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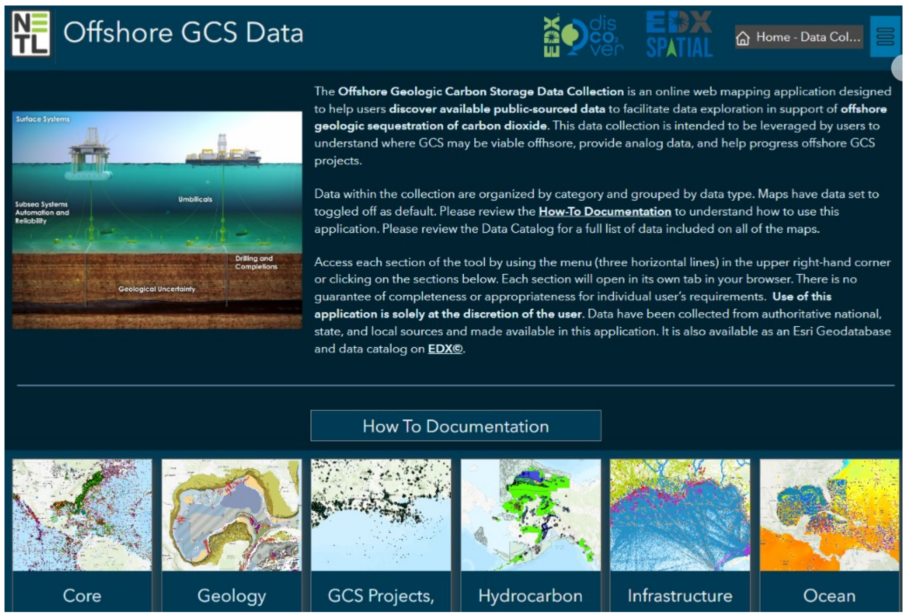

Offshore Geologic Carbon Storage Data Collection and Data Gaps Analysis

30 June 2024

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Office of Fossil Energy and Carbon Management

DOE/NETL-2024/4804

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Cover Illustration: The geology section of the Offshore Geologic Carbon Storage (GCS) Data Collection. The Offshore GCS Data Collection web application enables users to view and interact with data available to support carbon sequestration offshore.

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An electronic version of this report can be found at:

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The data in this report can be accessed from NETL's Energy Data eXchange (EDX) online system (https://edx.netl.doe.gov) using the following link: https://edx.netl.doe.gov/dataset/offshore-geologic-carbon-storage-gcs-data-collection-web-application

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Acronyms, Abbreviations, and Symbols

Term	Description
AI	Artificial intelligence
AIIM	Advanced Infrastructure Integrity Modeling
BOEM	Bureau of Ocean Energy Management
CIIAM	Climatalogical Instantaneous Isolation and Attraction Model
CCS	Carbon capture and storage
CO_2	Carbon dioxide
CS TVA	Carbon Storage Technical Viability Approach
EJ	Environmental Justice
EDX	Energy Data eXchange
GCS	Geologic carbon storage
GIS	Geographic Information System
OCS	Outer Continental Shelf
ML	Machine learning
NETL	National Energy Technology Laboratory
SIMPA	Spatially Integrated Multivariate Probabilistic Assessment
SJ	Social Justice

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ABSTRACT

Decarbonization strategies are being implemented worldwide, and research and development are accelerating geologic carbon storage (GCS) efforts. Offshore GCS presents specific advantages as a component of decarbonization strategies, including distance from population centers, security of the overlying water column, lower impact of CO_2 leakage, some existing infrastructure, simplified land ownership and leasing processes, and vast potential CO_2 storage resources within sedimentary basins and igneous deposits. However, challenges arise due to distance from major point sources, infrastructure necessary to transport CO_2 offshore, immature regulation and procedures, and extreme metocean (meteorological-oceanographic) environments, that vary depending on the location and setting of the GCS project. In this report, we present an interactive data collection and data gaps analysis to aggregate, understand, and disseminate the data that are publicly available to support offshore GCS in the United States. This data collection and data gaps analysis can be leveraged by stakeholders to understand where GCS may be viable offshore, create GCS project analogs, and address challenges to GCS in offshore environments.

1. INTRODUCTION

Offshore geologic carbon storage (GCS) has been taking place since 1996, and there are over 30 active projects, with recent new leases in the North Sea (Choisser et al., 2023). Beginning with the Sleipner in 1996, offshore carbon capture and storage (CCS) was initiated as a means to capture and store CO_2 produced at a high percentage with natural gas, removing it from the produced gas before the gas was transported to shore. While this process is ongoing at Sleipner, in the Santos Basin of Brazil, and in various other locations worldwide, including southeast Asia, GCS has also expanded and developed as technology advanced.

In recent years, initiatives to combat climate change by reducing CO_2 emissions have motivated offshore GCS projects (e.g., Infrastructure Investment and Jobs Act, 2021). Despite these ongoing efforts, offshore GCS remains a relatively nascent industry, therefore aggregations and summaries of offshore projects, opportunities, and learnings are disparate. Access to data and understanding of the data required to begin offshore GCS assessments and projects can hinder project progress. Because of the immature status of offshore GCS, the majority of data for the offshore have been collected with different motivations and for other project types, primarily oil and gas exploration and production, risk mitigation, and climate analysis. Here, we aggregate available offshore data for the United States into a new data collection and group datasets by category to understand what types of data are available and their spatial distribution.

2. DATA COLLECTION AND WEB APPLICATION

Data were gathered from internal and external sources and aggregated into a catalog a series of maps (Mulhern et al., 2024). These maps comprise the Offshore Geologic Carbon Storage (GCS) Data Collection which can be accessed and interacted with through an ESRI Arc Enterprise Story Map Collection web application. The combined collection contains a Data Collection Overview Story Map which describes how to use the collection and a series of nine interactive maps (Figure 1). Each map has a variety of data groups within which each layer can be turned on and off. The user can navigate around the map and view the data spatially and in any layer combinations they desire. The web application also links to a "sandbox" feature of Energy Data eXchange (EDX) Spatial, an interactive tool where users can develop their own maps and data combinations using the "Create Custom Map" button.

Within the online collection, the data gathered are hosted through online web services which link to the data via their original online locations. This cloud-based method of calling data has distinct advantages relative to more traditional hard drive stored, or static download type datasets. Leveraging online web data services allows the user to see the latest, most up-to-date version of each data type. The data are hosted by their original owner, with many layers coming from National Energy Technology Laboratory's (NETL) EDX Spatial Enterprise server. This method of data access ensures that data remain evergreen, rather than static data versions. It also leaves data ownership with the original authoring institution, helping to keep data integrity in place. This helps avoid data duplication and makes it less likely that errors are introduced into the data during download or duplication processes. It also reduces local data storage capacity requirements.

The online web browser application format allows the user the ability to access, visualize, and manipulate the data online without requiring spatial visualization software, often expensive and/or proprietary in nature and requiring computer memory and computation power, not necessary for a web-browser application. The ArcGIS Enterprise web application format being leveraged is also compatible with NETL's EDX Spatial platform, allowing this visualization tool to be seamlessly integrated with other applications and landing pages in development.

Creating a set of maps also allows the research team to point the user to an entire series of maps at the same time. Labels, categorization, and grouping provide built in organization for the user, allowing them to easily find desired information independently.

The web browser application is intuitive and easy to use. It is also accompanied by explanatory documentation for those less familiar with mapping software. Users can toggle layers on and off on each map to view data in different combinations (Figure 2). The user can easily navigate back to the landing page to access other maps using the home button in the top corner of each map page (Figure 3).

Some disadvantages of this web hosted format are that data are not available in a singular location for download and analysis. Remedying this issue may be the focus of research in the future. Additionally, using links to cloud stored data can results in delays and lags during loading.

Accompanying the database is a downloadable catalog which includes the files, labeled with the map and group designations applied. This catalog allows the user to search, sort, and filter the full dataset to aid in querying.

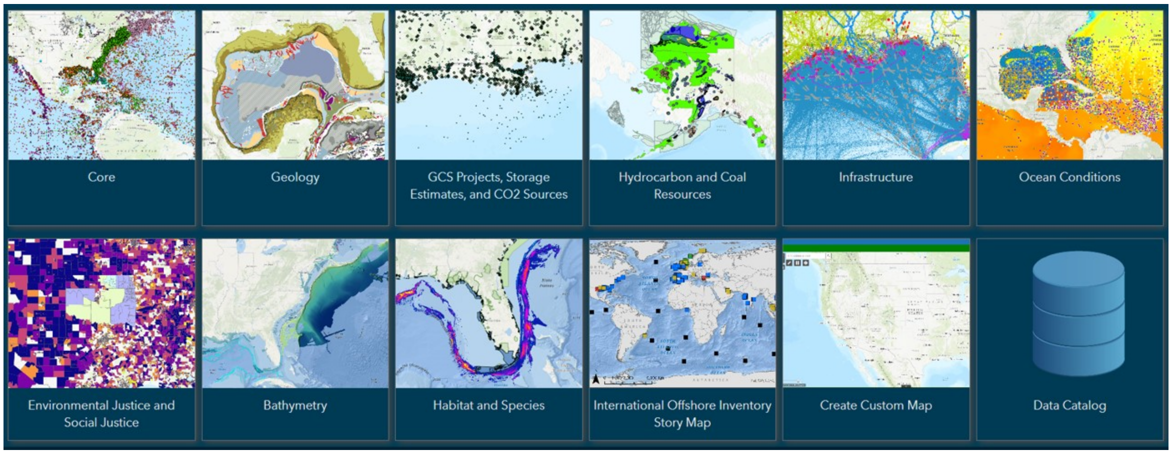

Figure 1: Offshore Geologic Carbon Storage Data Collection contains nine interactive maps displaying data grouped by topic, a story map of the International Offshore Inventory of GCS projects around the globe, a Create Custom Map feature where users can build unique layouts, and a link to the data catalog.

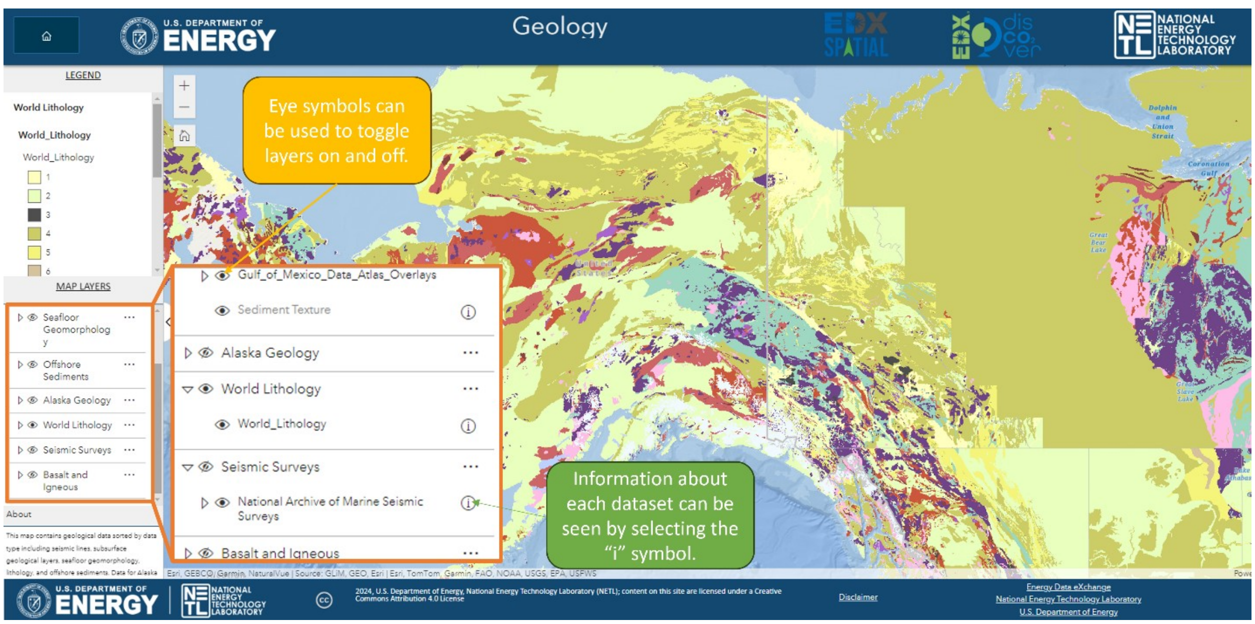

Figure 2: Example interactive map showing the layer groups and individual layers which can be toggled on and off.

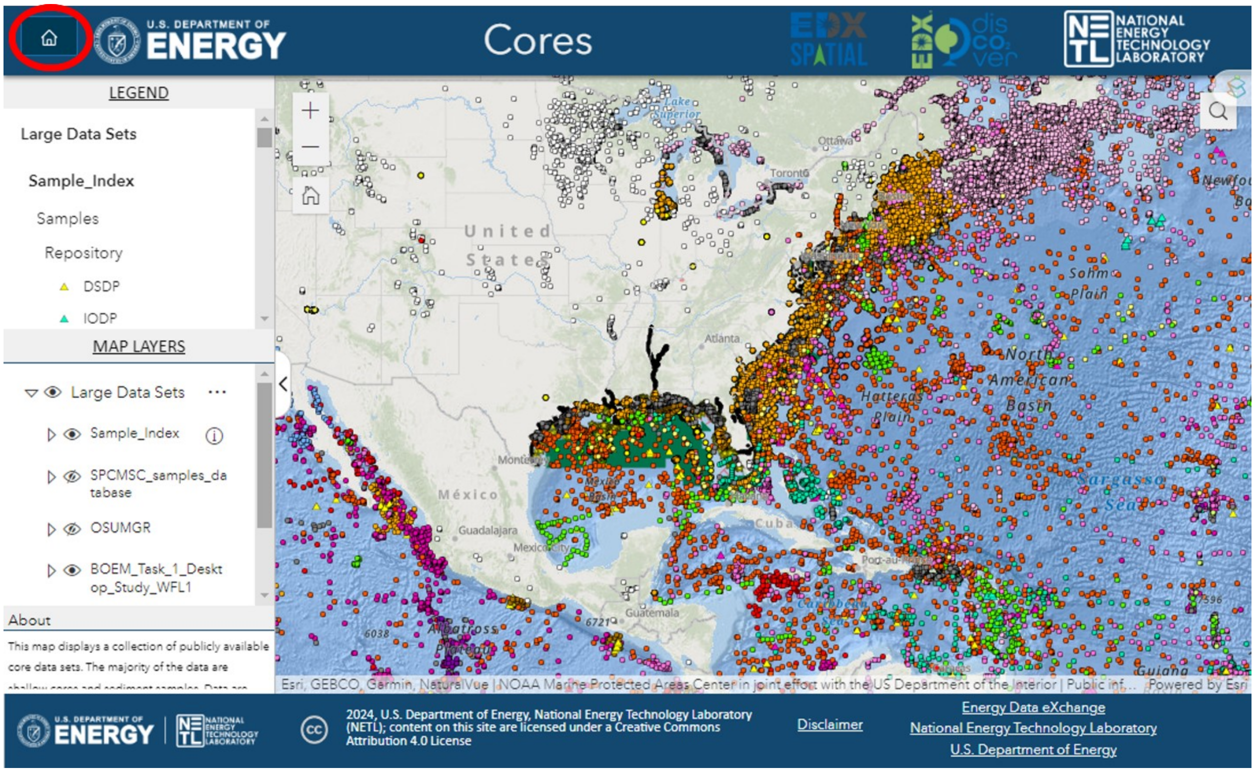

Figure 3: Example map showing the home button (red circle) which can be used to easily navigate back to the landing page.

3. DATA GAPS ANALYSIS

Once the Offshore Geologic Carbon Storage Data Collection was developed, the available datasets were compared against the Carbon Storage Technical Viability Assessment Matrix (CS TVA) (Mulhern et al., 2023) to understand what data types are publicly available relative to what is needed for a viability assessment. The matrix contains five main categories, each of which has various sub-categories and components. Tables developed for each of the categories show the status of the data currently in the data collection (see Appendix). The assessment was performed by region using the Outer Continental Shelf (OCS) regions used by the Bureau of Ocean Energy Management (BOEM) for carbon storage assessments (BOEM, 2024).

Currently the data collection has a moderate amount of data on reservoir suitability, primarily focused in the Gulf of Mexico and Alaska, which have been the epicenter for subsurface exploration to date. There are some mapped geologic layers with depth, temperature, and pressure information. While these data are included, significantly more data exist and could be collected for more effective analysis. Data for the Pacific and Atlantic are significantly sparser, correlating with the decreased drilling activity and seismic data along those coastlines (BOEM, 2024 and maps therein). Information on the subsurface and the state of exploration in an area can be gained from the Hydrocarbon and Coal Resources map.

The available data for the Retention and Geomechanical Risks category are abundant in existing EDX datasets, however, are less common in the online web data service datasets gathered into this collection. Subsurface data on faulting, traps, and seals are central to understanding GCS reservoir plays. Mapped faults are available for the contiguous United States as well as Alaska. Some information could be interpreted from publicly available seismic data, however, additional subsurface information, such as well logs, would be required to perform that analysis. Information on existing traps and seals can be inferred from the data in the Hydrocarbon and Coal Resources map. Extensive information on traps has been gathered as part of the Prospective Seal Name Catalog for U.S. Sedimentary Basins V1.0 (Pantaleone et al., 2024) and can be integrated into this data collection in the future.

Hazards assessment and risk mitigation have been the focus of past research and consequently a comprehensive data for surface hazards assessment is aggregated. Extensive existing infrastructure data are gathered in the collection. Overburden drilling hazards have more scarce data available, however, can be interpreted from some existing subsurface data for the Gulf of Mexico, where exploration has been prolific. However, there are abundant data on existing wells, water depth, topography, climate, natural hazards, and infrastructure hazards. Maps on Ocean Conditions and Habitat and Species Data are important for hazards assessments. These raw datasets are accompanied by available data and tools developed for risk assessment, such as machine learning (ML) informed landslide susceptibility maps and metocean pathway prediction outputs from the Climatalogical Instantaneous Isolation and Attraction Model (CIIAM; Duran et al., 2018).

Siting, Regulatory, and Jurisdictional Feasibility is a central category to understand technical viability, however, the data types needed to inform this category are less often spatial than those for other categories within the CS TVA Matrix. There are some boundary layers included in the data collection that are helpful for interpreting jurisdictional boundaries. The map of GCS Project, Storage Estimates, and CO_2 sources also includes locations of Class VI permit applications which can be combined to understand ongoing GCS in a given area. However, more information could be gathered to understand governmental policies and the maturity of the regulatory framework.

Maps by county leverage census data to denote a variety of socioeconomic categories including tax credit eligibility and social parameters.

The Environmental Justice (EJ), Social Justice (SJ), and Community Impacts data are currently relatively limited and have been gathered where available. Some social vulnerability and economic data are included. However, novel data on community sentiment toward industrial development and GCS would likely need to be gathered and generated, this is currently the focus of ongoing research within NETL.

4. DISCUSSION

While the current data collection gathers available resources into one location, it is currently limited by the methods being used. The data collection includes only those which are hosted online by either NETL or other organizations. While the data gaps analysis was expanded to include broader data hosted and archived by NETL via EDX, additional time is required to transition the full EDX dataset to the EDX Spatial Enterprise in order for the data to be integrated into this data collection tool.

The CS TVA Matrix is a helpful guide to evaluating data resources to support carbon storage viability assessments. The components within the matrix require multiple data types for interpretation, and inversely, data types can be leveraged for multiple components. A full and detailed database evaluation exercise is required to link the matrix to data required. This evaluation process is underway as part of ongoing research to develop data gaps analyses which will be more rigorous and thorough than the first-pass analysis presented here.

The focus of this current first pass data collection effort has been on spatial data gathering and aggregation. Using the CS TVA Matrix to categorize data available reveals data gaps, some of which are being highlighted because the data types required to fill those gaps are not data types that are traditionally displayed spatially. For example, governmental policies for onshore permitting are established, but not currently mapped spatially for easy integration into a spatial dataset. Non-spatial data types will need to be gathered and rendered spatially to fill these gaps.

Two of the five major categories of the matrix are subsurface data types. The current dataset does not include a significant amount of subsurface data (layer, faults, models, pressure data, etc.) as these data have traditionally been gathered as part of proprietary projects. It should be noted that there are vast collections of proprietary data in addition to those aggregated and archived via EDX.

Existing data primarily target oil and gas reservoirs or coal formations as those have been the focus of exploration in the past, therefore GCS projects targeting saline formations may not be well-supported by existing data. Existing data more aptly support analysis of depleted oil and gas reservoirs for GCS storage. Integrating additional publicly available datasets would enable further analysis to highlight data gaps.

Other data types, such as community sentiment information, simply do not exist or have not been formally documented. Environmental justice and social justice data types are relatively novel, and methods are still being developed to best gather and accurately generate these data types. Therefore, it is unsurprising that there is a significant gap in this information type. Tools are being developed to address these data gaps.

5. NETL'S OFFSHORE DATA TOOLS

Over the last 13 years NETL has taken a leading role developing tools for offshore assessments which can be leveraged and used for a variety of purposes including data access, resource management, hazards and risk assessment, and planning and evaluation, and, importantly, tools that can address data gaps (Figure 4). These tools can make predictions to address resources, risks, hazards and impacts in support of project planning and evaluation for the entire engineered natural offshore system, from the subsurface, through the water column to the coastline.

To predict subsurface properties, including reservoir properties, the Subsurface Trend Analysis Method can be applied (Rose et al., 2020). This method utilizes geologic information to constrain spatial predictions of subsurface properties and can be integrated into the workflow for the Offshore CO_2 Storage Calculator, which calculates potential volumes of storage resources for saline reservoirs (Romeo et al., 2022). The Spatially Integrated Multivariate Probabilistic Assessment (SIMPA) tool utilizes fuzzy logic to predict subsurface structural complexity, contributing to knowledge of potential hazards (Justman et al., 2020). At the seafloor, several modules with the Ocean & Geohazard Analysis Tool can address potential hazards including submarine landslides and earthquakes (Mark-Moser et al., in prep). Additional modules within the Ocean & Geohazard Analysis tool address the metocean environment, including probabilistic and statistical analyses for extreme wind, wave, and current events and metocean pathways for hazard material transport via CIIAM (Duran et al., 2018). Advanced Infrastructure Integrity Modeling (AIIM) utilizes multiple artificial intelligence/machine learning (AI/ML) models to address infrastructure integrity (Dyer et al., 2022; Dyer et al., 2024). The Spatially Weighted Impact Model and the Cumulative Spatial Impact Layers tool can be applied to understand the impacts of deleterious events in the offshore and at coastal areas (Romeo et al., 2015; Romeo et al., 2019). Finally, the Variable Grid Method can be applied to understand data that underlie these analysis (Bauer et al., 2015).

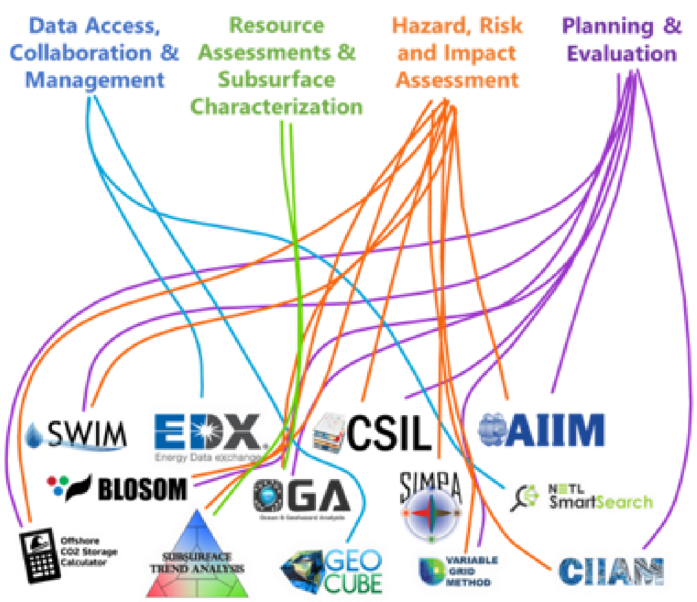

Figure 4: Schematic graphic summarizing NETL's offshore tools and resources.

6. CONCLUSIONS

The Offshore Geologic Carbon Storage Data Collection is a novel tool that stakeholders can use to interactively spatially view data available to support offshore GCS. This tool is currently in the developmental stage and will continue to be expanded as additional data are migrated to web service format required to enable inclusion. The current web application provides a centralized location for GCS data gathering and assessments. The data collection gathers hazards, species, and surface data into one location. Gaps analysis, which was expanded to include a broader swath of EDX and NETL available data, indicates that subsurface data types in particular should be the focus of future data gathering efforts. Additionally, environmental and social justice data may need to be generated for analysis.

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APPENDIX A - COMPREHENSIVE TABLE OF DATA GAPS ANALYSIS

(green)	Data are available
(yellow)	Insufficient data are available
(orange)	Limited or no data are available within the current collection

Reservoir Suitability					
Sub-Cat	**Components**	**Gulf of Mexico**	**Atlantic**	**Pacific**	**Alaska**
Reservoir Quality	Reservoir Porosity; Reservoir Permeability; Depositional Environment, Lithology, Grainsize, and Sorting; Diagenesis, Grain Scale Deformation, Secondary Alteration, Reservoir Fractures	Some aggregated well data and regional geologic interpolations for reservoir properties exist, primarily for the Gulf of Mexico.	A limited number of wells (~30) were drilled in the late 1970s and no drilling has taken place since then. Core data are available for seafloor sediments.	Drilling data and information for coastal California are limited. Core data are available for seafloor sediments.	Extensive well data for oil and gas regions is available. Core data are available for seafloor sediments.
Reservoir Geometry	Reservoir Thickness Distribution, Spatial Extent, and Lateral Variability; Reservoir Internal Variability, Geobody Architecture, and Net-to-Gross; Depth to Top of Formation	Some mapped extent layers and interpreted well data exist with limited coverage. Seismic datasets are available. Some depth to reservoir top layers included.	Limited to no information is available.	Data status is uncertain but no data are included in current collections.	Data likely exist but are not currently included in collection.
Reservoir Conditions	Reservoir Temperature; Reservoir Pressure; In-situ Fluids, Salinity, and CO_2 Density	Some aggregated well data and regional geologic interpolations for reservoir properties exist, primarily for the Gulf of Mexico.	Limited to no information is available.	Data status is uncertain but no data are included in current collections.	Data likely exist but are not currently included in collection.

Retention and Geomechanical Risk					
Sub-Cat	**Components**	**Gulf of Mexico**	**Atlantic**	**Pacific**	**Alaska**
Seals and Pressure	Proven/Demonstrated Effectiveness of Top Seal	Some aggregated well data and regional geologic interpolations of seal properties exist. Included in some interpretations of nationwide datasets.	Understanding of seals is limited by sparse drilling and seismic data for the region.		Seals are mapped in regions where oil and gas exploration has taken place.
	Top Seal Thickness and Spatial Variability				
	Top Seal Viability, Fracture Pressure, Lithology, Porosity, and Permeability				
	Secondary Confining Unit Presence and Viability				
	Bottom Seal, Downward Flow, and Induced Seismicity				
	Pressure Communication with Reservoir				
Trap	Geological Trap Type and Certainty	Aggregated data on traps are available. Some information can be garnered from existing hydrocarbon field information.	Limited data on traps for the region are based on limited subsurface mapping.		Some information can be garnered from existing hydrocarbon field information.
	Trap Viability and Previously Demonstrated Integrity				
Faulting	Fault Presence, Depth, Spacing, Magnitude, Status (Active vs. Inactive)	Mapped faults from USGS. Some earthquake occurrence data are aggregated.	Mapped faults from USGS. Some earthquake occurrence data are aggregated.	Mapped faults from USGS. Some earthquake occurrence data are aggregated.	Mapped faults from USGS. Faults mapped for Alaska are included in dataset.
	Fracture Type and Density				
	Fault Reactivation Likelihood with Increased Pressure				
	Fault Gouge and Cementation/Fault Seal Viability				
	Earthquake Prevalence and Likelihood				

Hazards					
Sub-Cat	**Components**	**Gulf of Mexico**	**Atlantic**	**Pacific**	**Alaska**
Subsurface Hazards	Overburden Drilling Hazards	Some geologic layers are mapped and included. Overburden hazards can be interpreted from seismic.	Limited drilling has taken place in the region, therefore, subsurface hazards are relatively unconstrained.	Subsurface hazards are understood where drilling has taken place but more information is needed for unexplored areas.	Some geologic layers are mapped and included. Overburden hazards can be interpreted from seismic.
	Pre-existing Well Density, Depths, and Ages				
Surface Hazards	Depth and Certainty of Drinking Water Aquifers in Overburden	Hurricane paths are available for the Gulf of Mexico. Wind speed data are included. Seafloor geomorphology and offshore sediments data are available. Multiple types of infrastructure layers are available.	Multiple types of infrastructure layers are available.		
	Water Depth (if offshore)				
	Topography or Location Risks				
	Climate, Weather, and Metocean				
	Natural Hazards - Land Surface or Seafloor Hazards				
	Infrastructure Hazards				

Siting, Regulatory, and Jurisdictional Feasibility					
Sub-Cat	**Components**	**Gulf of Mexico**	**Atlantic**	**Pacific**	**Alaska**
Land Rights/Use	Surface - Land Ownership and Access	Leases and boundaries are included in dataset.			
	Subsurface Pore Space Rights				
Population and Habitats	Protected Areas and Sensitive Habitats	Many species and habitat data are included. Census data are available.	Some species and habitat data available. Census data are available.		
	Population Density				
Jurisdiction	Jurisdictional Boundaries, Support, and Stability	Maps of tax credit eligibility distribution are available. County maps by various eligibility labels are available.			
	Governmental Policies and Incentives				
Regulatory	Maturity of Regulatory Framework	Class VI permit locations and status are available as well as ongoing and historic GCS projects.			
	Maturity of CCS Activity in Area				

Environmental Justice (EJ), Social Justice (SJ) , and Community Impacts					
Sub-Cat	**Components**	**Gulf of Mexico**	**Atlantic**	**Pacific**	**Alaska**
Community Sentiment	Community Familiarity with Drilling Process	Social well-being and vulnerability data are available. Maps of county types are available. Some information within publications are available.	Nationwide EJ/SJ and census datasets are available; localized data on carbon storage impacts are unknown.		
	Community Attitude Toward Industrial Development				
	Community Attitude Toward Climate Change and Net Zero Ambitions				
	Community Cohesiveness and Jurisdiction Authority				
Impact on Community	Environmental Impact of Operations	Existing infrastructure data are available. Some pollution datasets are available. Economics and trade data are available.	Nationwide EJ/SJ and census datasets are available; localized data on carbon storage impacts are unknown.		
	Infrastructure and Resource Impacts				
	Workforce Development and Job Creation				

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