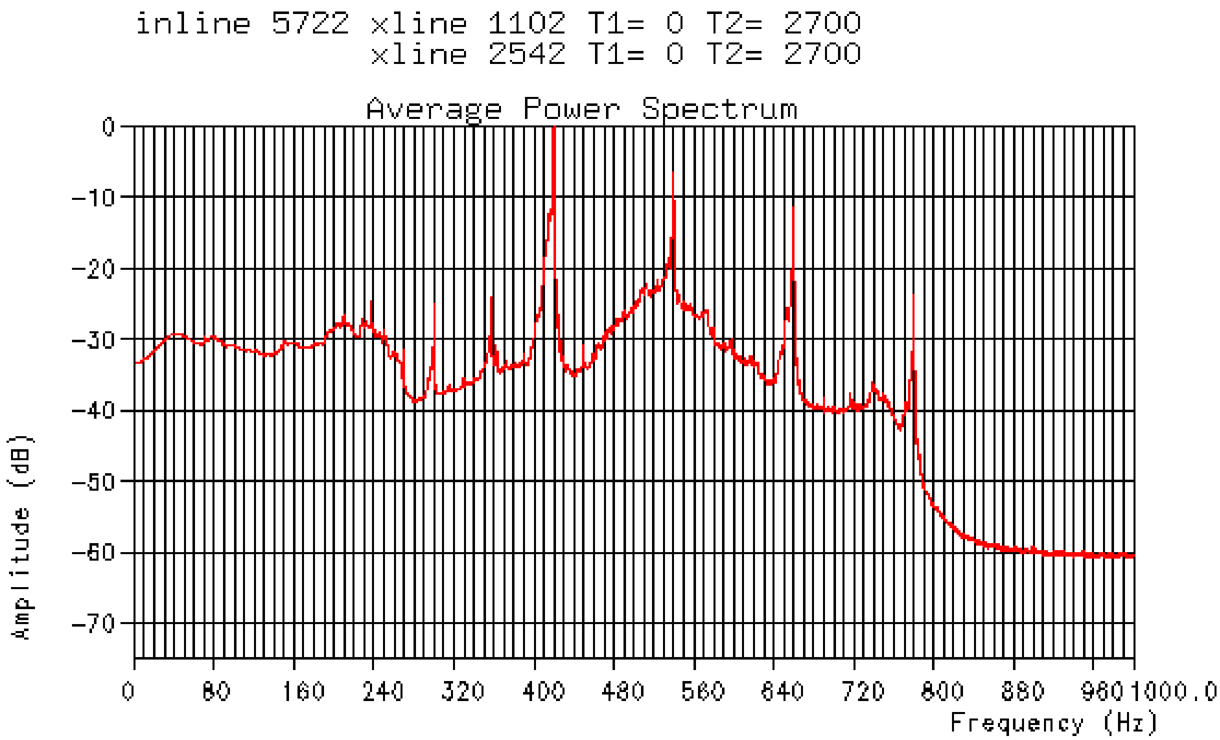

Figure 2.1.3.4- Spectrum of data in figure 2.1.3.2. High frequency noise and signal to noise ratio of 1 or less.

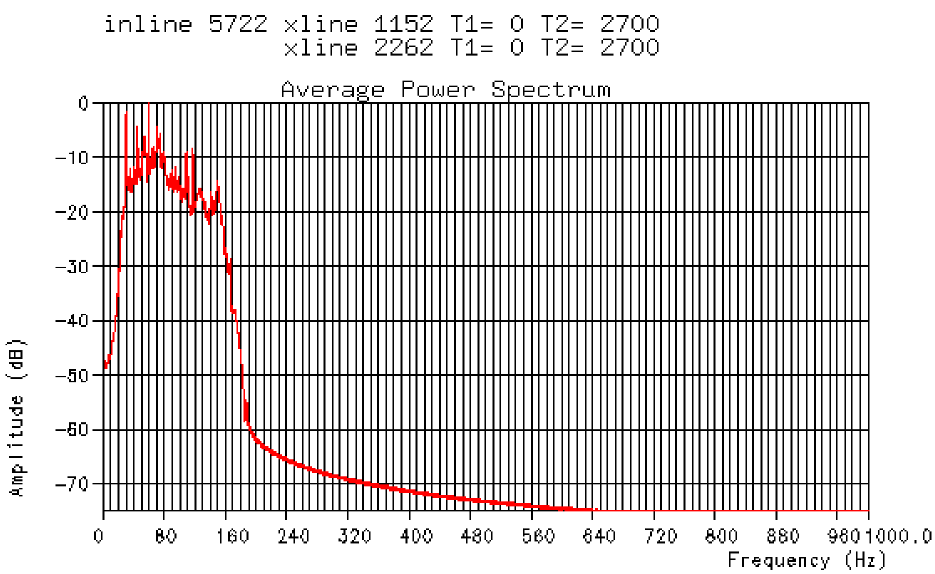

Figure 2.1.3.5- Spectrum of data in Figure 2.1.3.3. Nearly 40Db cut on the low side and 50Db on all high frequencies contribute visually to better resolution.

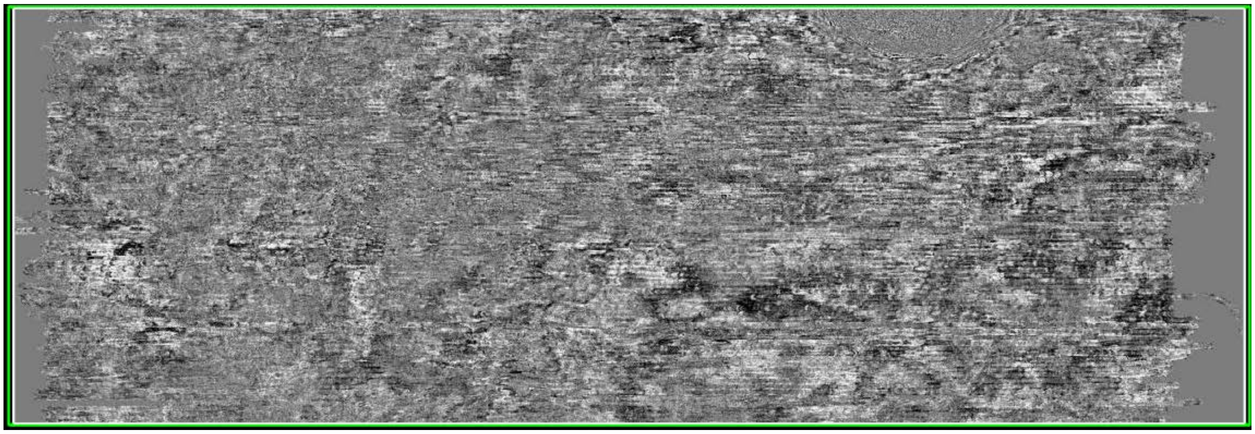

Figure 2.1.3.6- Gom2012 Time slice at 145ms. Note the complete lack of resolution versus the results of new techniques (Figure 2.1.6).

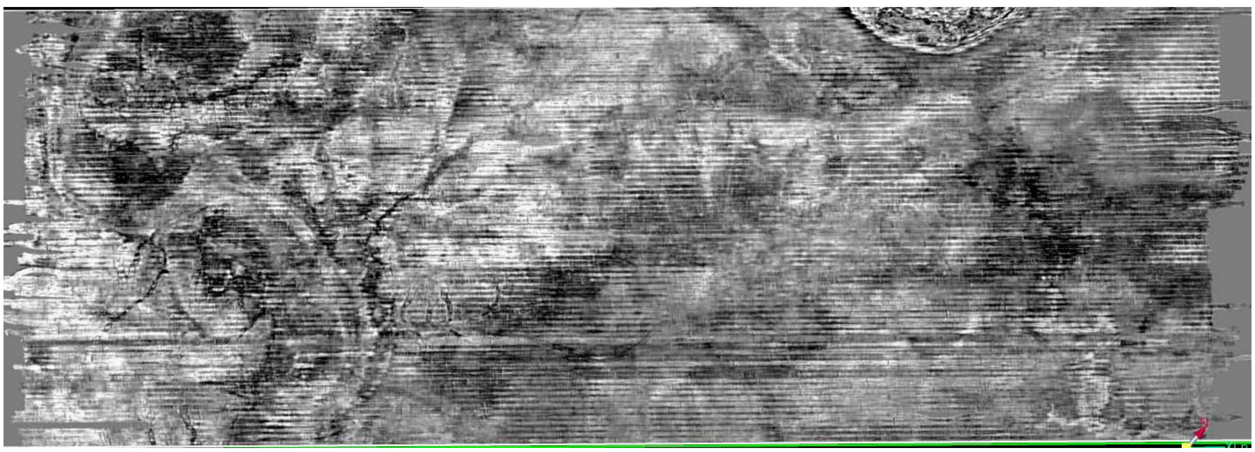

Figure 2.1.3.7- GOM2012 survey timeslice at 145 ms. Enhanced resolution of geologic features and amplitude balancing versus Figure 2.1.5. Banding along inlines is still evident but improved, it may be mitigated after migration.

References

1 Kenneth L. Peacock, (1979), "An optimum filter design for discrete integration," *GEOPHYSICS* 44: 722-729. https://doi.org/10.1190/1.1440972

2 The Wilson-Burg method of spectral factorization with application to helical Filtering
Geophysical Prospecting, 51, 409-420 (2003)
Sergey Fomel, Paul Savay, James Rickettz, and Jon F. Claerbout
https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=2ahUKEwiw0dfKnrfjAhVDVc0KHXznBDMQFjAAegQIAhAC&url=https%3A%2F%2Fpdfs.semanticscholar.org%2F9566%2Fe933da4ffe2fd19ca2e2c47a83c7ac25c1b0.pdf&usg=AOvVaw1doDWks_bofL1TfyNqlziA

The following is a summary of geologic analyses in the High Island area that were conducted under funding *from Project # DE-FE0026083, "Offshore CO2 Storage Resource Assessment of the Northern Gulf of Mexico (Texas-Louisiana)," but the analyses have relevance to the current project and quarterly report.*

Closures, fetch areas, existing fields, and faults vertical displacement

Integrated analysis was performed on structural closures, fetch areas, existing fields, and fault maximum vertical displacement within the TexLa Merge 3D seismic area. The analysis was based on MFS09 depth structure map as the structure that represents the bottom of a regional seal and the top of stacked potential reservoir strata (Figure 2.1.3.7). These reservoirs are within the MFS9 – MFS10 interval and correspond to the Lower Miocene (LM1 – LM4) and the Middle Miocene (MM1 – MM4), MM4 being the *Amphistegina B.*, based on the Atlas of Northern Gulf of Mexico Gas and Oil Reservoirs (Volume 1; Seni et al, 1997). Structural closures are mainly faulted anticlines and 3-way dip fault dependent closures (Figure 2.1.3.7). These types of closures are also described as oil and gas reservoir plays in the Seni et al atlas (1997). Each closure and its corresponding fetch area should be examined for its CO_2 storage resources potential (i.e., its integrity as a CO_2 storage site). The analyses should include the number of stacked storage strata below the regional seal, as previously reported for the 10-L site (DeAngelo et al, 2019), and the integrity of the faults, such as the relationship between maximum vertical displacement of the faults versus the sealing capacity and the juxtapositions of the sand-shale strata (Figure 2.1.3.8). The integrity of the faults, or the closures in general, may be related to the column height of existing gas fields within the TXLA area. The 24-L and 10-L sites provide ideal information for the relationship between fault integrity, juxtaposition, closures, and column height to be examined further (Figure 2.1.3.9).

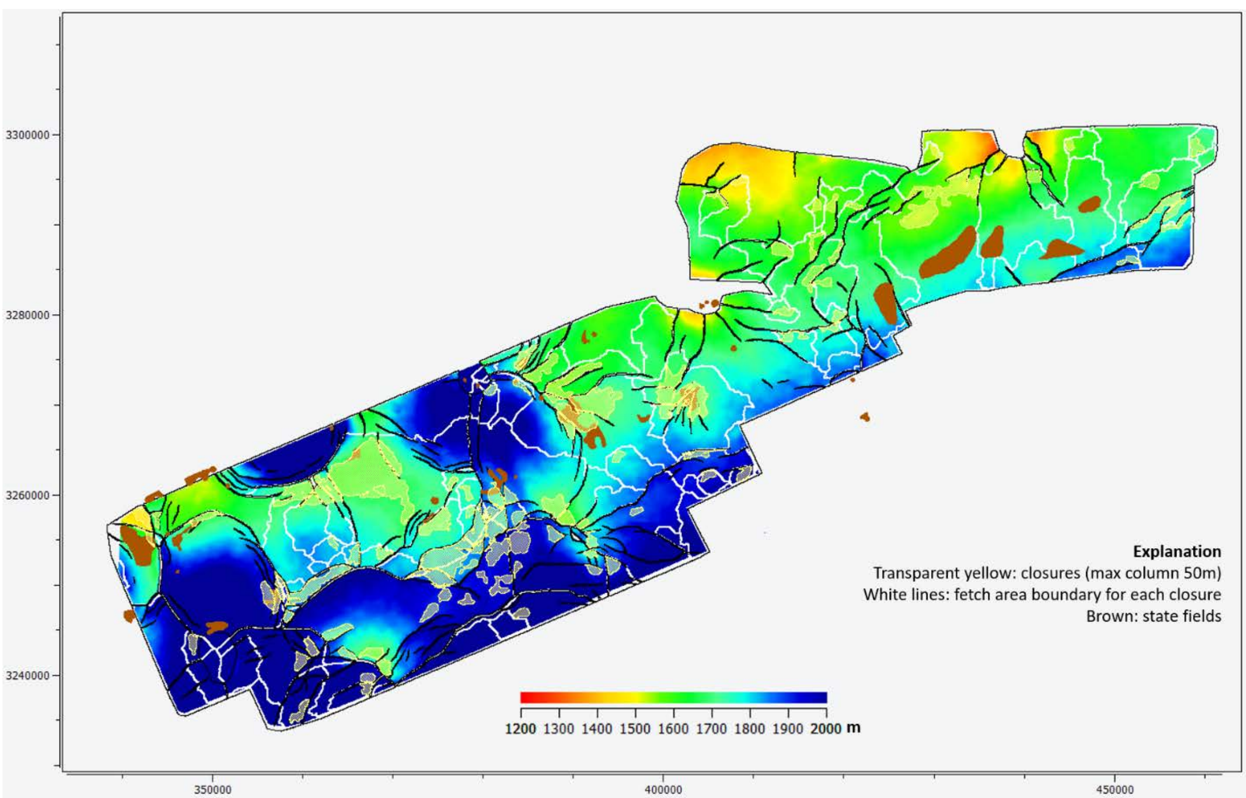

Figure 2.1.3.7 - Depth structure map of the MFS09 horizon (i.e., the base of regional seal) and the top of

stacked reservoir layers within TexLa Merge area. Transparent yellow polygons are structural closures with maximum column height of 50 meters. White lines are the fetch area boundaries for their corresponding closures. Brown polygon are existing oil and gas fields in the state waters as defined by Seni et al. (1997).

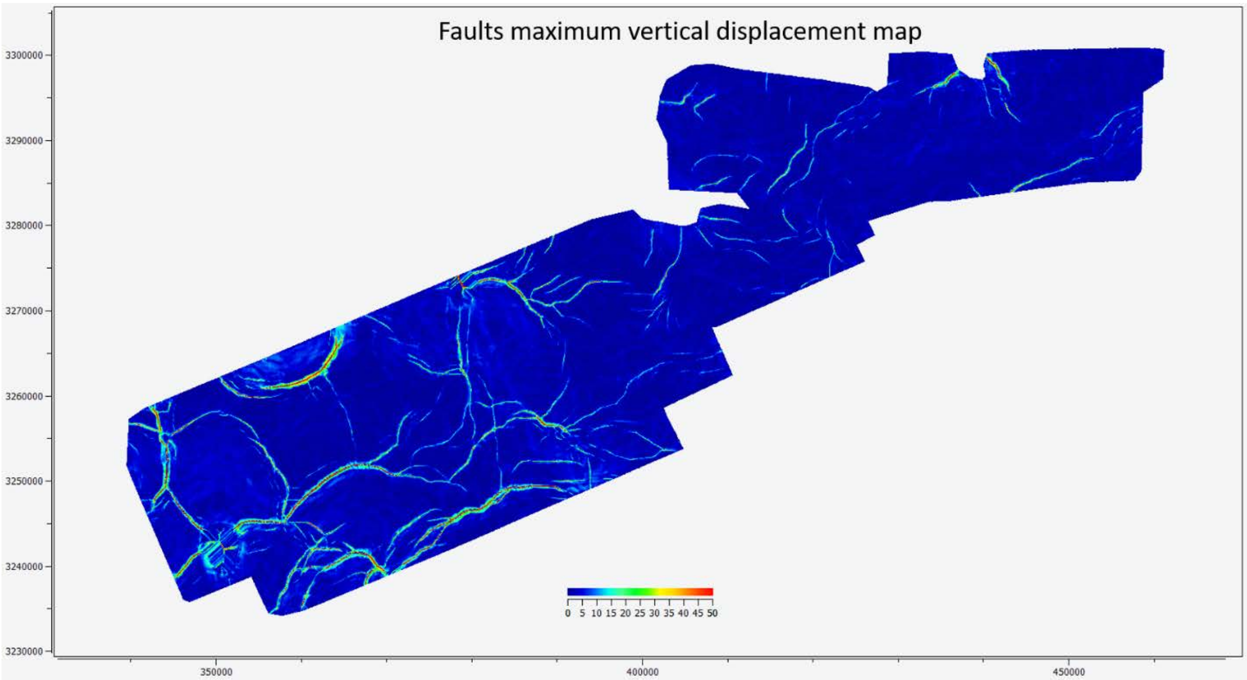

Figure 2.1.3.8 - Map of faults' maximum vertical displacements. The average displacement is approximately 20 meters; however, some major faults are much more than 50 meters. The scale is set to maximum 50-meter displacement (red) to better show the distribution.

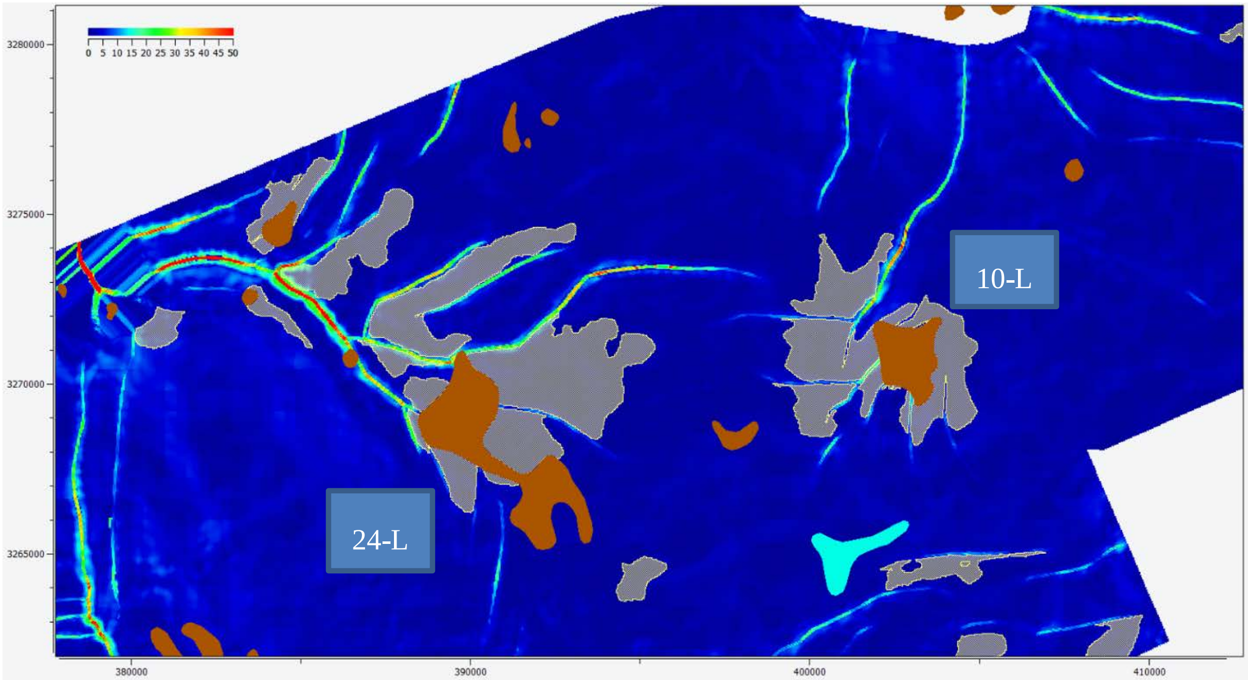

Figure 2.1.3.9 - Closures (grey), existing field outlines (brown) as defined by Seni et al, (1997) without the benefit of 3D seismic data, and faults' maximum vertical displacements around the 24-L and 10-L sites.

Validation to porosity prediction using depositional systems and sequence stratigraphic interpretation

Porosity prediction using multi-attribute analysis with limited well-log data was reported in the previous quarterly report. Two methods were used, porosity derived from 1) linear regression and 2) PNN (Probabilistic Neural Network). In order to validate the porosity prediction, it was compared to the depositional systems and sequence stratigraphic interpretation of the studied area. Non-linear PNN porosity was then chosen as the preferred predicted porosity volume due to its high-degree of agreement with the geologic interpretation.

Depositional systems interpretation

The interval of interest between MFS09-MFS10 is interpreted as a potential CO_2 storage interval due its comprising aggradational sandstones of as much as 750 m overlain by the thick, regionally extensive Amph-B shale (DeAngelo et al, 2019). Advanced seismic interpretation using stratal slices on seismic attributes was performed in order to improve subsurface imaging of geomorphic features to better understand the depositional systems of this interval (MFS09-MFS10), which is crucial in characterizing reservoirs in term of the distribution, connectivity, and quality.

The RMS amplitude map has been widely used to represent geologic features with regards to their lithofacies variation (DeAngelo et al., 2019). In this study, we performed interpretation of depositional systems based on RMS amplitude map of the horizon SS01 located in the middle of the interval MFS09-MFS10 (Figure 2.1.3.11). The predicted porosity volume was compared to the equivalent map of RMS amplitude and evaluated using the interpretation from the RMS amplitude map. The SS01 horizon extracted from both linear and PNN porosity volumes centered at 51 ms window (Figure 2.1.3.10 A & B), and the RMS amplitude map of SS01 horizon using the same window length of 51 ms (Figure 2.1.3.10 C).

The RMS amplitude map of this horizon shows prominent channel belts with relatively N-S orientation (darker brown on figure 2.1.3.10 C and dashed lines on figure 2.1.3.10 D). The channel belts have widths of 2 – 5 km and comprise smaller, individual, sinuous, meandering, fluvio-deltaic channels. Channels or channel belt features in the RMS amplitude map exhibit low-amplitude, sub-parallel-chaotic seismic facies in the channel versus high-amplitude parallel seismic facies in the adjacent non-channel areas. Normal faults shown by the RMS amplitude map are interpreted as post-depositional. Low RMS amplitude values represent both channels and faults (Figure 2.1.3.10 C & D) but are easily distinguishable from each other because faults are much narrower than the channel belts.

Sequence stratigraphic interpretation

Gamma ray log patterns (Figure 2.1.3.11) of the interval of interest were utilized in order to validate the seismic-based geomorphic features shown in RMS amplitude map (Figure 2.1.3.10 C). Figure 2.1.3.11 shows the sequence stratigraphic interpretation of the interval of interest. The interval above MFS10 is interpreted as Highstand Systems Tract (HST), which is characterized by progradational followed by aggradational stacking pattern of parasquence sets. The SS01 horizon, on which the geomorphic interpretation was performed, is interpreted as, or around, a sequence boundary (SB). The interval above this horizon is interpreted as Lowstand Systems Tract (LST) in the lower part, and mostly Transgressive Systems Tract (TST) in the upper part. This interval is dominated by retrogradational followed by aggradational stacking pattern of parasequence sets. This sequence stratigraphic interpretation suggests that the channels were formed during, or shortly after, a period of relative sea-level fall (LST), in which they cut through non-channelized inner shelf deposits. This supports the interpretation that the horizon with channels is only observed in the middle of the interval between MFS09 and MFS10.

Proprietary Data Redacted

Figure 2.1.3.10 – A) Linear multi-attribute derived porosity map of horizon SS01; B) Non-linear PNN derived porosity of horizon SS01; C) RMS amplitude map of horizon SS01 shows seismic geomorphic depositional features (channel belts). The channel belts were also observed in the porosity maps. The agreement between porosity maps and RMS amplitude map have increased our confidence level of the porosity prediction; D) Interpretation of depositional features and faults based on RMS amplitude map of horizon SS01. Channel belts' orientations follow regional trend of deposition towards south – southeast. Faults are mostly post-depositional. Circular features are salt-related post-depositional elements.

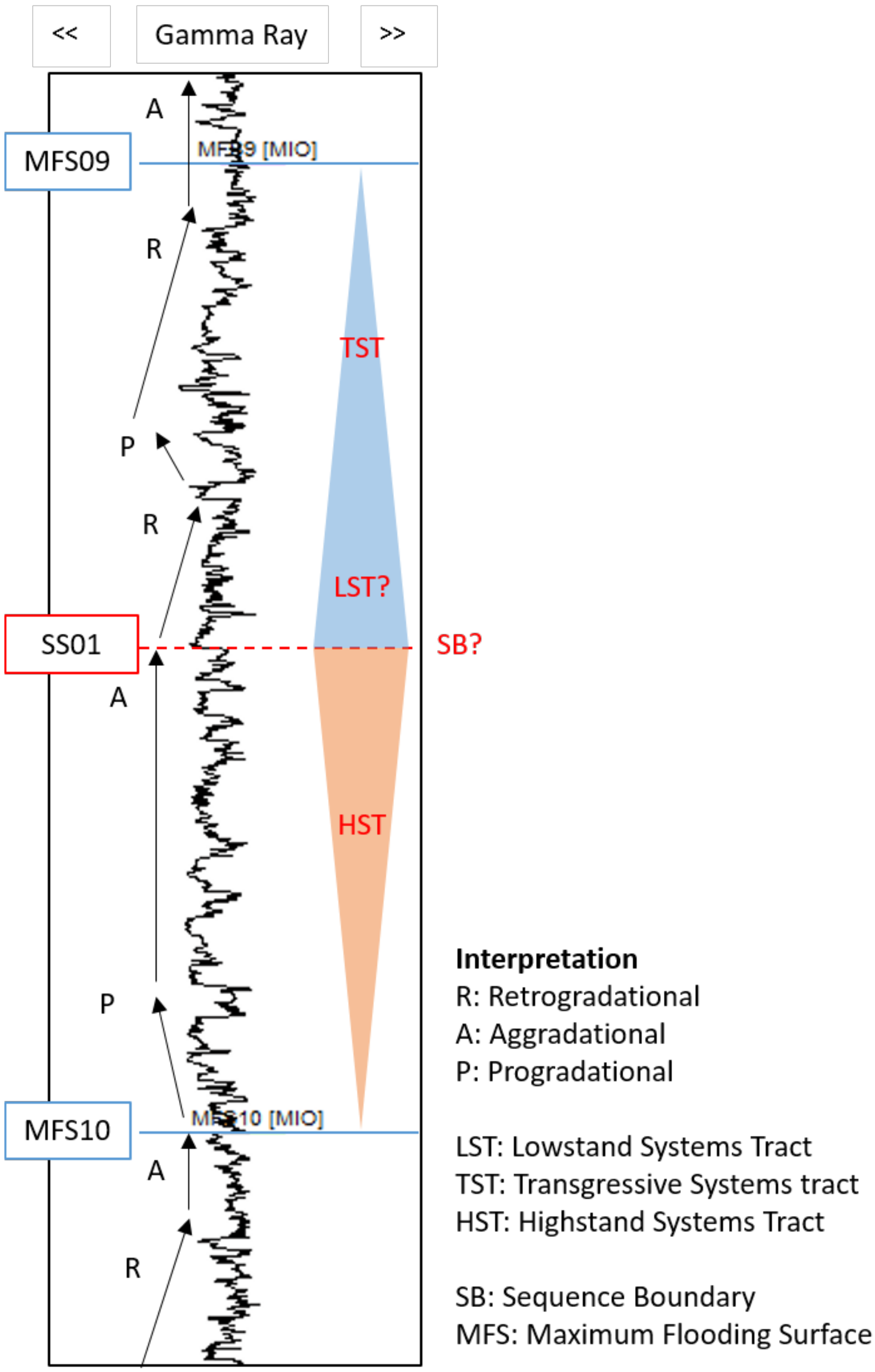

Figure 2.1.3.11 – Sequence stratigraphic interpretation of Gamma ray log around the MFS09-MFS10 interval. The SS01 is interpreted to coincide with the sequence boundary between MFS09 and MFS10. This supports the development of channelized fluvio-deltaic systems between non-channelized inner shelf deposits below-and-above the SS01 level.

Reference

Seni, S. J., T. F. Hentz, W. R. Kaiser, and E. G. Wermund Jr., 1997, Atlas of Northern Gulf of Mexico Gas and Oil Reservoirs: Miocene and Older Reservoirs, v. 1: Austin, Texas, The University of Texas at Austin, Bureau of Economic Geology, 199 p.

Subtask 2.2 – Data Gap Assessment

No activity this quarter

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)

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

LBNL (Lawrence Berkeley National Laboratory) reports, "because the Sintef water-column transport code identified in Q2FY19 could not be shared with the GoMCarb project, we continued to search for water-column CO_2 modeling capability and found an open-source code called TAMOC, the Texas A&M Oilspill Calculator. We downloaded and installed and ran TAMOC on test problems. We reviewed multiple papers related to the theory behind TAMOC and ran the code for various cases to understand how it works. We interacted with TAMOC developer and expert, Scott Socolofsky and Jonas Gros, respectively, who answered questions and assisted with preliminary runs. We made figures of the 24L and 10L sites and determined the water column depth is approximately 10 m (Fig. 1). Based on this information, we carried out an additional blowout simulation with T2Well for a water column depth of 10 m. The CO_2 blowout emission transitions from a jet to a buoyant plume during its rise through the water column and we are in the process of understanding whether this transition will occur in the shallow (10 m water depth) near-offshore region at the 24L and 10L locations."

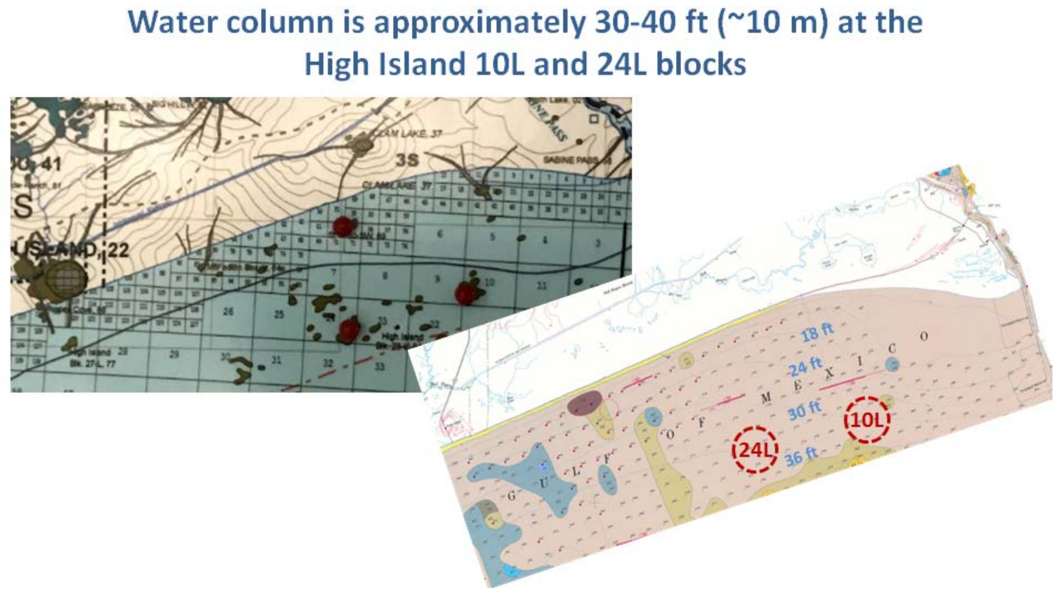

Figure 3.1.1 - Maps of hydrocarbon lease blocks and bathymetry in the near off-shore Texas Gulf Coast between High Island and Sabine Pass show water depth is approximately 10 m at the 10L and 24L blocks.

<u>Subtask 3.1.2 Extend geomechanical assessment to additional areas of the basin</u>

No activity this quarter.

<u>Subtask 3.1.3 Dissolution and bubbling in water column</u>

See subtask 3.1.1.

<u>Subtask 3.1.4 Numerical modeling of heterogeneous reservoirs</u>

LBNL finalized the field observations of multiscale and multipath channeling of CO_2 flow in the hierarchical fluvial sedimentary storage formation at the Cranfield, MS site. The three-scale channeling of CO_2 flow includes (1) a large-scale fluvial channel imaged by time-lapse 3-D seismic surveys, (2) small-scale channels in the cross section between the two monitoring wells imaged by daily ERT images and 2-D cross-well seismic surveys, and (3) 2-3 intermediate-scale channels normal to the cross section and connected with the large-scale channel. In addition, the dynamic processes of invasion, lateral spreading, and breakthrough of supercritical CO_2 were also observed in the Massive Sand of the Late Cretaceous Lower Tuscaloosa Formation at the site, and these processes were related CO_2 trapping. The field behavior of CO_2 migration and trapping is relevant to any heterogeneous storage site, potentially like GoMCarb sites because better understanding of the field processes will support accurate modeling CO_2-brine flow in heterogeneous reservoir formations.

Subtask 3.2 – Geologic Modeling

We have continued work on generating a simulation grid and property model for the High Island (HI) 24L site. It has proven more challenging than expected to generate a grid that smoothly conforms to the complex fault geometry at the site in a way suitable for geomechanical simulations (i.e. without the stair-stepping common to corner point meshes). The partially penetrating faults at the HI site are particularly difficult to address. We have found that good quality unstructured meshes (Figure 3.1.2.1) require very high resolution to capture both the fault geometry and fine-level vertical heterogeneity. We are now exploring alternative methods to generate these meshes. If no good alternatives are found next quarter, we will proceed with our good-but-very-high-resolution meshes and simply accept the computational cost. We do not want meshing challenges to be a bottleneck to further progress on the key geomechanical questions.

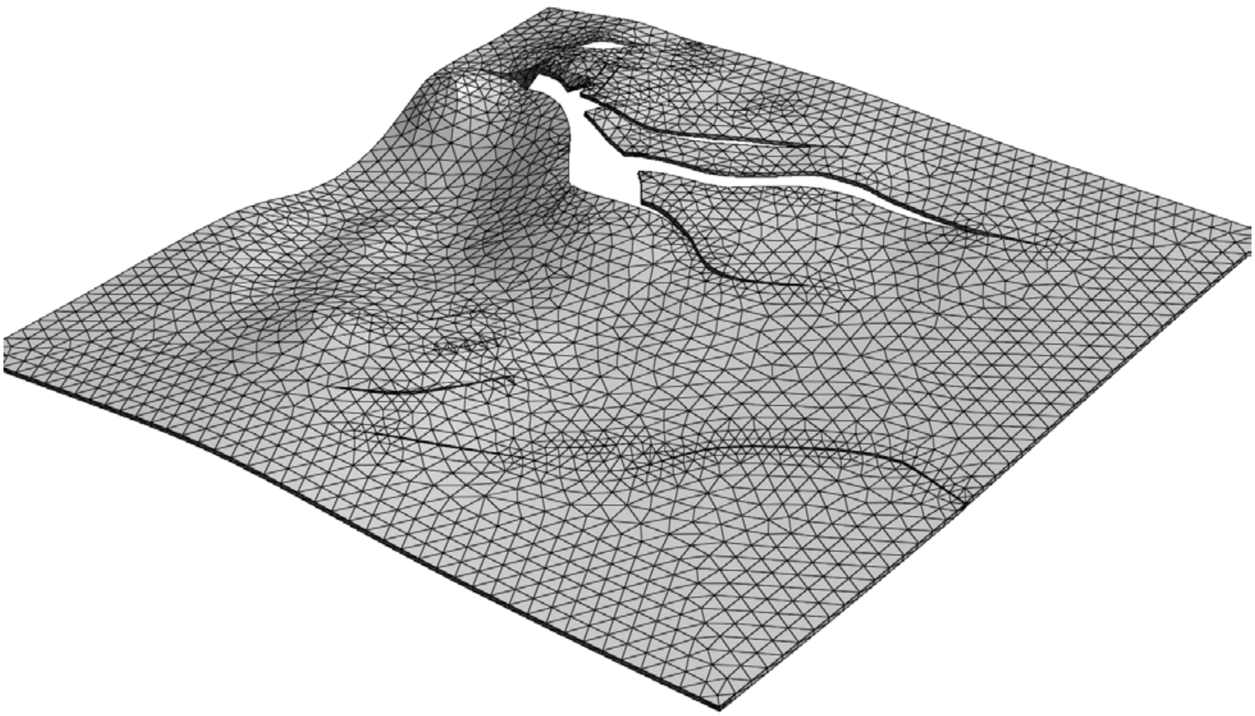

Figure 3.1.2.1 – Simulation mesh generated from static geological model of the High Island 24L Field.

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

During Q2 FY19, research in the MVA effort continued to evaluate the potential of marine DAS (distributed acoustic sensing) for GCS (geological carbon sequestration) monitoring. We were exploring data extraction and processing approaches using a seafloor passive DAS dataset acquired off the northern California coast in 2018. A central focus of the last several months has been investigating passive imaging approaches that might be useful in this context, in the absence of controlled seismic sources in the water column or on the seabed. Using several regional earthquakes, we tested an autocorrelation-based reflection imaging algorithm which used EQ multiples recorded by DAS to generate a low-fold seismic image. Preliminary results from this approach seem promising and a section of the profile previously identified as a fault zone from boomer surveys was imaged. In the next quarter, we anticipate refining this approach as well as continuing design of a controlled source for continuous DAS imaging in the water column and near-seafloor sediment.

Another task we continued working on was identification of existing offshore fiber optic cables that might provide a location for a GoM test of these methodologies. Several candidate cables were found and we have initiated on-going discussions with owners regarding access for sensing applications.

Subtask 4.1.5 Pipeline MVA

Co-PI, Dr. Daniel Chen, (Project Partner Lamar University) worked on literature survey for CO_2 Pipeline Design and Monitoring Technologies for Large-Scale CO_2 Storage Projects. The details of this literature survey are as follows:

Abstract

Carbon Capture and Storage (CCS) has been gaining attention over the past few years as a crucial strategy for meeting CO_2 emission reduction targets from industrial sources. Safe transportation of CO_2 through pipelines to prevent any CO_2 releases is of utmost importance. Various available technologies and upcoming modeling methods for CO_2 pipeline design and monitoring have been discussed in this literature survey. In this review, challenges that pose a threat to the deployment of CO_2 pipeline transport and the latest research and modeling efforts in this regard are presented. Validated CFD /ANN and analytical modeling studies on factors that need to be considered at the early stages of the project such as the effect of depressurization during CO_2 releases, presence of impurities, corrosion/ fracturing/ material selection of the pipelines, the effect of terrain on CO_2 dense phase properties, and the acceptable water content in liquefied CO_2 are reviewed.

Introduction

High-pressure CO_2 derived from carbon capture and sequestration (CCS) technology can be transported by pipelines before being injected into a reservoir for Enhanced Oil Recovery (EOR) or being used as a raw material for chemical feed stock of urea, soda ash, and polycarbonates. Transport of CO_2 through pipes allows a large amount of CO_2 from multiple sources to be transported long distances and comparatively cheaper with respect to other modes of transport such as via a barge and truck. However, despite all the benefits, there are challenges associated with pipeline transport of CO_2 that need attention for a successful CCS project. The biggest challenges of CO_2 pipeline transport are associated with flow assurance, cost, overall integrity, and health, safety and other environmental factors.

Objectives and Scope

CO_2 transport by pipeline is being done in the USA for over 30 years. Various available technologies and upcoming modeling methods for CO_2 pipeline design, monitoring, and risk assessment are discussed in this literature survey. Up-to-date CO_2 pipeline monitoring and risk assessment technologies to minimize the hazards associated with accidental CO_2 releases CO_2 pipeline construction for CO_2 storage purposes are reviewed.

LITERATURE SURVEY ON CO_2 PIPELINE DESIGN & OPERATION BASICS

Effect of impurities

CO_2 streams that have impurities may face more challenges when compared to pure CO_2 streams. Issues like pipeline pressure, re-pressurization intervals, and pipeline integrity need to be considered when transporting CO_2 with above-specification impurities. This applies to all modes of transport across a variety of terrains regardless of the CO_2 phases (gaseous, liquid, or supercritical) [1-4]. Various CO2 emission sources and capture technologies will inevitably produce different levels of impurities present in CO_2 streams. Skaugen et al. [5] show it costs roughly 20–40% more when transporting impure CO_2 in comparison to pure CO_2 in a pipeline. In another study done by Neele et al. [6] in IMPACTS project, it was concluded that it is more economical to remove CO_2 impurities at capture rather than to deal with the downstream problems later on. Further, models that are capable of predicting thermophysical properties of CO_2 with impurities need to be emphasized in CCS projects. Water is the most significant impurity to be removed as an above-specification water level in the CO_2 stream can cause many problems in pipelines such as corrosion or hydrate formation [7]. H_2O content should be controlled to below 350 ppm to prevent corrosion, below 250 ppm to avoid hydrates, and below 100 ppm. Further, if there is significant (>1000 ppm) moisture in the pipeline/injection systems, H_2 levels need to be controlled below 100 ppm to prevent brittle fracture. Likewise, H_2S levels need to be kept below 100 ppm to guard against corrosion [6,8]. Some trace compounds require more compression while some need higher strength to the pipeline to resist ductility issues [9,10]. There has been significant work performed on the effect of each impurity on the critical point of CO_2 , pipeline sizing, re-pressurization distances, etc. It has been found that the presence of impurities such as CH_4, N_2, H_2O and amines in the CO_2 stream affects the solubility of H_2O [11,12].

Pipeline Design considerations

Pipelines in the USA are divided into relatively small sections to reduce the blowdown and refilling times and limit the risk to the public in case of leaks. For a safe and cost-effective design of CO_2 transport, it is important to understand transient behavior such as start-up, shutdown, etc. [6]. Severe pressure/temperature drops can be seen during depressurization. In a study conducted by Huh et al, both experiment and simulation of the transient behavior of CO_2 pipeline transportation were conducted [5-7,13]. It was found that the behavior of dense phase CO_2 can be very sensitive to steep elevations and impurities. Pipeline sizing, distance before depressurization, number of pumps, and sizes and energy requirements of pumping or compressor stations need to be thoroughly investigated while designing [14–18]. Consideration to corrosion problem that may arise from low pH and use of corrosion inhibitors to keep the pipeline integrity and to extend useful life are important to control annual operating costs [19-22]. Though options such as the use of corrosion inhibitors, pre-drying, or improved pipeline material selection are available, a better approach should be to operate CO_2 pipelines under such conditions that the free water phase does not exist [23,24]. To avoid pipeline failure due to fracture propagation, use of fracture arrestors, selection of pipeline materials, or determination of operating conditions can be conducted in the design stage to prevent such failures.

Total annual cost can be estimated with rigorous modeling and simulation of CO_2 transport via pipelines [25]. Since the concentration and species of the impurities can vary widely, actual stream composition needs to be provided to accurately model CO_2 properties such as density, viscosity, critical constants, and phase behavior [26, 27, 28, 29].

Modeling of CO_2 pipelines

In a review by Peletiri et al. [29] on CO_2 pipeline design, it was found that most models ignored the effects of impurities while in practicality the properties (density, viscosity, and critical constants) are all changed by the presence of impurities [30]. Pressure drop due to velocity change as well as the impact of density and viscosity change (due to impurities) on the pipeline diameter and pressure drop are mostly ignored [29]. To design an efficient CO_2 transport pipeline network and to control operating costs, factors including material roughness, pipe diameter, CO_2 flow rate, pressure drop per unit length, viscosity/density of the fluid, differences in topography, as well as the environment temperature need to be considered [31, 32, 33]. In addition, the distance between the CO_2 source and storage site, network topology, and CO_2 transportation mode must be carefully studied [34-36].

Literature Survey on CO_2 Pipeline Monitoring Technologies

Atmospheric CO_2 sensors have been used to detect a slight increases in CO_2 in the atmosphere due to pipeline leaks and to provide an alarm system for CO_2 pipeline leaks in the Netherlands [37]. A sensor-based autonomous pipeline monitoring system (SPAMMS) has been proposed by Kim et al. [38]. SPAMMS consists of mobile sensors, fixed sensors, radio-frequency identification (RFID) technology, and autonomous robots that can detect the type/ location of faults early on and take corrective actions in a timely and cost-effective manner.

Summary and Conclusions

This review has presented the major issues and identified knowledge gaps related to CO_2 transport design and monitoring. Methods to assess the growth rate of a crack during its lifetime to schedule timely maintenance, root causes that challenge the deployment of CO_2 pipeline transport such as threats to marine wildlife and populated urban areas, and validated computational fluid dynamics (CFD), artificial neural network (ANN), and analytical modeling studies have been covered. It was found that commercial deployment of carbon capture and sequestration (CCS) pipelines makes it crucial to evaluate the economics of CO_2 transport, especially the issue of pipeline over-specification because of expected future use.

There exist needs for good computational fluid dynamics (CFD), artificial neural network (ANN), and analytical models that incorporate the right equation of state to account for factors that are important at the early design stage such as gaseous, liquid, or supercritical CO_2 behavior, interaction with ocean water, pipeline material resistance to corrosion in the presence of impurities (water, H_2, etc.), the effect of terrain/ocean depth or pressure on CO_2 dense phase properties, acceptable water content in liquefied CO_2, and pipeline fracture mitigation measures. Recommendations for the deployment of monitoring devices and design/modeling technologies are made for the future construction of sub-sea and on-land CO_2 pipelines for storage of CO_2 in onshore/offshore storage sites.

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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

Subtask 5.1: CO_2 Transport and Delivery

Subtask 5.1.1 Data assessment near-shore sites…initially in the High Island area

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 a screening tool 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 assets in the High Island Large Block 10 region as a test case. 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.

The work accomplished by Trimeric in support of Subtask 5.1 is described herein. The discussion is organized by infrastructure type: wells, pipelines, and platforms. The following sources of information on the HI-10L assets were reviewed: The Railroad Commission of Texas's GIS database for pipeline and well information [Railroad Commission of Texas 2019a], and data reports from a UT database of well information [Prentice 2019a]. Trimeric has not yet identified a database that addresses production platform infrastructure for HI-10L.

Wells

HI-10L has 41 wells according to the UT database, while only 33 wells appear in the RRC database. It is unclear whether each of the 33 wells in the RRC database is within the subset of the UT database; there was not a direct one-to-one correspondence for API numbers for some of the wells. Regardless, data from both databases were useful for a preliminary screening of wells as candidates for re-use for CO_2 injection. The following well properties were evaluated for the HI-10L wells:

- **Date of well construction:** Fourteen wells constructed pre-1970 were excluded from consideration, per guidance from an industry expert that these older wells would not meet modern construction standards [Interview 2019].
- **Presence of full API number:** Wells without a full API number (11 of them in the RRC database) were excluded from consideration. Based on an email from the RRC [RRC Mapping 2019[, it appears these wells are old enough to not have been given a full API number, with records only available in hard copy at a RRC office.
- **Well status (active, dry, plugged):** There do not appear to be any active wells in HI-10L. Per the RRC database, there were 12 dry holes in HI-10L, with the remainder of wells being oil and/or gas producing wells that have been plugged. Both dry holes and plugged oil and/or gas wells are currently considered by Trimeric as potentially viable infrastructure for re-use.
- **Total vertical depth:** Trimeric needs to work with the project team to determine how to use well depth as a screening criterion. Total vertical depths of wells in HI-10L range from 5,800 to 14,000 ft. The deepest of these wells are deeper than the depths to which CO_2 injection has been demonstrated [Prentice 2019b]. Also, deeper wells will be more expensive for CO_2 injection than shallower wells.
- **Perforation length:** In HI-10L, perforation lengths averaged 20 feet, with a range of 3 to 200 feet. In general, perforation lengths will need to be greater for CO_2 injection than for oil/gas production wells in order to have sufficient throughput of CO_2 [Prentice 2019b].

- **Casing diameter:** Casing diameters ranged from 5.5” to 10.8” for HI-10L wells. Trimeric is not currently using casing diameter as a screening parameter.
- **Wellbore integrity:** Wellbore integrity, for both the injection well as well as for other wells within the reservoir, is important for ensuring that injected CO_2 stays within the intended formation. The *potential* for leakage could be indicated by factors such as age of well, applicable regulations, the well abandonment method, well completion activities, cement, and well type [Glazewski 2016]. As these factors are simply indicators for potential leakage and since well integrity issues can be remediated, Trimeric does not intend to use these factors (other than age of well, as described previously) in the preliminary screening of wells. For wells that merit more consideration for a particular project, a review of records would provide some indication of the condition of the well. Even with that records review, a wellbore evaluation would be required to assess the downhole status, including formation characteristics, casing condition, cement location, and joint locations.
- **Number of wells in reservoir:** Trimeric does not necessarily intend to use a screening criterion based on the number of wells in the reservoir; however, this parameter may be useful for a relative ranking of potentially viable storage locations. The greater the number of wells in a reservoir, the greater the risk of CO_2 leakage from the reservoir and the greater the upfront cost for ensuring the integrity of existing wells in the reservoir.
- **Wellhead construction:** Wellhead construction is not a planned screening criterion. Best practice is to use new well-heads with materials (alloys and elastomers) and pressure ratings suitable for CO_2 service.

Pipelines

According to the RRC database, there are two pipelines that pass through HI-10L and terminate on shore. Both pipeline permits are “orphaned”, as indicated by the presence of an initial “9” in the T-4 permit number; this does not necessarily mean that the pipeline itself is “orphaned” or not operating. An RRC employee indicated to Trimeric that a common situation resulting in an orphaned pipeline permit is when the pipeline is sold and the new owner does not file permits with the RRC [Waterman 2019]. As these two HI-10L pipelines are interstate assets that are not regulated by the Texas RRC, the new owner may file permits with RRC as a courtesy but the owner is not required to file permits with RRC. Instead, these pipelines fall under the jurisdiction of the Pipeline and Hazardous Materials Safety Administration (PHMSA). Trimeric will attempt to find more information on these pipelines through a search of online materials available through PHMSA. The RRC employee indicated that the RRC database is typically accurate in terms of its representation of existing pipeline assets; owners want their asset locations disclosed to protect them from accidental physical intrusion.

Natural gas pipelines are possible candidates for re-purposing for CO_2 service. The following criteria could be useful in assessing the suitability of a pipeline for re-use for CO_2 transport:

- **Carbon steel construction**: Dehydrated CO_2 with sufficient impurity (i.e., H_2S and O_2) removal can be transported in carbon steel pipes.
- **ANSI Class**: ANSI Class 900 construction is preferred as it provides flexibility for longer transportation distances with fewer booster stations; however, natural gas pipelines are unlikely to be Class 900 (working pressure of 2,220 psig at 100°F) as natural gas can be transported at lower pressure than CO_2. Class 600 (working pressure 1,480 psig at 100°F) construction is more common for natural gas pipelines, and would be the minimum class required to accommodate

supercritical CO_2 pressures (> 1056 psig) or pressures of dense liquid CO_2 (saturation pressure of 850 psi at 70°F). However, the lower pressure rating may limit the scenarios in which re-use of Class 600 pipelines is economical for CO_2 service. To transport CO_2 in Class 600 pipelines over long distances would require more frequent booster stations to overcome frictional losses while keeping the fluid below the pipe's pressure rating.

- **Pipe diameter**: Larger diameter pipe is preferred to reduce frictional losses, thereby improving the economics of using Class 600 pipelines over longer distances.
- **Pipeline distance**: Shorter pipeline distances are preferred to reduce frictional losses, thereby improving the economics of using Class 600 pipelines by reducing the number of required booster stations.

Production Platforms

Trimeric has not yet identified a database that addresses production platform infrastructure in HI-10L. The following criteria may be useful in screening production platforms for re-use:

- **Age of platform:** Platforms are designed for typical lifespan of 20 to 30 years [Chakrabarti 2005].
- **Structure is idle, has been converted to auxiliary asset, or is nearing end of production life**: Production platforms are expected to be decommissioned no later than five years after the platform became idle [BSEE 2019]
- **Platform type:** Fixed platforms have an economic driver to re-purpose for CO_2 injection in order to postpone decommissioning costs, while floating platforms can be deployed at other producing wells.
- **Available space on platform:** Platform details are unlikely to be available for a preliminary screening effort. Space on the platform may be needed for a CO_2 pump, if a pressure boost is required; for a workover rig to modify and repair existing well; for a new slot if a new well is to be drilled. Space could be made available if other equipment on the platform is no longer needed.

Subtask 5.1.2 Evaluate feasibility of subsea template in GoM

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

Lamar University conducted a literature survey of CO_2 pipeline monitoring and risk assessment technologies for large-scale CO_2 storage projects.

Results, Observations, Conclusions

The biggest challenges of CO_2 pipeline transport are associated with the flow assurance, cost, overall integrity, and health, safety and environmental factors (HSE). The root causes that pose a threat to the deployment of CO_2 pipeline transport were reviewed and the latest research, development, and modeling efforts are presented. Presence of impurities, consideration of corrosion at the early stages, the effect of terrain on CO_2 dense phase properties, acceptable water content in liquefied CO2 are some of the factors that need to be considered and the data gaps were identified. To achieve safe and cost-effective design of CO_2 transport, understanding of the thermodynamics of the CO_2 impurities corrosion mechanism is important to avoid the formation of free water in the pipeline. Pipeline fracture mitigation measures such as the use of fracture arrestors placed at regular intervals, the selection of appropriate pipeline materials, and operating conditions which are less likely to lead to such failures are discussed. A novel and cost-effective sensor based autonomous monitoring system, SPAMMS, is of considerable interest. Methods to assess the growth rate of a crack during its lifetime in order to schedule timely maintenance are covered. Validated CFD modeling studies to describe depressurization behavior of CO_2 pipelines, CO_2 discharge and dispersion, and terrain effects on CO2 releases have been reviewed. Finally, optimization efforts with respect to valve spacing, selection of materials and booster stations, etc. are presented.

Effect of impurities

CO_2 streams that have impurities may face more challenges when compared to pure CO_2 streams. Issues like pipeline pressure, re-pressurization intervals, and pipeline integrity need to be considered when transporting CO_2 with above-specification impurities. This applies to all modes of transport across a variety of terrains regardless of the CO_2 phases (gaseous, liquid, or supercritical) [1-4]. Various CO2 emission sources and capture technologies will inevitably produce different levels of impurities present in CO_2 .streams. Skaugen et al. [5] shows it costs roughly 20–40% more when transporting impure CO_2 in comparison to pure CO_2 in a pipeline. In another study done by Neele et al. [6] in IMPACTS project, it was concluded that it is more economical to remove CO_2 impurities at capture rather than to deal with the downstream problems later on. Further, models that are capable of predicting thermophysical properties of CO_2 with impurities need to be emphasized in CCS projects. Water is the most significant impurity to be removed as an above-specification water level in the CO_2 stream can cause many problems in pipelines such as corrosion or hydrate formation [7]. H_2O content should be controlled to below 350 ppm to prevent corrosion, below 250 ppm to avoid hydrates, and below 100 ppm. Further, if there is significant (>1000 ppm) moisture in the pipeline/injection systems, H_2 levels need to be controlled below 100 ppm to prevent from brittle fracture. Likewise, H_2S levels need to be kept below 100 ppm to guard against corrosion [6,8]. Some trace compounds require more compression while some need higher strength to the pipeline to resist ductility issues [9,10]. There has been significant work performed on the effect of each impurity on the critical point of CO_2 , pipeline sizing, repressurisation distances, etc. It has been found that the presence of impurities such as CH_4, N_2, H_2O and amines in the CO_2 stream affects the solubility of H_2O [11,12].

Pipeline Design considerations

The pipelines in the USA are divided into relatively small sections to reduce the blowdown and refilling times and limit the risk to the public in case of leaks. For a safe and cost-effective design of CO_2 transport, it is important to understand transient behavior such as start-up, shutdown, etc. [6]. Severe pressure/temperature drops can be seen during depressurization. In a study conducted by Huh et al, both experiment and simulation of the transient behavior of CO_2 pipeline transportation were conducted [5-7,13]. It was found that the behavior of dense phase CO_2 can be very sensitive to steep elevations and impurities. Pipeline sizing, distance before depressurization, number of pumps, and sizes and energy requirements of pumping or compressor stations need to be thoroughly investigated while designing [14–18]. Consideration to corrosion problem that may arise from low pH and use of corrosion inhibitors to keep the pipeline integrity and to extend useful life are important to control annual operating costs [19-22]. Though options such as the use of corrosion inhibitors, pre-drying, or improved pipeline material selection are available, a better approach should be to operate CO_2 pipelines under such conditions that the free water phase does not exist [23,24]. To avoid pipeline failure due to fracture propagation, use of fracture arrestors, selection of pipeline materials, or determination of operating conditions can be conducted in the design stage to prevent such failures.

Total annual cost can be estimated with rigorous modeling and simulation of CO_2 transport via pipelines [25]. Since the concentration and species of the impurities can vary widely, actual stream composition needs to be provided to accurately model CO_2 properties such as density, viscosity, critical constants, and phase behavior [26, 27, 28, 29].

Modeling of CO_2 pipelines

In a review by Peletiri et al. [29] on CO2 pipeline design, it was found that most models ignored the effects of impurities while in practicality the properties (density, viscosity, and critical constants) are all changed by presence of impurities [30]. Pressure drop due to velocity change as well as the impact of density and viscosity change (due to impurities) on the pipeline diameter and pressure drop are mostly ignored [29]. To design an efficient CO_2 transport pipeline network and to control the operating costs, factors need to be considered including material roughness, pipe diameter, CO_2 flow rate, pressure drop per unit length, viscosity/density of the fluid, differences in topography, as well as the environment temperature [31, 32, 33]. In addition, the distance between the CO_2 source and storage site, network topology, and CO_2 transportation mode must be carefully studied [34-36].

Literature Survey on CO_2 Pipeline Monitoring Technologies

Atmospheric CO_2 sensors has been used to detect a slight increase in CO_2 in the atmosphere due to pipeline leaks and to provide an alarm system for CO_2 pipeline leaks in the Netherlands [37]. A sensor-based autonomous pipeline monitoring system (SPAMMS) has been proposed by Kim et al. [38]. SPAMMS consists of mobile sensors, fixed sensors, radio-frequency identification (RFID) technology, and autonomous robots that can detect the type/ location of faults early on and take corrective actions in a timely and cost-effective manner.

Literature Survey on CO_2 Pipeline Risk Assessment Technologies

High concentrations CO_2 in large quantities can pose a threat to HSE. There are several studies that focus on addressing the risks involved in CO_2 pipeline transport [39]. Major causes of pipeline damage may rise from leaks through valves, human error, excavations near the pipes, or low-quality welding seams. Essential element to assure safety of pipeline transport is the appropriate positioning of safety valves together with automatic gas leak detection systems. Pipeline failures may be eliminated by removing any moisture from the CO_2 stream to prevent corrosion, avoiding use of materials like elastomers for seals that the gas could dissolve, and considering brittle cracking during the design stage of the pipelines. Knowledge of the behavior of CO_2 in supercritical phase is required when there is an elevation in the CO_2 pipeline. Simulations can help fill the data gap to determine the pipeline length before installing booster stations and any pressure drops that may result from changes in elevation [40, 41]. Simulations and experiments help understand the probabilities of the CO_2 stream to lose its supercritical state and whether this behavior is reversible.

Decompression behavior of high-pressure CO_2 mixtures was studied by Liu et al., [42] using a multi-phase CFD model with GERG-2008 Equation of state. It was concluded that delayed bubble formation can cause a CO_2 phase at a pressure lower than the bubble point. Analytical dispersion and CFD (e.g., Fluent) models are useful risk assessment tools due to their capabilities to predict the discharge rate, transient jet releases during pipeline leakage, and the minimum safe distances to populated areas [43]. Among the impurities in a CO_2 stream, H_2 has the most significant impact on the discharge rate when compared to other compounds like N_2, O_2, Ar , and CH_4 [44].

Mathematical models were developed and validated against data available in the open literature for multiphase discharge and dispersion from CO_2 pipelines in a study conducted by Woolley et al. [45]. Models were found to be useful in the investigation of risk assessments, to assess the effects of terrain heights on dispersion. The size of solid CO_2 particles released from the crater has a significant effect on the dispersion characteristics of the release [45]. Drescher et al., [46], measured the flow through an orifice to study pressure-release and the Joule-Thompson effect in a tube filled with liquid CO_2. Shahirpour et al. [47] applied CFD large eddy simulation (LES) to model turbulent channel flow and pipe flow and reported a good agreement between the primary results and experimental measurements on pipe test facility. In another study by Abidoye et al., [48], it was shown how reliable and applicable are Artificial Neural Networks (ANN) in characterizing and predicting the dielectric property of pure CO_2 as well as its mixture or impurities.

Numerical case studies from the North Sea of CO_2 leaks at various depths were conducted to analyze bubble/droplet and hydrate formations. It was shown that the lack of large currents dispersing the dissolved CO_2 gives rise to change in pH > 2 and pose the largest risk to marine life such as off the west coast of Scotland. On the other hand, leakages occurring at deeper depth subject to larger currents were more difficult to monitor [49].

Summary and Conclusions

This review has presented the major issues and identified knowledge gaps related to CO_2 transport design and monitoring. Methods to assess the growth rate of a crack during its lifetime to schedule timely maintenance, root causes that challenge the deployment of CO_2 pipeline transport such as threats to marine wildlife and populated urban areas, and validated computational fluid dynamics (CFD), artificial neural network (ANN), and analytical modeling studies have been covered. Future commercial deployment of carbon capture and sequestration (CCS) pipelines makes it crucial to evaluate the economics of CO_2 transport, especially the issue of pipeline over-specification because of expected future use.

There exist needs for good computational fluid dynamics (CFD), artificial neural network (ANN), and analytical models that incorporate the right equation of state to account for factors that are important at the early design stage such as gaseous, liquid, or supercritical CO_2 behavior, interaction with ocean water, pipeline material resistance to corrosion in the presence of impurities (water, H_2, etc.), the effect of terrain/ocean depth or pressure on CO_2 dense phase properties, acceptable water content in liquefied CO_2, and pipeline fracture mitigation measures. Recommendations for the deployment of monitoring devices and design/modeling technologies are made for the future construction of sub-sea and on-land CO_2 pipelines for storage of CO_2 in onshore/offshore storage sites.

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Subtask 5.1.4 Site Leasing

Subtask 5.2: Scenario Optimization

Trimeric Corp.

During the most recent quarter, Trimeric engaged an LNG operator with a new facility along the Texas Gulf Coast. LNG facilities represent an important potential source of CO_2 for long-term storage near shore for the following reasons:

- CO_2 is already separated from the incoming natural gas to facilitate the liquefaction process – this leads to a potentially large, high purity CO_2 source
- The CO_2 is often sent to an incinerator as part of the gas separated from the natural gas. CO_2 (an inert in the combustion process) increases the cost of the incineration process. Diverting CO_2 from the incinerator would potentially provide benefits to the LNG facility.
- LNG facilities are near the coastline, simplifying transport logistics for storage.

Trimeric engaged the Vice President of Business Development for the LNG facility operator. The following highlights key notes from the discussion:

- The LNG operator is interested in any opportunities to minimize environmental impact and has been studying CO_2 capture and storage. The permit application for the facility required consideration of CO_2 emissions.
- They were not aware of 45Q tax credits. Trimeric provided a brief overview of the credits. The operator says the tax credits likely would not incentivize a project on their own, but they would be interested in learning more about the credits in general.
- From a broader business perspective for the facility, a CO_2 storage project would be compared on a common basis to any other new project the facility would implement. Key criteria for the new project would include risk to existing operations, return on investment (including uncertainty/risk in the return).
- The environmental focus for the facility in the near-term is managing any sulfur-related emissions, but CO_2 remains a long-term consideration for the facility.
- The operator does not envision a near-term business case for CO_2 capture and storage due to potential for disruption to current operations and the prior business case evaluation for CO_2 capture, but there is a strong interest in learning about storage opportunities along the Gulf Coast.
- The operator would like to stay apprised of progress and results from the GoMCarb project and is available to provide additional comments and feedback as needed for the project.

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Lamar University

To investigate the injection conditions for CO_2 at the well head, two projects were reviewed: the Peterhead CCS Project in the UK and the Tomakomai CCS Project in Japan. While the Peterhead CCS project stores CO_2 into the now depleted Goldeneye Gas Field Reservoir, the Tomakomai CCS plant injects CO_2 into the deep saline aquifer found underneath. Despite their differences, the well head injection conditions of both projects are largely the same.

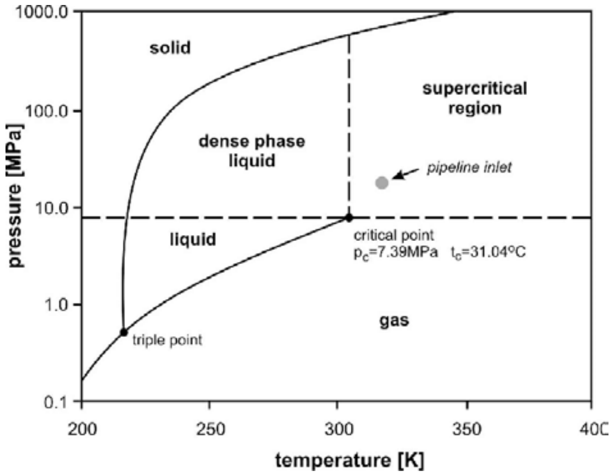
Injection Pressure: 80 - 120 Bar(g) or 8 - 12 MPa

Injection Temperature: 40 – 80 °C

Injection Flow rate: ~140 tons CO_2/hr (Peterhead CCS Plant)

7.6 – 25.3 tons CO_2/hr (Tomakomai CCS Plant)

From these conditions, it is concluded that CO_2 is compressed to the supercritical stage at the well head before injection.



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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

No activity during this quarter

Subtask 6.1: Stakeholder Outreach

University of Texas, Stan Richards School of Advertising & Public Relations

In April, we finalized recruitment for our post doc position. We received eight applications, and after interviewing five candidates, we offered the position to Rachel Lim, a PhD student in our department. Dr. Lim successfully defended her dissertation in April after which she began familiarizing herself with the relevant literature on carbon capture and storage as it relates to public opinion and communication.

Dr. Lim represented our team at the May 13th GoMCarb offshore communications webinar and spoke for about 20 minutes on communication related to CCS. She summarized findings so far from related projects and outlined where our project will be going this summer and fall. These goals are two-fold: 1) conducting focus groups and in-depth interviews to generate insights from relevant stakeholders about communication related to CCS and 2) developing and fielding a survey to test specific messages related to CCS.

In collaboration with Lamar University team member, Dr. Tracy Benson, it was determined that a comprehensive plan to raise awareness, a study to determine the current knowledge of CO_2 effects on the environment and geologic storage must first be conducted. Through a brainstorming session, the outreach team developed a list of stakeholder groups from the Southeast Texas community. A plan was then developed to meet with members of each stakeholder group to conduct the initial assessment.

The various groups included:

Hunters & Fishers

Conservationists & Birding

Vo-Tech, Workforce

Academic Higher Education

Real Estate and Development

Chambers of Commerce

In May and June, the team worked on developing the focus group and in-depth interview component. We identified a list of stakeholders to reach out to for the focus groups, developed a list of focus group questions, and have started thinking about recruitment of subjects. We submitted our IRB* protocol to UT's Office of Research Support and expect to hear back from them by late July. In addition to working on this first phase of data collection, we continue to compile and review relevant literature on CCS, public opinion and communication.

* IRB is the Institutional Review Board. This is an administrative body established to protect the rights and welfare of human research subjects recruited to participate in research activities conducted under the auspices of the institution with which it is affiliated.

Subtask 6.2: Technical Outreach

Dr. Curtis Oldenburg (Figure 6.2.1) of Lawrence Berkeley National laboratory presented a talk at the 50^{th} annual Offshore Technology Conference, session 46, in Houston, TX on May 9, 2019. The talk was based on a conference proceedings paper (Oldenburg and Pan). The talk presented the finding that offshore and onshore CO_2 well blowouts and high-pressure pipeline loss-of-containment (LOC) incidents will be very similar in terms of intra-well and intra-pipeline flow and phase-change processes and that the main differences will arise from differences in how CO_2 is transported after discharge from the well/pipe onshore above ground versus offshore in the water column. The goal of the conference is to provide a venue for energy professionals to transfer knowledge and skills to further scientific and technical advancements in offshore environments.

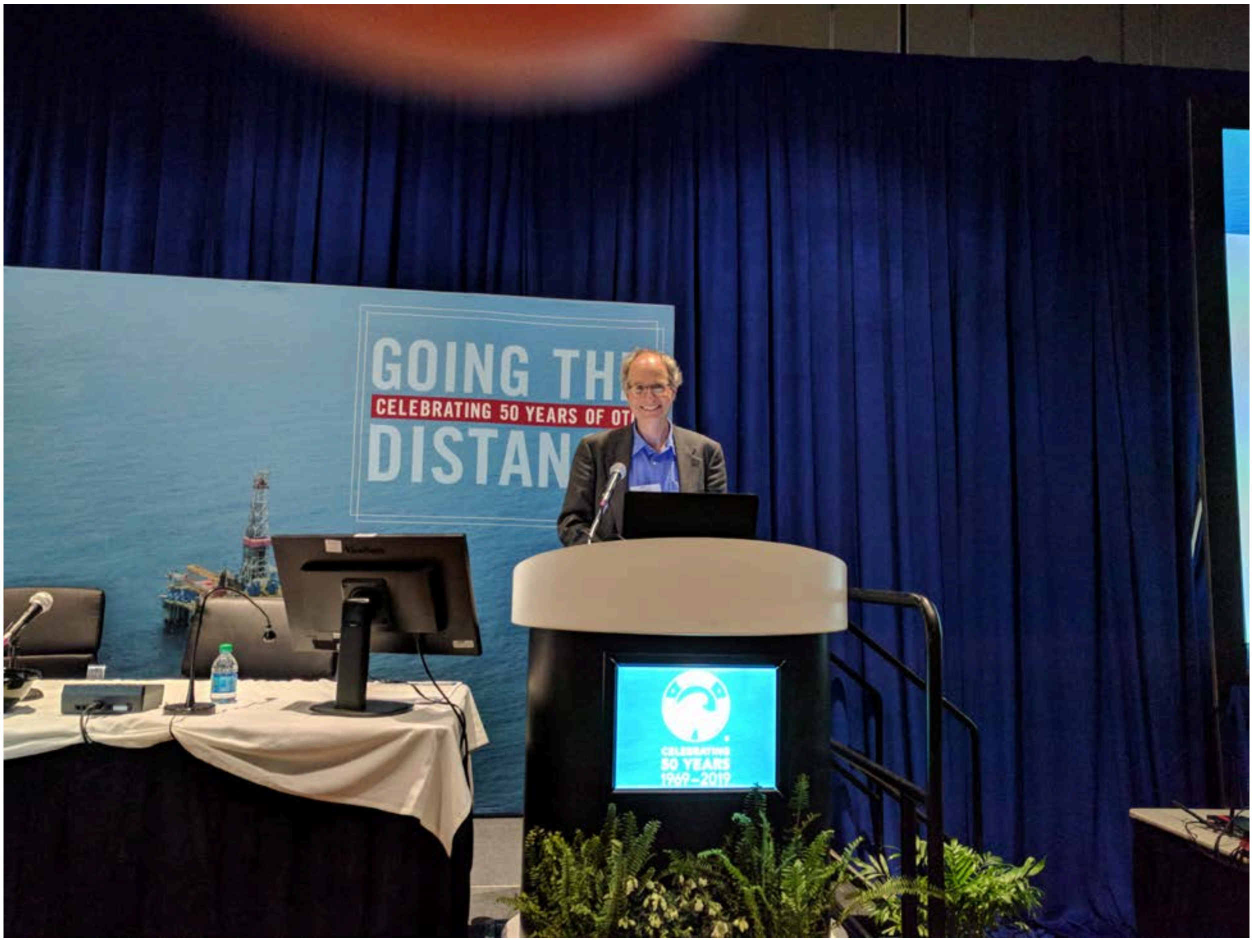

Figure 6.2.1 – Dr. Curtis Oldenburg at the 50th annual Offshore Technology Conference in Houston, Texas.

On April 15 and 16, 2019, co-PI Ramón Treviño attended a symposium and field trip (Figure 6.2.2) of the American Beach and Shore Preservation Association (ASBPA), Texas Chapter.

Figure 6.2.2 – Photo of attendees of the ASBPA field trip, April 15, 2019, on the last stop of the field trip, Mustang Island, Texas.

The symposium was held at the Harte Research Institute, Texas A&M University-Corpus Christi. As indicated by ASBPA's website, the organization's membership comprises a variety of professionals including engineers, scientists, planners, public officials, and other professionals engaged in the management and operation of the shores and beaches of U.S. bays, harbors, oceans and the Great Lakes and who are also interested in the protection, restoration, and management of these resources.

Treviño presented an introductory CCS symposium talk titled, "Carbon Capture and Sequestration (Storage) – CCS: A Climate Change Mitigation Strategy for the Near-Offshore Northwestern Gulf of Mexico."

Global climate change, specifically sea-level rise, was either an explicit or implicit focus of most of the symposium talks. Treviño's talk emphasized the potential of CCS to reduce the amount of CO_2 emitted into the atmosphere from CO_2 point sources and thus mitigate sea level rise and its negative impacts on the coast. After the presentation, several audience members, who were previously unfamiliar with the technology, expressed interest in CCS.

On May 9, 2019 project co-PI, Ramón Treviño (Figure 6.2.3) presented two talks, "What Offshore CCS Will Look Like in The Gulf of Mexico: Perspectives from Texas" and "Monitoring Stored CO_2 to Document Permanence" at the 50^{th} annual Offshore Technology Conference in Houston, session 46. The talks are based on manuscripts OTC 29268-MS and OTC 29525-MS, respectively, which will be published in the 2019 issue of the OTC Proceedings.

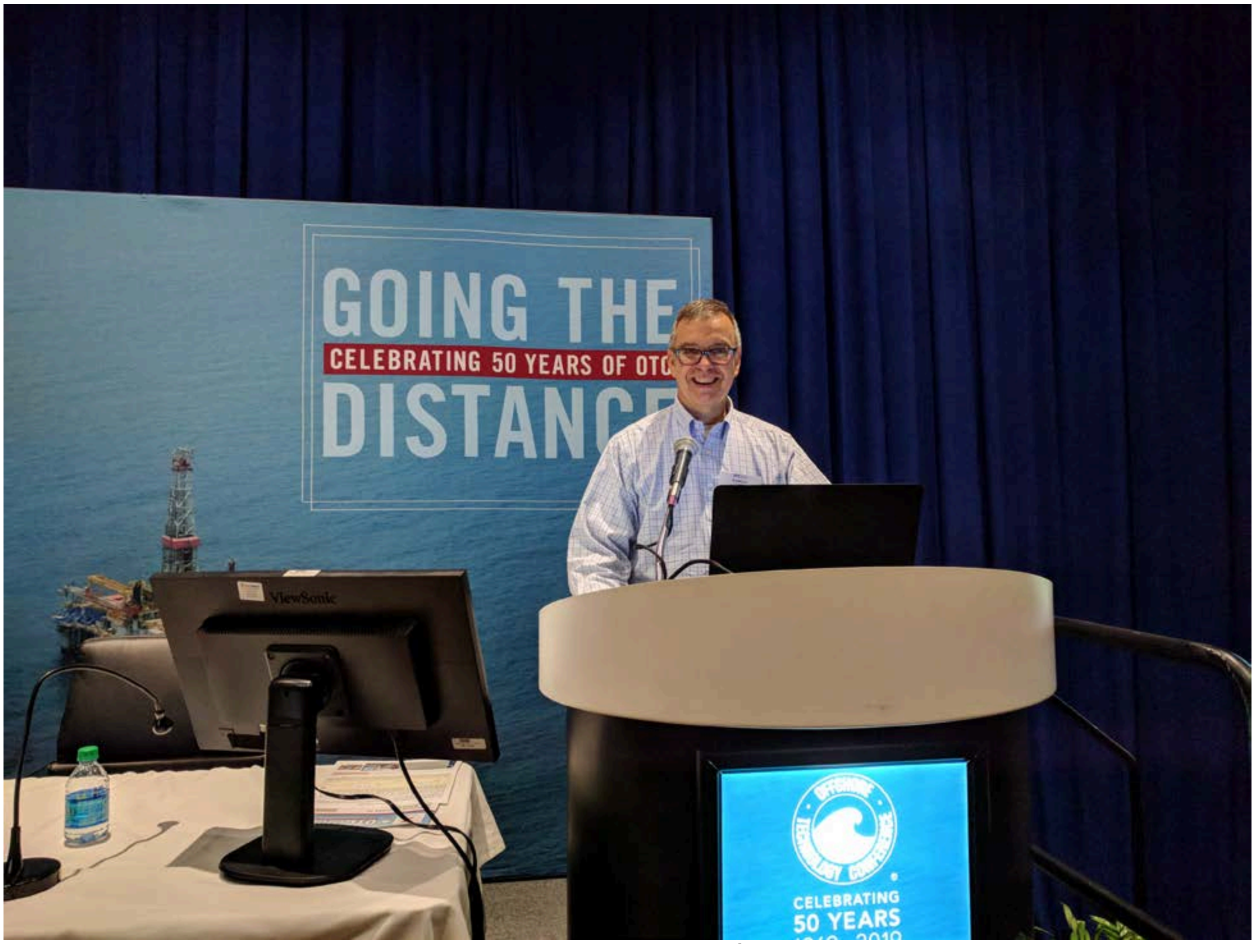

Figure 6.2.3 – Ramón Treviño presenting a CCS talk at the 50th annual Offshore Technology Conference (OTC) in Houston.

Dr. Darshan Sachde (Figure 6.2.4) from GoMCarb Partner, Trimeric Corp., presented a talk at the 50th annual Offshore Technology Conference, session 46, in Houston, TX on May 9, 2019. The talk, "Review of Technical Challenges, Risks, Path Forward, and Economics of Offshore CO2 Transportation and Infrastructure," is based on a paper, OTC-29253 MS, which will be in the OTC's proceedings when published.

Figure 6.2.4 – Dr. Darshan Sachde presenting his CCS talk at the 50th annual Offshore Technology Conference (OTC) in Houston.

Subtask 6.3: Advisory Committee

Advisory committee chair, Tim Dixon chaired the first session of the first annual GoMCarb Partnership meeting at Lamar University.

PLANS FOR THE NEXT PROJECT QUARTER

In the next quarter, work will continue on:

Task 1

- Establish subcontract with Aker Solutions.
- Take possession of and test equipment ordered from Geometrics.
- Conduct update/technical meeting with Partners and Advisory Committee members.

Task 2

Subtask 2.1: Generate a contiguous velocity model for all the leased portion of the Texas Offshore OBS.

Subtask 2.1.3:

- Work to be done on HR3D datasets:

Re-processing of GOM2012 will be finished. GOM2013 and GOM2014 are prepped and reloaded with geometry and quality tested. Experiments have begun to see if the same or similar techniques used in GOM2012 will produce good results in the other two datasets. Once the parameters are optimized the same steps will quickly follow GOM2012 to completion.

	Data QC	Positional Corrections	Signal Processing	3D Statics and Balancing	Migration
GOM2012	Done	Done	Done	In Progress	In Progress
GOM2013	Done	Testing	Testing		
GOM2014	Done	Testing	Testing		

Task 3 Risk Assessment, Simulation and Modeling

- Subtask 3.1.1:

  Continue dialogue with A&M on CO_2 transport and jet to buoyant plume transition in the water column.

  Consider likelihood of loss of containment from existing wells in the Texas Gulf Coast region of interest.

  Develop powerpoints on modeling subsea CO_2 blowouts for presentation at August review meeting.
- Summarize the findings of field CISB at Cranfield in a journal paper and quantify these processes in heterogeneous formations.
- Subtask 3.1.2: Continue detailed geomechanical modeling; incorporate results from porosity modeling (e.g., seismic inversion
- Subtask 3.1.4: Continue design of a controlled source for continuous DAS imaging in the water column and near-seafloor sediment.

Task 4 Monitoring Verification and Assessment

- Subtask 4.1.4: Continue design of a controlled source for continuous DAS imaging in the water column and near-seafloor sediment

Task 5 Infrastructure, Operations and Permitting

- Subtask 5.1: Continued development of existing infrastructure “database” for High Island region. Trimeric will be seeking data on the existing platforms and pipelines.
- Subtask 5.1: Continued development of methodology to evaluate existing infrastructure for re-use in CO_2 transportation with a focus of gathering and assessing industry expertise/experience on the subject. An industry survey will be deployed to a selected group of experts identified.

- Subtask 5.2: Continued development of CO_2 source list along the Texas coast, including outreach and education of industry in the region.
- Subtask 5.2: Add existing infrastructure data to CO_2 source data (in maps and database/spreadsheets) to provide first steps for longer-term scenario optimization.
-

Task 6

- Present project update at NETL annual review, "Addressing the Nation's Energy Needs Through Technology Innovation – 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting."
- The planned assessment to determine the current knowledge of CO_2 effects on the environment and geologic storage by target groups in the southeast Texas community will occur in late July and early August.
- Other outreach opportunities will be engaged as possible.

STATUS OF PROJECT SCHEDULE AND MAJOR GOALS/MILESTONES OF PROJECT

Schedule/Timeline

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

Partnership for Offshore Carbon Storage Resources and Technology Development in the Gulf of Mexico		BUDGET PERIOD 1								BUDGET PERIOD 2											
		2018			2019				2020				2021				2022				2023
Task	Tasks	qtr2	qtr3	qtr4	qtr 1	qtr2	qtr3	qtr4	qtr 1	qtr2	qtr3	qtr4	qtr 1	qtr2	qtr3	qtr4	qtr 1	qtr2	qtr3	qtr4	qtr 1
		A-M-J	J-A-S	O-N-D	J-F-M	A-M-J	J-A-S	O-N-D	J-F-M	A-M-J	J-A-S	O-N-D	J-F-M	A-M-J	J-A-S	O-N-D	J-F-M	A-M-J	J-A-S	O-N-D	J-F-M
1	**Project Management, Planning, and Reporting**	M1		M2																	
	Revision and Maintenance of Project Management Plan								G-NG												
	Progress Report	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q	Q
2	**Offshore Storage Resources Characterization**						M4								M8						
2.1	Database Development				M3																
2.2	Data Gap Assessment																				
2.3	Offshore EOR Potential																				
3	**Risk Assessment, Simulation and Modeling**								M5				M6								
3.1	Risk Assessment and Mitigation Strategies																				
3.2	Geologic Modeling																				
4	**Monitoring, Verification, Accounting (MVA) and Assessment**												M7								
4.1	MVA Technologies and Methodologies																				
4.2	Plans for Field Testing of MVA Technologies																				
4.3	Testing MVA Technologies																				
5	**Infrastructure, Operations, and Permitting**																				
5.1	CO2 Transport and Delivery																				
5.2	Scenario Optimization																				
5.3	Communication																				
6	**Knowledge Dissemination**																				
6.1	Stakeholder Outreach																				
6.2	Technical Outreach																				
6.3	Advisory Panel																				

Q = Quarterly Report; A = Annual Report; M = Milestone; DP = Decision Point; D = Deliverable; G-NG = Go/no-go decision point; FR = Final Report

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	9/30/2019	Summary Report
3	M5: Risk assessment, simulation and modeling of prospects	3/13/2020	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.

See Subtask 6.2 (Offshore Technology Conference presentations and manuscripts).

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)
Contribution to Project: Mr. DeAngelo conducted structural interpretation of the "TexLa Merge," "Texas OBS" and "Chandeleur Sound" regional 3D seismic datasets.

Name: Katherine Romanak, PhD
Project Role: sediment geochemist
Nearest person month worked: 1
Contribution to Project: Liaison with Texas A&M GERG

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

Name: John Snedden
Project Role: Senior Research Scientist
Nearest person month worked: 1
Contribution to Project: Dr. Snedden provided expertise in seismic stratigraphy and siliciclastic depositional systems.

Name: Jon Virdell
Project Role: Project Manager
Nearest person month worked: 1

Contribution to Project: Mr. Virdell provided project and GIS data management support.

Name: Marcie Purkey Phillips
Project Role: Biostratigrapher
Nearest person month worked: 1
Contribution to Project: Mrs. Purkey Phillips contributed expertise in biostratigraphy and integrated well and seismic data in the Chandeleur 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: **None**

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