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CCS Opportunity Along the Gulf Coast Corridor

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Abstract

Carbon capture and storage (CCS) activity along the Gulf Coast from Corpus Christi to the Mississippi River and in state waters of the Gulf of Mexico is increasing. ExxonMobil, Chevron, Talos, Denbury, Occidental, Repsol and many other companies are forming partnerships to take advantage of evolving business opportunities or government co-funding of CarbonSAFE projects.

The Gulf Coast corridor, onshore and offshore, from Corpus Christ to the Mississippi River presents a high concentration of CO_2 from industrial sources and excellent storage reservoirs in the underlying Cretaceous and Tertiary sands. Analysis of the technical, geologic, economic and social aspects of this CCS opportunity is necessary for successful deployment of CCS technology and eventual attainment of NetZero goals.

To provide analysis of the CCS opportunity along the Gulf Coast Corridor, the National Energy Technology Laboratory (NETL) has developed a CO_2 Transport Cost Model and an Onshore CO_2 Storage Cost Model. Nearing completion is the Offshore CO_2 Saline Storage Cost Model. These models can provide comparative analysis of storage and transport opportunities for multiple CO_2 sources to storage locations onshore, offshore or between either.

The Onshore CO_2 Storage Cost Model is aligned with EPA's Class VI regulations which are also applicable in offshore State waters. Carbon dioxide storage regulations for offshore operations in Federal waters are being developed, built upon existing offshore oil & gas operations but are expected to dovetail with onshore Class VI regulations to minimize any conflicting requirements.

Financing CCS project development and operations is a primary challenge that is evolving towards a solution. A key component here is the 45Q credit, which in turn will support offtake agreements between a source and storage operations.

Initial industry interest in the Gulf Coast region presents an opportunity to examine business opportunities for deployment of CCS technology in this area, either onshore, offshore of both.

Introduction

Carbon capture and storage (CCS) activity occurs along the United States (U.S.) Gulf Coast from Corpus Christi to the Mississippi River and in state waters of the Gulf of Mexico. The number of these projects is steadily increasing. ExxonMobil, Chevron, Talos, Denbury, Occidental, Repsol, and many others are forming partnerships to take advantage of evolving business opportunities or government co-funding of Carbon Storage Assurance Facility Enterprise (CarbonSAFE) projects. This region presents a high concentration of carbon dioxide (CO_2) emissions from industrial sources and excellent storage reservoirs in the underlying Cretaceous and Tertiary sands. Analysis of the technical, geologic, economic, and social aspects of this CCS opportunity is necessary for successful deployment of CCS technology and eventual attainment of net zero goals., a carbon pollution-free power sector by 2035 and a net zero emissions economy by no later than 2050 (White House, 2023).

Current Activity

Onshore, the Gulf Coast Corridor (**Figure 1**) can be defined by the concentration of CO_2 emission sources with potential for nearby storage within the Gulf Coast Basin. Offshore, the corridor can be defined by the continental shelf/deepwater boundary. Within the mapped area of **Figure 1**, CO_2 emissions of about 490 million tonnes (Mt) originate from just over 1,000 sources in the Gulf Coast Corridor. Power plants generate about 44% of total CO_2 emissions while nearly half of the point sources are petroleum and natural gas system plants (**Table 1**). Offshore storage activity will have economic competition from onshore opportunities.

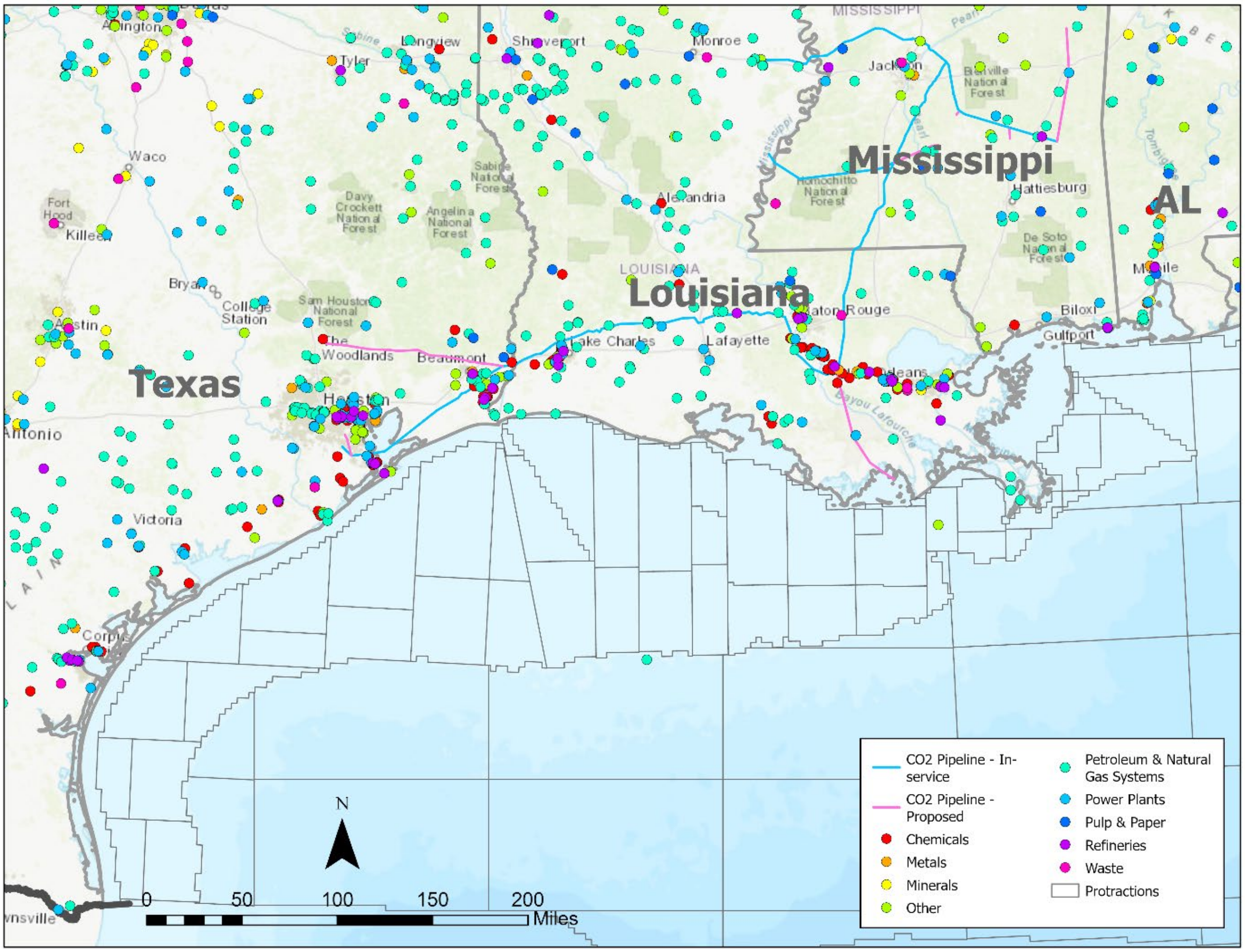

Figure 1. CO_2 emissions point sources colored by sector and CO_2 pipelines, in-service and proposed, in the Gulf Coast Corridor.

Industrial Sector	Texas		Louisiana		Alabama		Mississippi		Total	
	CO_2 Emissions (Mt)	***Point Source Count***	***CO_2 Emissions (Mt)***	***Point Source Count***	***CO_2 Emissions (Mt)***	***Point Source Count***	***CO_2 Emissions (Mt)***	***Point Source Count***	***CO_2 Emissions (Mt)***	***Point Source Count***
Power Plants	150.71	89	42.10	33	9.83	6	12.12	13	214.75	141
Chemicals	57.50	92	40.43	77	0.45	6	1.62	3	100.00	178
Refineries	49.50	25	25.98	16	0.42	2	3.91	3	79.81	46
Petroleum & Natural Gas Systems	45.74	293	22.85	136	1.27	16	1.16	22	71.03	467
Minerals	9.00	22	0.08	2	1.33	3	0.00	0	10.40	27
Metals	2.02	11	1.83	3	1.08	4	0.09	1	5.03	19
Pulp & Paper	0.72	4	2.01	8	1.09	6	0.65	3	4.47	21
Waste	0.08	11	0.00	4	0.00	0	0.00	2	0.09	17
Other	3.07	57	1.33	22	0.12	3	0.38	12	4.91	94
Total	**318.34**	**604**	**136.62**	**301**	**15.60**	**46**	**19.92**	**59**	**490.48**	**1,010**

Table 1. CO_2 sources and emissions located within the mapped area of Figure 1.

Industry activity can be illustrated by a few companies active in developing CCS projects in the region. Denbury has conducted enhanced oil recovery (EOR) operations in the Gulf Coast area for years, supported by a CO_2 pipeline network of more than 900 miles (**Figure 1**) (Denbury, 2023a) in Mississippi, Louisiana, and Texas. Denbury has a natural source of CO_2 in the Jackson Dome but has worked to connect to industrial sources to conserve their natural source. Denbury Carbon Solutions, LLC was established in 2021 (Denbury, 2023b). They are currently expanding their CO_2 storage operations with nine proposed sites in Texas, Louisiana, Mississippi, and Alabama (Denbury, 2023b). These sites, encompassing 287,000 acres, have a prospective storage resource capacity of 2.4 gigatonnes (Gt) of CO_2 (**Table 2**). Anticipated injection rate is 5–20 Mt per year (Mt/yr) with potential initial injection beginning between 2025 and 2027 for all currently proposed projects.

Site *State*	Aries, Gemini	Pegasus	Orion	Draco	Leo	Dorado	Libra	Virgo	Total
	Louisiana	*Louisiana*	*Alabama*	*Louisiana*	*Mississippi*	*Texas*	*Louisiana*	*Louisiana*	
Potential injection capacity (Mt)	300	500	300	250	275	115	200	100	**2,040**
Anticipated injection capacity (Mt/yr)	10–20	10–20+	10–20	5–10	5–10	5–10	5–10	5–10	
Distance to Denbury pipeline (miles)	5, 10	95	90	25	0	60	45	5	
Acreage	29,000	84,000	75,000	31,000	16,000	30,000	14,000	8,000	**287,000**
Potential 1st injection	2025–2026	2026–2027	2026	2026	2025	2026	2027	2026	

Table 2. Denbury CCS projects in the Gulf Coast Corridor.

ExxonMobil announced their plans to capture and sequester industrial emissions in 2021 (Woods and Blommaert, 2021). Based on DOE numbers, they estimate a storage potential along the Gulf Coast for CO_2 at around 500 Gt (Woods and Blommaert, 2021). In 2022, they announced a hydrogen production plant capable of producing up to 1 billion cubic feet per day of blue hydrogen from natural gas with capture and storage of the CO_2 emissions (Breisford, 2022). In conjunction with this project, related CCS infrastructure will be built for the Baytown complex providing the potential to transport and store up to 10 Mt/yr. This project also begins the establishment of a Houston CCS Hub. In addition to ExxonMobil, there are 13 additional members of the Houston CCS Hub: Air Liquide, BASF, Shell, Calpine, Chevron, Dow, INEOS, Linde, LyondellBasell, Marathon Petroleum, NRG Energy, Phillips 66, and Valero (ExxonMobil, 2022).

Chevron has also invested in the Bayou Bend CCS project with partners Talos Energy Inc. and Carbonvert Inc (Chevron, 2023). Talos and Carbonvert acquired a lease hold of 40,000 acres offshore from Jefferson County, Texas, from the Texas General Land Office in 2021. Once Chevron joined, the project acquired another 100,000 acres onshore in Chambers County, Texas. Carbonvert has since sold their interest in the Bayou Bend CCS project to Equinor (Carbonvert, 2023).

Aside from these operators and their associated projects, there are many other CCS projects in the works in the Gulf Coast Corridor. **Table 3** presents a list of 31 projects in the region; 18 projects are focused on storage, two of which include pipeline work, and 13 are developing the whole CCS chain from capture to transport and storage. The locations of these projects are illustrated in **Figure 2**. The Houston Ship Channel CCUS Hub represents the largest of the storage projects with an estimated injection rate of 100 Mt/yr distributed over several injection sites. The River Bend CCS Pipeline project in Louisiana is of comparable size at 80 Mt/yr transported and injected. The remaining projects plan to inject 0.5–20 Mt/yr of CO_2. Operational dates are between 2024 and 2028. Ten of the projects are actively pursuing Class VI permits (EPA, 2024)

Project name	State/ Province	Partners	Project Type	Class VI Permit Application	Operation Date	Planned CO_2 Injection Rate (Mt/yr)	Reference Link
Bayou Bend CCS hub	Texas	Talos Energy, Carbonvert, Chevron	Storage		2027	20	Ref 1, Ref 2
Central Louisiana Regional CCUS Hub (CENLA)	Louisiana	CapturePoint, Energy Transfer	Transport & Storage		2024	1	Ref 1, Ref 2, Ref 3, Ref 4
Cyclus Capio Sherburne Sequestration	Louisiana	Fidelis New Energy LLC, Capio Sherburne Sequestration LLC, Gron Fuels, Gron GigaSystem	Storage			5	Ref 1, Ref 2
Diamond Vault CCS	Louisiana	Cleco Power	Full Chain		2028	3.297	Ref 1, Ref 2, Ref 3, Ref 4
Donaldsonville Complex	Louisiana	CF industries	Full Chain	1		2	Ref 1, Ref 2
Eastern Louisiana Clean Hydrogen Complex	Louisiana	Air Products	Full Chain		2026	5	Ref 1, Ref 2
El Camino	Louisiana	Shell US Power and Gas LLC, GeoStock Sandia LLC	Storage	2		1.5	Ref 1, Ref 2
Freeport LNG	Texas	Freeport LNG Development, Talos Energy Inc, Storegga Geotechnologies	Full Chain		2024	1	Ref 1
Goose Lake	Louisiana	Gulf Coast Sequestration, Stream Family	Storage	2		1	Ref 1, Ref 2
Hackberry Carbon Sequestration Project	Louisiana	Hackberry Carbon Sequestration, Cameron LNG, Sempra Infrastructure, Total Energies, Mitsui & Co., Ltd, Mitsubishi Corporation	Full Chain	1		2	Ref 1, Ref 2

Project name	State/ Province	Partners	Project Type	Class VI Permit Application	Operation Date	Planned CO_2 Injection Rate (Mt/yr)	Reference Link
Houston Ship Channel CCUS Hub	Texas	Calpine, Chevron, Dow, ExxonMobil, INEOS, Linde, LyondellBasell, Marathon Petroleum, NRG Energy, Phillips 66, Valero, Shell,	Storage			100	Ref 1, Ref 2, Ref 3
LA CCS Project	Louisiana	DT Midstream	Full Chain	1		1	Ref 1, Ref 2
Lake Charles Methanol	Louisiana	Lake Charles Methanol, Denbury	Full Chain		2025	4	Ref 1, Ref 2
LGF Columbia Facility	Louisiana	Strategic Biofuels LLC, Louisiana Green Fuels LLC	Storage	3	2025	1.36	Ref 1, Ref 2, Ref 3
Minerva	Louisiana	Gulf Coast Sequestration, Steam Family, GeoStock Sandia	Storage	4		2.7	Ref 1, Ref 2, Ref 3
NextDecade Rio Grande LNG CCS	Texas	NextDecade	Full Chain		2025	5	Ref 1, Ref 2
PCS Nitrogen Geismar Ammonia Plant	Louisiana	Nutrien, Denbury	Full Chain		2027	1.8	Ref 1, Ref 2
Project Aries and Gemini	Louisiana	Denbury Inc.	Storage		2026	20	Ref 1
Project Dorado	Texas	Denbury Inc.	Storage		2026	10	Ref 1, Ref 2
Project Draco	Louisiana	Denbury Inc.	Storage	6	2026	10	Ref 1, Ref 2, Ref 3
Project Leo	Mississippi	Denbury Inc., Weyerhaeuser Co.	Storage	6	2025	10	Ref 1, Ref 2, Ref 3, Ref 4
Project Libra	Louisiana	Denbury Inc., Lapis Energy	Storage		2027	10	Ref 1, Ref 2, Ref 3
Project Orion	Alabama	Denbury Inc.,	Storage	3	2026	20	Ref 1, Ref 2
Project Pegasus	Louisiana	Denbury Inc.,	Storage		2027	20	Ref 1
Project Virgo	Louisiana	Denbury Inc., Soterra LLC (Greif Inc.)	Storage		2026	10	Ref 1, Ref 2
River Bend CCS Pipeline	Louisiana	Talos Energy, EnLink Midstream	Transport & Storage		2026	80	Ref 1, Ref 2
South Texas DAC Hub	Texas	1PointFive, a subsidiary of Occidental (DAC Hub owner), Carbon Engineering Ltd., Worley Group Inc., Carbon Direct Inc., Lawrence Livermore National Laboratory, Texas A&M University Kingsville, Coastal Bend Bays and Estuaries Program, Livermore Lab Foundation, University of Texas at Austin Gulf Coast Carbon Center	Full Chain			1	Ref 1, Ref 2, Ref 3
Venture Global - Calcasieu Pass	Louisiana	Venture Global	Full Chain			0.5	Ref 1, Ref 2
Venture Global - Plaquemines	Louisiana	Venture Global	Full Chain			0.5	Ref 1
Vermilion Parish Storage (Pecan Island)	Louisiana	ExxonMobil, CF Industries, EnLink Midstream, Nucor	Storage		2025	2	Ref 1, Ref 2
YAMS (West Bay Sequestration Hub)	Louisiana	Oxy Low Carbon Ventures LLC	Full Chain			0.5	Ref 1, Ref 2

Table 3. CCS projects in the Gulf Coast Corridor.

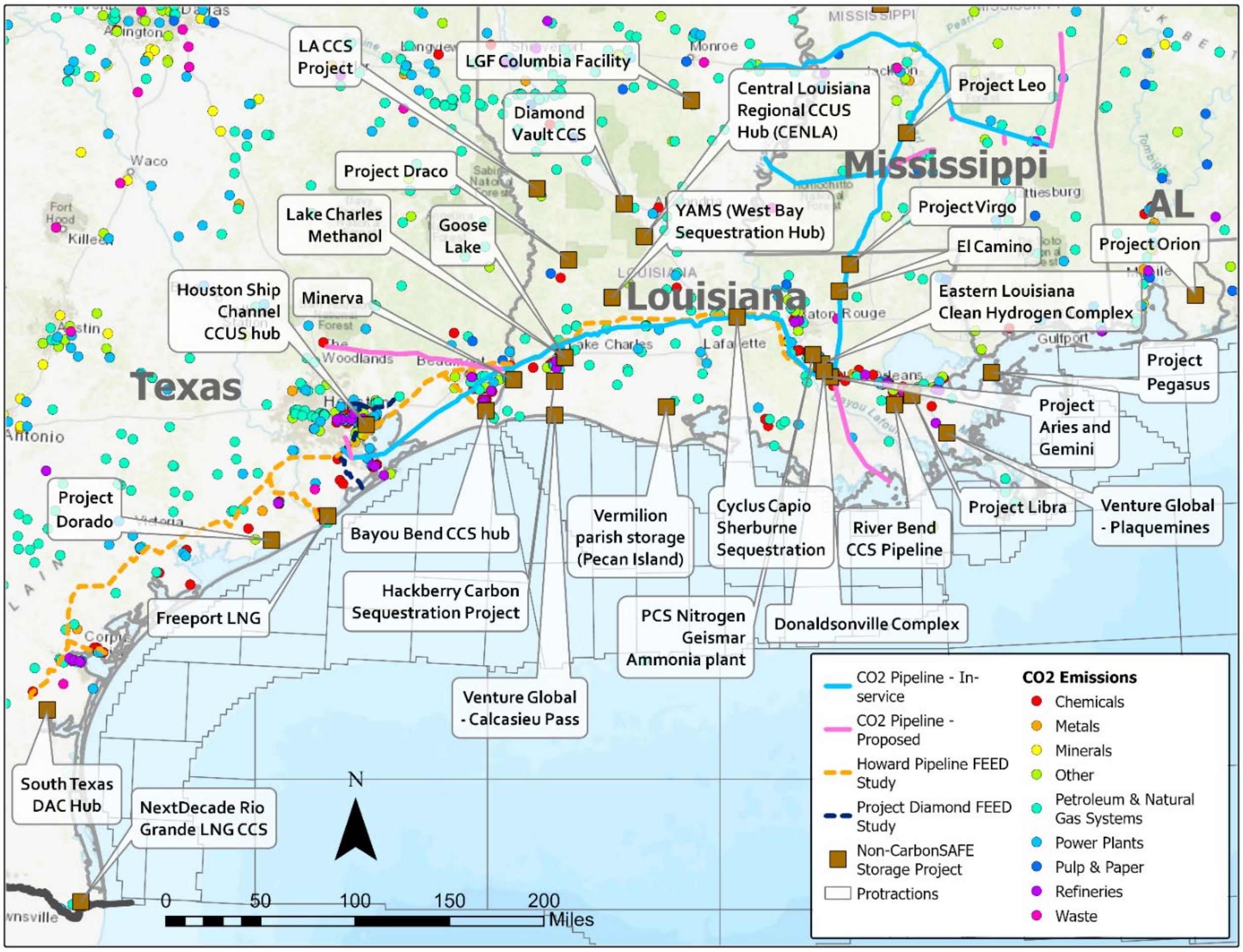

Figure 2. Location of industry-sponsored CCS projects in the Gulf Coast Corridor with CO_2 emissions point sources colored by sector. Links to information for each of these projects can be found in the reference list under the project name.

CCS project development under the CarbonSAFE program is being funded by the Department of Energy (DOE) and managed by the National Energy Technology Laboratory (NETL). Ten CarbonSAFE projects (grouped by Funding Opportunity Announcement [FOA]) are listed in **Table 4** (also see **Figure 3**). Three are Phase II projects, looking at storage complex feasibility. Two of these projects are in the Corpus Christi, Texas, area and one is offshore Louisiana in the South Timbalier Lease area. Seven of the CarbonSAFE projects are Phase III, performing carbon storage validation and testing work that will lead to filing for an Underground Injection Control (UIC) Class VI permit. Three of these projects are in Louisiana, two in Alabama, and two in Texas. Two of the awarded projects listed in **Table 4** are CO_2 pipeline front-end engineering and design (FEED) studies looking at pipeline development in the Galveston Bay area and along the coast between Corpus Christi and the Mississippi River near New Orleans. Altogether, the 12 projects listed in **Table 4** represent a $268.8 million investment in CCS development in the region, $78 million from project operators and $190.8 million from the DOE.

FOA	Project Name	Project Area	Performer
FOA 2730 CO_2 Transport Engineering and Design (Round 1) (NETL, 2023a)	FEED study for a 600+ mile regional, commercial-scale, common carrier, CO_2 pipeline system for moving SC (super critical) CO_2 from multiple sources to multiple sinks on the Gulf Coast.	Gulf Coast CO_2 pipeline from Corpus Christi Bay to Mississippi River. Provide connection for sources within 30 miles. Multiple booster stations and "take-off" points. Transport 250 Mt/yr to geologic storage.	Howard Midstream Energy Partnership LLC
	Project Diamond FEED for CO_2	Design pipeline to carry CO_2 across Houston-Galveston region. 60+ miles of pipeline with multiple connection points. Initially link two sources to storage.	Southern States Energy Board
FOA 2610: CarbonSAFE Phase II - Storage Complex Feasibility (NETL, 2022)	Louisiana Offshore CO_2 Hub Repurposing infrastructure to Decrease GHG Emissions. (Formerly Project Lockridge)	Intend to establish an offshore CO_2 storage complex in the Gulf of Mexico South Timbalier Lease Area off the coast of Louisiana.	Southern States Energy Board
	Coastal Bend Carbon Management Project	Feasibility of CO_2 capture and onshore geologic storage under port-owned property.	Port of Corpus Christi Authority
	Coastal Bend Offshore Carbon storage	Assess commercial scale CO_2 geologic storage site in near offshore waters of Coastal Bend region.	Port of Corpus Christi Authority

FOA	Project Name	Project Area	Performer
FOA 2711: Carbon Storage Validation and Testing (Round 1) (NETL, 2023b)	Bluebonnet Sequestration Project	Current design will enable capture and storage of 8 Mt/yr CO_2 for a 15-yr period with potential expansion to 26 Mt/yr and more than 350 Mt potential storage.	Bluebonnet Sequestration Hub
	Lone Star Storage Hub Project	Texas Gulf Coast industrial corridor. Lone Star Storage Hub includes two CO_2 storage sites interconnected by pipeline and will ultimately store up to 15 Mt/yr.	BP Corp North America
	Magnolia Sequestration Project	Enable sequestration of 4 Mt/yr CO_2 for a 15-yr period with potential expansion to 10 Mt/yr.	Magnolia Sequestration Hub
	Longleaf CCS	Stacked storage in south Alabama with initial commitment of 2.6 Mt/yr CO_2 storage, total of 78 Mt CO_2 stored over 30 years.	Southern States Energy Board
	Timberlands Sequestration Project	Capture and store 2 Mt/yr CO_2 from single source in Monroe County, Alabama for 30 years. Capture and storage on single site with 0.3-mile pipeline connection.	Timberlands Sequestration LLC
FOA 2711: Carbon Storage Validation and Testing (Round 2) (NETL, 2023c)	Monkey Island Carbon Storage Project	Establishing and performing a detailed commercial CO_2 site assessment for offshore CCS development for CO_2 storage projects in Louisiana State waters.	Advanced Resources International
	A Critical Carbon Storage Hub for the Louisiana Chemical Corridor	Between Baton Rouge to New Orleans about 50 industrial sources emit about 60 Mt/yr. Project will complete three injection wells for a combine storage potential of 176 Mt over 30 years of injection.	River Parish Sequestration LLC

Table 4. CarbonSAFE projects in the Gulf Coast Corridor.

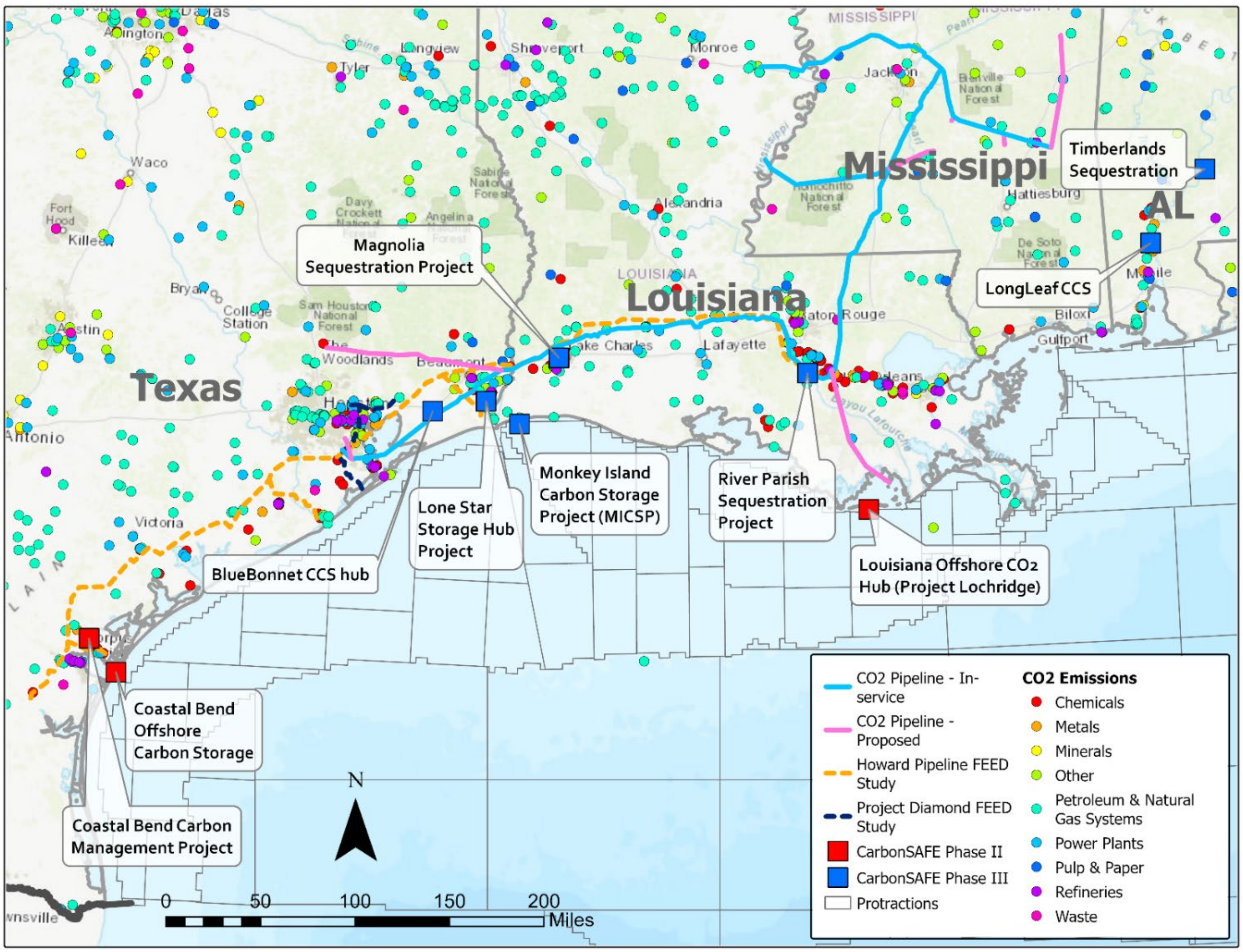

Figure 3. Map locations of CarbonSAFE projects in the Gulf Coast Corridor with CO_2 emissions point sources colored by sector. Information for each project can be found in Table 4. (NETL)

Techno-Economic Assessment

Analysis of the technical, geologic, economic, and social aspects of this CCS opportunity is necessary for successful deployment of CCS technology and eventual attainment of net zero goals. The DOE Office of Fossil Energy and Carbon Management (FECM) NETL has developed techno-economic onshore models to assess the performance and costs of the transport and storage components of the CCS/carbon capture, utilization, and storage (CCUS) value chain. The models can be used individually or together to evaluate the economic impact of various items such as policies, integrated CCS/CCUS networks (i.e., source-to-sink matching assessments), and specific project cost assessments. While an offshore model is in development, the onshore CCS/CCUS models (i.e., CO_2 transport, CO_2 saline storage, and CO_2 EOR) are publicly available and are open source.

NETL's models can be used for such things as comparative analysis of transport and storage of captured CO_2 from a source's perspective. A cost comparison is presented regarding the use of a dedicated pipeline (**Figure 4**) for a source located at the E200 location (source is 200 km east of the Rose Run 3 or 4 storage reservoir) versus the use of a trunkline (**Figure 5**). The trunkline provides good savings on transportation, lowering overall CCS costs for the source, especially at further distances. CCS cost savings for the Frio 3a (a storage formation in the Texas Gulf Coast Basin) is $18 per tonne of CO_2 when relying on a trunkline. However, the lowest cost for CCS is with the use of the Mount Simon 6 (a storage formation in Indiana between the Illinois and Michigan Basins) . Here, CCS cost is $82 per tonne CO_2 with a dedicated pipeline or $78 per tonne CO_2 with a trunkline (Grant et al., 2018). A similar comparative cost analysis was done in the midwestern states between the Mississippi River and Rocky Mountains (Guinan et al., 2023) that demonstrated that CO_2 pipelines will be regional in overall extent. This type of analysis can be applied in the Gulf Coast Corridor and has probably been utilized considering the number of projects underway in this area.

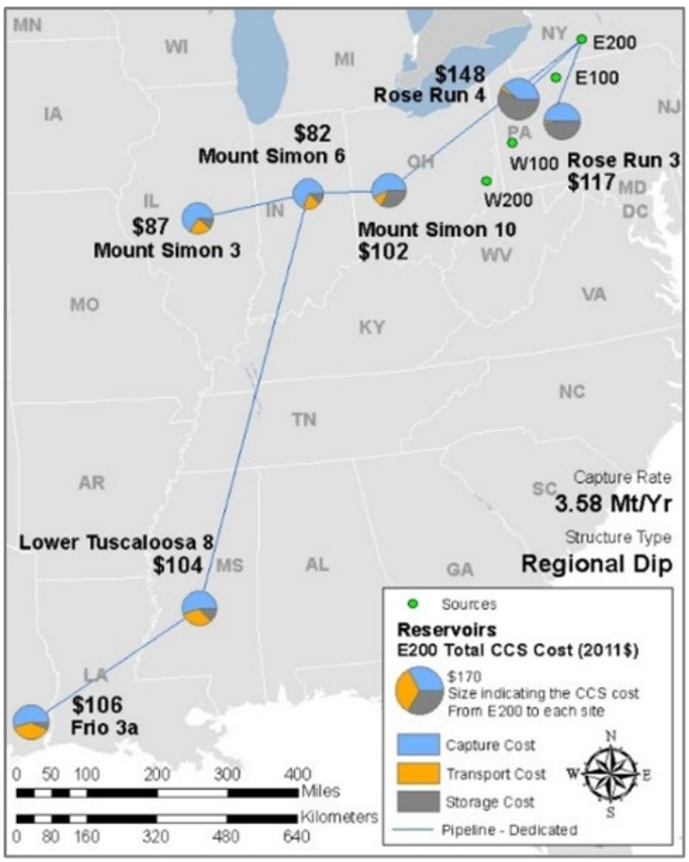

Figure 4. Depiction of a dedicated pipeline system resulting from an assessment of an integrated CCS network in the Eastern United States using CO2_T_COM and CO2_S_COM with NETL capture data to determine CO_2 management options from the CO_2 source's perspective.

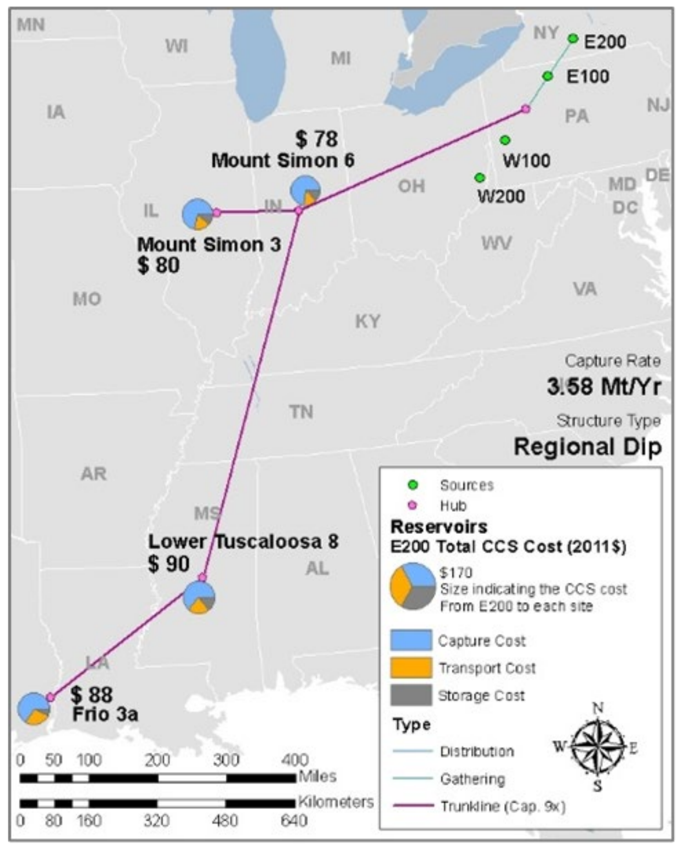

Figure 5. Depiction of a trunkline pipeline system resulting from an assessment of an integrated CCS network in the Eastern United States using CO2_T_COM and CO2_S_COM with NETL capture data to determine CO_2 management options from the CO_2 source's perspective

Two of the CO_2 cost models listed in **Table 5** are used in this analysis, the CO2_S_COM and CO2_T_COM models. The CO2_S_COM model was designed to estimate costs of an onshore CO_2 storage project that meets the Environmental Protection Agency's (EPA) UIC Class VI and Subpart RR regulations. It has a geologic database with 314 storage/reservoir formations across the lower 48 states, 117 of which are located along the Gulf Coast. The model also provides financial responsibility instruments per Class VI regulations, a financial module, drilling costs, testing, and monitoring costs as well as capital and operating costs. A first-year break-even price to store a tonne of CO_2 is calculated by the model. This price can be calculated for one potential storage reservoir or multiple reservoirs. The range of storage costs for Gulf Coast CO_2 storage reservoirs is illustrated in **Figure 6**; lower cost, higher quality storage reservoirs are plotted in the upper left-hand side.

Model Type	Model Name	Trade Name
Saline Storage	FECM/NETL CO_2 Saline Storage Cost Model	CO2_S_COM
	FECM/NETL Offshore CO_2 Saline Storage Cost Model (planned release 2024)	CO2_S_COM_Offshore
FECM/NETL Onshore CO_2 EOR Evaluation System	FECM/NETL CO_2 Prophet Model	CO2 Prophet
	FECM/NETL CO_2 EOR Cost Model	CO2_E_COM
	FECM/NETL Onshore CO_2 EOR Evaluation Tool (planned release 2024)	CO2_E_EvTool
Transport	FECM/NETL CO_2 Transport Cost Model	CO2_T_COM

Table 5. FECM/NETL CO_2 storage and transport-related techno-economic models

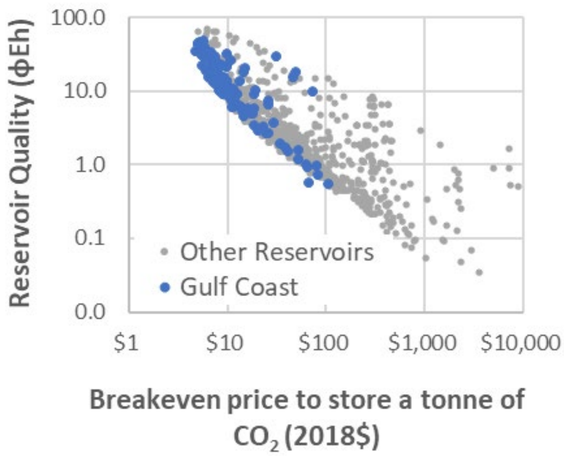

Figure 6. Reservoir quality vs first-year break-even price to store a tonne of CO_2. Better quality reservoirs are in the upper left of the diagram.

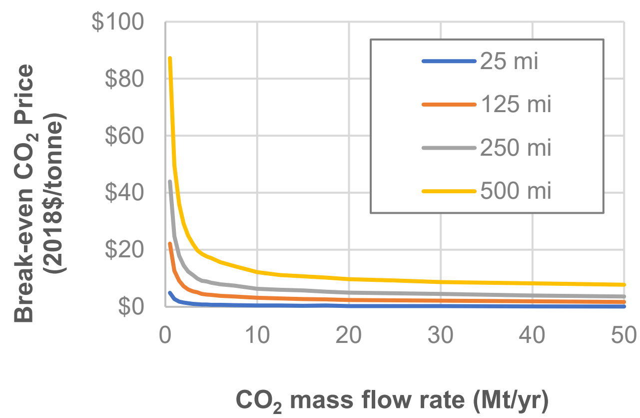

Figure 7. Break-even price to transport a tonne of CO_2 over various distances.

The CO2_T_COM model calculates the first-year break-even price to transport a tonne of CO_2 between two points. These two points usually represent the source and storage location but can also represent hub transfer points as illustrated in the maps of **Figure 4** and **Figure 5**. Inlet and outlet pressure are provided by the modeler. It assumes that the CO_2 is transported as a dense phase liquid and optimizes pipeline diameter and the number of booster pumps. Transport costs are illustrated in **Figure 7**. Unit cost of transporting CO_2 falls with increasing mass of CO_2 transported, especially over longer distances. Transport costs also increase with increasing distance of transport. For the analysis in **Figure 4** and **Figure 5**, three costs are summed to provide the CCS cost. The third component is the cost of capture, which was provided by NETL's "Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity," (James et al., 2019) or NETL's "Cost of Capturing CO_2 from Industrial Sources" (Summers et al., 2014).

Though the initial version of the Offshore CO_2 Storage Cost Model is not yet complete (planned 2024 release), NETL conducted an analysis of a potential pilot CO_2 storage project offshore in the Gulf of Mexico using other means (Wijaya et al., 2022). A multicriteria analysis was used to help select the project location in federal waters. This particular analysis utilizes pertinent data associated with the prospective goal to high-grade areas of interest. For selection of an offshore CO_2 storage site, parameters selected for analysis would include those related to geology, infrastructure, source-to-sink, development, and risks. Other parameters could also be selected. The weight of importance for each parameter can be adjusted depending on the analytical goal: saline storage or EOR or shallow-water operations (Wendt et al., 2020).

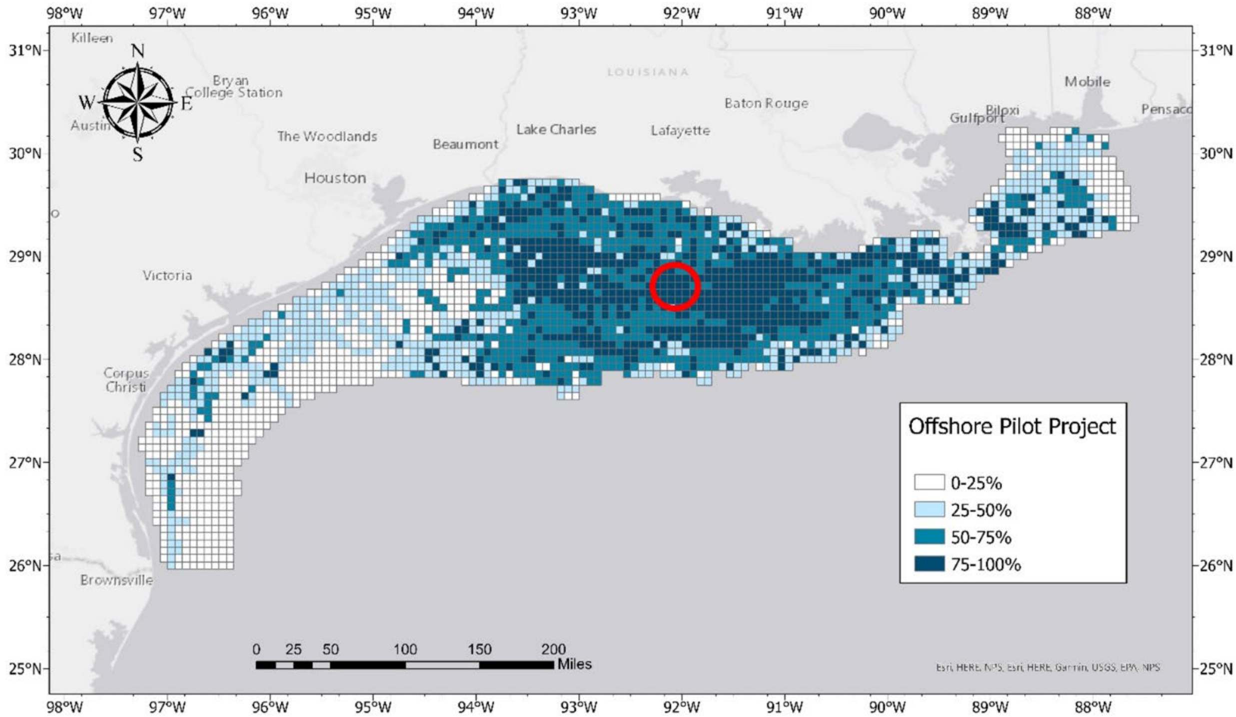

Figure 8. Application of multicriteria analysis in the selection of location for pilot project analysis. (Wendt et al., 2020; Wijaya et al., 2022)

The prospective pilot project is 95 miles from shore in 145 feet of water. It would inject 0.5 Mt/yr of CO_2 for 12 years, storing a total of 6 Mt of CO_2. At the time of the study, the injected mass of CO_2 was the smallest capture volume needed to quality for tax credits from Section 45Q per the Bipartisan Budget Act of 2018, which can be claimed for a period of 12 years. Total cost of the project utilizing new equipment and pipeline is $2,114 million, about $225 per tonne of CO_2 injected.

CO_2 Injection Permitting

Onshore, underground injection of captured CO_2 is regulated by EPA's UIC Class VI Injection regulations. Regulations associated with a Class VI permit were published in the Federal Register in December 2010. The first Class VI permit was issued in September 2014 for the Illinois Industrial Carbon Capture project in Decatur, Illinois (Greenberg, 2016). As of the beginning of 2024, 179 Class VI permit applications, representing 63 projects, have been filed with the EPA (EPA, 2024). A significant number of permits (43%) and projects (46%) are in the Gulf Coast Corridor. EPA intends to review each application and issue a permit within or close to two years. This timing depends on several factors including the level of complexity of the project and completeness and quality of the submitted application. To facilitate issuing Class VI permits, states can apply for and be granted primacy over the administration of Class VI permits. To date, three states have primacy: North Dakota, Wyoming, and Louisiana. Louisiana's Class VI primacy was published in the Federal Register January 5, 2024 (Federal Register, 2024). Texas, West Virginia, and Arizona are working on their Class VI primacy applications (Thompkins, 2023). For Texas and Louisiana (EPA Region 6) and other coastal states in the Gulf of Mexico (EPA Region 4), EPA's Class VI regulations also apply to state waters.

Acquiring a Class VI permit for a CO_2 injection well is essentially a two-step process. Based on a successful application review, EPA issues a permit to drill and test an injection well (pre-injection in **Table 6**). This test data is incorporated with the submitted application information to confirm/support the analysis provided by the earlier submitted data. With EPA approval, a final permit is issued and CO_2 injection begins. Injection operations continue for a period per permit instructions, most likely 30 years. Once injection operations cease, the operator monitors the CO_2 storage reservoir post-injection until non-endangerment is established and EPA approves site closure (Thompkins, 2023).

Table 5. Comparison of EPA Class VI CO_2 injection and storage regulations and BOEM/BSEE-proposed regulatory framework for offshore carbon storage.

EPA Class VI Permitting Process					
N/A	N/A	**Pre-Construction**	**Pre-Injection**	**Injection**	**Post-Injection and Site Closure**
N/A	N/A	• EPA performs completeness evaluation and technical review of application materials • EPA makes draft permitting decision (denial or permitted) • Draft permit is publicly noticed • EPA prepares final permit decision	• Well owner or operator (o/o) constructs well • Well o/o collects additional data per permit requirements and submits to EPA • EPA reviews additional data and evaluates whether authorization of injection is appropriate	• Well o/o collects monitoring data and submits reporting data to EPA • Permit is updated as appropriate	• Well o/o continues to collect monitoring data and submits reporting data to EPA • Permit is updated as appropriate • Well o/o demonstrates non-endangerment to EPA • EPA approves site closure
BOEM/BSEE Regulatory Framework for Offshore Carbon Storage					
Pre-Sale Site Selection	**Lease Sale**	**Project Review**		**Injection and Monitoring**	**Site Closure and Decommissioning**
• Regional scale assessment • Stakeholder input • Multiple-use considerations • National Environmental Policy Act analysis	• Terms and conditions • Location of offerings • Size of offerings	• Site characterization • Risk management • Plan/permit submittal and revision • Static/dynamic modeling		• Safety and environmental monitoring • Pressure monitoring • CO_2 plume migration	• Ensure containment and CO_2 plume stability

The Bureau of Ocean Management (BOEM) manages the development of energy and mineral resources on the U.S. Outer Continental Shelf. The Bureau of Safety and Environmental Enforcement (BSEE) provides regulatory oversight to conserve these resources, protect the offshore environment, and promote safe operations. BOEM and BSEE operations are governed by the Outer Continental Shelf Lands Act (OCSLA). The OCSLA was modified in 2021 by the Infrastructure Investment and Jobs Act, also known as the Bipartisan Infrastructure Law (BIL) that was recently modified providing authorization for the Secretary of the Department of Interior (DOI) to develop regulations for CO_2 storage operations in federal offshore waters. DOI's framework for regulation of offshore CO_2 storage operations consists of five stages and is illustrated in **Table 6**. While the details are still being sorted out, BOEM/BSEE's Project Review stage appears consistent with EPA's Pre-Construction and Pre-Injection stages. EPA's Injection and Post-Injection stages align well with BOEM/BSEE's Injection and Monitoring and Site Closure and Decommissioning stages. Both BOEM/BSEE and EPA have Site Closure, a point in time where the operator demonstrates non-endangerment to the EPA or can ensure containment and CO_2 plume stability for BOEM/BSEE (Maclay, 2023; Thompkins, 2023).

It appears that there will be a high level of continuity in regulations governing CO_2 storage operations onshore and offshore. Like EPA before them, BOEM/BSEE are sorting through financial and economic considerations, leasing issues, liability, emergency response and mitigation, monitoring and reporting, and decommissioning and other considerations regarding offshore CO_2 storage operations (Maclay, 2023).

Financing

Financing CCS project development and operations is a primary challenge that is evolving toward a solution. A key component here is the 45Q tax credit and the Inflation Reduction Act (IRA), signed in August 2022, which provided for some significant changes to 45Q credit values (IRA, Sec. 13104). To earn a 45Q tax credit, the IRA lowered the qualifying mass of captured CO_2 for power generation facilities from 500,000 tonnes to 18,750 tonnes, for industrial facilities from 100,000 tonnes of CO_2 captured to 12,500 tonnes, and for direct air capture (DAC) from 100,000 tonnes of CO_2 captured to 1,000 tonnes. For power generation or industrial facilities, the IRA increased the value of the 45Q tax credit from \$35 per tonne to \$60 per tonne for captured CO_2 that is utilized, for example, for EOR. Should these facilities decide to geologically store their captured CO_2 without utilization, the 45Q tax credit value increases from \$50 per tonne to \$85 per tonne. DAC 45Q tax credit values increased from \$35 per tonne to \$130 per tonne for utilization and from \$50 per tonne to \$180 per tonne for storage.

Construction on a qualifying CCS project must begin before January 1, 2033. The captured CO_2 must be certified as sequestered via a Subpart RR monitoring, reporting, and verification plan. The 45Q credit can be claimed over a period of 12 years and is delivered to the owner of the capture equipment. Regardless of the change in the value of the 45Q tax credit and qualifying mass of CO_2 captured, a 45Q tax credit is now directly paid to the qualifying owner of the capture equipment, whether as a fully refundable payment or as a non-refundable tax credit. The direct payment is only for five years. For the remaining seven years of eligibility, the incentive is a regular tax credit and can be sold to any tax equity investor who can make full use of the credit's value. There are also wage and apprentice requirements tied to earning the full value of the 45Q tax credit. The value of the credit can be reduced by 80% if these requirements are not met.

CO_2 pipeline development, can take advantage of another financing opportunity that is being provided by the DOE Loan Program Office. The CO_2 Infrastructure Finance and Innovation program was established by the Infrastructure Investment and Jobs Act ("IIJA"), also know as the Bipartisan Investment Law. (BIL). BIL will invest $2.1 billion to support CCUS and DAC technology deployment by financing projects that build shared CO_2 transport infrastructure (CIFIA, 2022).

Conclusions

The approximately 490 Mt/yr of CO_2 emissions from about 1,000 sources along the Gulf Coast Corridor is significant, equating to about 42% of the emissions in the lower 48 states. CO_2 emission sources and potential storage reservoirs in the Gulf Coast Corridor are frequently in close proximity, likely requiring the development of pipeline(s) on a regional or local scale, while being amenable to the creation of storage hubs where two or more sources connect to two or more injection wells. The estimated CO_2 storage resource potential of 500 billion Mt here is more than ample to support this nascent industry far into the future.

Between private enterprise and DOE funding support, some 43 projects are underway or have been announced in the region, many of which are storage hubs. With the passage of the IRA in 2022, many corporations are taking advantage of the improved financial outlook of CCS and are exercising the opportunity to develop these projects to reduce their CO_2 emissions. The CCS projects presented in this paper represent about 30 different operators, a list that continues to grow. Denbury was an early mover here, utilizing a pipeline network that they developed for their CO_2 EOR projects in the area for gathering CO_2 emissions from anthropogenic sources near their pipeline. ExxonMobil has also been pioneering the CCS industry in the Gulf Coast Corridor by orchestrating a consortium of like-minded companies in the establishment of the Houston Ship Channel CCUS Hub. They have also doubled down on their CCS footprint by more recently acquiring Denbury Resources. To date, offshore activity is confined to a few projects in state waters such as Bayou Bend CCS in Texas, led by Chevron and Talos, or the Louisiana Offshore CO_2 Hub, a CarbonSAFE Phase II project. However, with greater understanding of costs and opportunity, utilization of offshore reservoirs will undoubtedly expand.

CCS opportunities abound in this resource rich region. With organizations moving expeditiously to take advantage of the opportunities, well-informed decision making is paramount. FECM/NETL's suite of open source techno-economic models provide an excellent resource for assessing the true potential of CCS/CCUS in the region. Based on current activity, storage resource potential, and the abundance of emissions sources, CCS has an unquestionably bright future in the Gulf Coast Corridor.

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