16th International Conference on Greenhouse Gas Control Technologies, GHGT-16

23rd -27th October 2022, Lyon, France

Offshore Oil and Gas Infrastructure Reuse for CCS: Opportunities and Challenges in the U.S. Gulf of Mexico

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Abstract

The United States Gulf of Mexico has historically been a significant oil and gas producing region and continues to produce hydrocarbons today. As such, significant investments have been made to install oil and gas infrastructure such as pipelines, platforms, and wells. As these assets reach the end of their useful life or production associated with the assets is curtailed, the assets become a liability for both the owner/operators and the U.S. and state governments responsible for regulating the assets. There are costs and risks associated with safely decommissioning the assets, and in some cases, the assets may be abandoned (e.g., the owner is no longer a going concern). In parallel, carbon capture and storage (CCS) technology has developed in the United States and interest and incentives for CCS projects have accelerated in recent years, with many public announcements of CCS projects in development in the U.S. Gulf of Mexico region. The region is particularly well-suited to CCS due to the high density of industry on the coastline (i.e., CO_2 sources) and favorable geology in the near-offshore region. CCS also requires the use of many of the same assets required for oil and gas production (pipelines, platforms, wells) and the oil and gas industry has direct experience with CO_2 transport and injection (i.e., EOR). Therefore, the combination of existing infrastructure in close proximity to potential CCS project sites appears to provide a potential "win-win" solution for re-use of existing oil and gas assets.

This paper presents a high-level evaluation of oil and gas infrastructure in the Gulf of Mexico with the goals of identifying the scale of the opportunity (e.g., how much existing infrastructure is realistically re-usable), identifying gaps in knowledge/policy/information required to evaluate existing infrastructure for re-use, and proposing key actions that could be pursued to further the assessment of existing infrastructure re-use for CCS.

Keywords: Infrastructure, reuse, re-purpose, oil and gas, pipelines, platforms, wells, CO_2, CCS, Gulf of Mexico, transport, existing infrastructure

1. Introduction

The United States Gulf Coast and offshore Gulf of Mexico (GoM) represents an important strategic region for carbon capture and sequestration (CCS). The region includes a high density of industry along the coastline, particularly in Texas and Louisiana. This high concentration of industrial facilities represents potential CO_2 sources for CCS – for example, within 50 miles of the Texas coastline, there are approximately 75 facilities producing at least 400,000 tonnes/year of CO_2 [1]. In addition, the near-offshore Gulf of Mexico has been identified as a region with favorable geology for long-term sequestration of CO_2 [2]. The offshore region is appealing for CO_2 storage to avoid some of the

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potential barriers for developing geologic storage onshore (land acquisition costs, population centers, public perception, etc.). Therefore, favorable CO_2 source and sink opportunities are within close proximity of each other and have led to increasing interest in the development of large-scale CO_2 capture and storage projects and hubs [3].

The remaining component of the CCS value chain is CO_2 transport. While constructing new pipelines, platforms, and injection wells represents a viable option for CCS project development, the Gulf of Mexico has historically been a major oil and gas producing region for the United States. The oil and gas industry has made substantial investments in offshore infrastructure in the region over the course of several decades. When this infrastructure reaches end-of-life or production is curtailed, however, the assets become a liability for the industry as there are costs associated with proper decommissioning of the infrastructure [4]. The obsolete infrastructure also represents an environmental risk which regulatory agencies must manage if asset owners do not, or are unable to, undertake decommissioning. Therefore, many groups have highlighted the potential "win-win" for new CCS projects to utilize existing oil and gas infrastructure, reducing CCS project costs while simultaneously reducing oil and gas industry and government liability.

1.1. GoMCarb Partnership and Region of Focus

The United States Department of Energy (U.S. DOE) has funded two regional partnerships focused on offshore (sub-seafloor) geologic carbon storage beneath the Gulf of Mexico. The infrastructure re-use evaluation presented in this paper was developed as part of the Gulf of Mexico Partnership for Offshore Carbon Storage (GoMCarb). The GoMCarb partnership is focused on the Northwestern Gulf of Mexico in the waters offshore of Texas and Louisiana. This region includes an abundance of onshore industrial activity (CO_2 sources) and historical offshore oil and gas production (existing infrastructure), and thus provided ample data and information to assess infrastructure that could realistically be considered for re-use in CCS projects.

1.2. Objectives of this Paper

The primary objective of this paper (and underlying research activities) is to vet the conceptual opportunity of oil and gas infrastructure reuse for CCS for the U.S. Gulf of Mexico – specifically, this paper will focus on the GoMCarb region of study (Northwestern Gulf of Mexico, waters off of Texas and Louisiana coasts). The paper will also focus on the following major aspects of infrastructure reuse evaluation:

- An assessment of the state of data available for existing oil and gas assets and evaluation of the data to identify key information that can be used for reuse assessment.
- High-level screening of assets for reuse potential. Screening was performed using criteria that were selected to reflect the risk of reuse and potential value for CCS.
- Case study analysis of specific assets identified by screening to evaluate asset-specific characteristics that impact reuse, define limitations of data availability for individual assets, and identify specific steps and investment that would be required in practice to reuse the assets.

The paper will focus on pipelines as a representative example of infrastructure re-use, relying heavily on data available from public databases supplemented by discussions with asset owners and oil and gas industry experts. The paper will include comments on wells and platforms, particularly where the infrastructure re-use evaluation approach deviates significantly from the pipeline approach.

Key outcomes of the above proposed approach include identifying the overall scope and scale of the reuse opportunity after applying basic screening of the data, identification of critical limitations of the data available on assets which may represent a risk or obstacle to reuse, and the development of a reuse "workflow" which defines a general process to assess infrastructure for reuse and identifies key investment and decision points. This paper is not focused on evaluating specific projects or performing a detailed technical assessment of specific oil and gas assets. The authors recognize the decision to reuse an infrastructure asset will be highly project and asset specific – the goal of the current work is to highlight areas where reuse opportunity and risk exists more broadly to inform project developers, policymakers and regulators, and the oil and gas industry as interest in CCS increases in the US Gulf Coast region.

2. Literature Review

The following subsections will review literature that has focused specifically on existing oil and gas infrastructure in the Gulf Of Mexico or on re-use of existing oil and gas infrastructure for CO_2 transport and storage. The literature review is not exhaustive in terms of the sources identified or the information within the sources themselves. The intent of this literature review is to provide the reader with a high-level overview of other important work being done in this area and sources of additional information that will supplement this paper.

2.1. United States Bureau of Ocean Energy Management (BOEM)

The Bureau of Ocean Energy Management (BOEM), within the U.S. Department of Interior, is an important regulatory agency for offshore oil and gas infrastructure and is a critical source of data for offshore infrastructure. In addition to online databases, BOEM frequently publishes reports on the status of offshore oil and gas infrastructure, including decommissioning of the infrastructure. An exhaustive review of BOEM reports is not provided here. A recent (2018) report [5] titled “Gulf of Mexico Decommissioning Trends and Operating Cost Estimation” is representative of the type of information BOEM publishes on existing infrastructure in the GoM.

The report develops inventories and trends for oil and gas infrastructure (primary platforms) in federal waters in the GoM and develops forecast models for decommissioning requirements and active inventories. The inventories include classification as “shallow” and “deep” water infrastructure, an important distinction for the condition/age of the infrastructure, value of the assets, and cost for any work on the infrastructure (decommissioning, re-purposing, etc.). The report also reviews operating costs for active offshore oil and gas production – while not directly relevant to CO_2 injection, the operating costs may provide some insight into analogous costs for operating a CO_2 injection storage site offshore.

Note that the authors for the 2018 BOEM report [5] are from the Center for Energy Studies at Louisiana State University (LSU). The Center for Energy Studies at LSU has other related publications regarding oil and gas infrastructure and represents another useful resource when evaluating existing infrastructure in the GoM.

2.2. IEAGHG: Re-Use of Oil & Gas Facilities for CO_2 Transport and Storage

The International Energy Agency Greenhouse Gas (IEAGHG) R&D Program developed a report [6] focused specifically on the re-use of oil and gas infrastructure for CO_2 transport and storage. The report was organized as a series of five case studies where an “infrastructure reusability index” developed by the authors was applied to determine the potential for re-use of pipelines, platforms, wells, and other associated oil and gas infrastructure. The criteria included in the reusability index mirror the approach in this study to define re-use screening and evaluation criteria, as discussed in later sections of this paper. Some of the case studies (e.g., Goldeneye) are representative of the sort of evaluation and development work that would represent a logical “next step” following the evaluation presented in this paper. These case studies were not simply general reviews of assets - they were based on actual engineering development work that was performed on specific oil and gas assets for the purpose of developing real-world projects. A summary of high-level findings from the report, and the relevance to this paper, follows:

- Integrity of the existing infrastructure and the feasibility of lifetime extension are critical aspects of re-use assessment.
    - Relevance to this work: As discussed later in this paper, a substantial portion of the infrastructure in the U.S. Gulf of Mexico is inactive and older infrastructure, making questions of infrastructure integrity and lifetime extension particularly relevant.

- Existing oil and gas practices, specifications, and methods may be leveraged for re-use assessment of specific infrastructure.
  - Relevance to this work: As part of the infrastructure evaluation performed in this paper, the authors consulted oil and gas industry experts and reviewed specifications and methods to assess existing infrastructure. The existing oil and gas practices were central to the development of infrastructure re-use workflows developed as part of this work.
- The general criterion for re-use is "sufficiency". In other words, the asset under consideration must meet the technical requirements to transport CO_2 (pressure rating, materials adequacy, platform space and weight handling capability, etc.).
  - Relevance to this work: The concept of sufficiency underlies the selection of screening criteria, such as those defined as part of the infrastructure screening analyses presented in this paper. They reflect minimum standards or requirements for infrastructure to be considered for re-use, but are not sufficient on their own to determine viability for re-use.
- The report confirms that assessing re-use of infrastructure is a project-specific and case-by-case evaluation.
  - Relevance to this work: As the screening evaluation efforts for each infrastructure class in this paper illustrate, general assessments of infrastructure primarily serve to cull obviously infeasible or impractical assets from consideration for re-use. The screening level assessments, and even case studies, are not sufficient to make specific conclusions regarding whether an individual asset should be re-used. Project-specific criteria, including risk assessments and project economics must be part of a decision to re-use an existing asset.

2.3. Re-Stream Report by Carbon Limits and DNV

The Re-Stream report [7] is focused on the re-use of oil and gas infrastructure (primarily pipelines) in Europe for CCS and hydrogen applications. Goals of the report included identifying relevant pipelines (i.e., screening) and defining technical modifications and associated investments necessary to re-purpose infrastructure for CCS. Key findings of the report specific to offshore pipeline re-use for CO_2 include the following:

- The report considered both dense phase/supercritical and gas phase transport of CO_2.
- Pipeline screening focused on age, transport capacity ($\geq$ 10,000 t/year), pipeline design characteristics (susceptibility to running ductile fracture), maximum allowable operating pressure (MAOP), internal pipeline condition (based on inspection), and previous transport fluid. The authors of the report received data from pipeline operators to facilitate this screening.
  - Onshore and offshore natural gas and crude/crude product pipelines were evaluated.
  - The pipeline screening resulted in a tiered or ranked screening of lines by use of a continuous scale of "points" assigned to each screening category.
  - The authors did not find limitations or "showstoppers" to prevent gaseous phase transport.
  - Dense phase CO_2 transport was feasible in more than half of the offshore lines.
    - Relevance to this work: The feasibility of dense phase transport in the Re-Stream report provides a reference point for comparison to the pipelines evaluated in this paper in the GoM.
  - Relevance to this work: The pipeline screening criteria in the Re-Steam report overlap to some extent with the approach used in this paper. However, some criteria (e.g., running ductile fracture) and the ranked screening approach may represent a logical extension of the screening performed in this work.

- Case studies included a comparison of constructing new pipelines to re-use of existing pipelines and indicated a strong economic incentive (10 – 15% reduction in the overall cost of the CCUS value chain) for pipeline re-use.
  - Relevance to this work: Note that the Re-Stream result is in contrast to the results in the National Petroleum Council report discussed below – the contrast does not represent a contradiction,

however. The difference in conclusions confirms that re-use evaluation is very much context (e.g., region) and case specific and broad generalizations about re-use are not particularly useful for project developers/policymakers.

2.4. National Petroleum Council: Meeting the Dual Challenge

The National Petroleum Council (NPC) produced a report [8] covering a wide range of topics associated with large-scale deployment of CCS in the United States. One portion of the report (Chapter 6) focuses on CO_2 transport, including pipelines. The analysis by NPC includes a review of the potential reuse or re-purposing of existing onshore natural gas pipelines for CO_2 transport. Some of the authors of this current paper (from Trimeric Corporation) supported the assessment by performing hydraulic evaluations of the CO_2 pipeline system. As discussed further in Section 5.1, natural gas pipelines typically have a lower pressure rating than what would be specified for a new CO_2 pipeline to facilitate transport of CO_2 as a supercritical fluid. As such, CO_2 may be transported as a gas instead of supercritical fluid when re-using an existing natural gas pipeline and the pipeline capacity may be limited.

The overall conclusion from the NPC report was the re-use of natural gas pipelines for CO_2 transport is not practical when moving large volumes of gas (1 billion standard ft^3/day or 19 million tonnes/year) over long distances (hundreds of miles or more). However, the report did acknowledge that transporting smaller quantities of CO_2, transporting over shorter distances (e.g., dedicated CO_2 pipeline to nearby injection or a branch of a larger network), and certain project specific factors (e.g., lower ground/ambient temperatures) could yield scenarios where re-use was practical. The report did not specifically address offshore CO_2 transport.

2.5. CO_2 Pipeline Standards

There are specific pipeline standards for the development of new CO_2 pipelines. These standards also include some information on re-purposing existing pipelines for CO_2 transport. The standards are not reviewed in detail here but are noted for reference:

- DNVGL-RP-F104: Design and operation of carbon dioxide pipelines
- ISO 27913:2016: Carbon dioxide capture, transportation, and geological storage — Pipeline transportation systems
- API Standard 1104, 22nd edition: Welding Pipelines and Related Facilities (22nd edition updated to include CO_2 specific guidance)

The DNV standard includes a conceptual workflow for evaluating a pipeline for re-use (i.e., defines the general steps and sequence but does not provide technical criteria/methods/guidance).

3. Data Sources for the U.S. Gulf of Mexico by Infrastructure Type

The following evaluation for the U.S. GoM relied primarily on publicly available data sources (with noted exceptions for wells). The datasets included infrastructure in both U.S. federal waters and state waters. In the United States, regulatory authority of offshore waters, including corresponding oil and gas development and infrastructure, is split between the federal (national) level and individual state level. For the state of Texas, state waters extend 9 nautical miles from the shoreline until reaching federal jurisdiction; for the state of Louisiana, state waters extend 3 nautical miles from the shore. While data from federal waters are primarily presented in this paper, the authors did review select state infrastructure as well. The primary data sources used in this study are summarized in Table 1.

Table 1. Data Sources for Existing Oil and Gas Infrastructure

Infrastructure	Federal Waters	State Waters
Pipelines	BSEE[Note 1]	Texas RRC [Note 2], SONRIS[Note 3]
Platforms	BSEE[Note 1]	Texas GLO [Note 4]
Wells	BOEM[Note 5]	Texas RRC [Note 2], Subscription Databases[Note 6]

Notes:

1) BSEE = Bureau of Safety and Environmental Enforcement, U.S. Department of Interior (https://www.data.bsee.gov/).
2) Texas RRC = Texas Railroad Commission (https://www.rrc.texas.gov/resource-center/research/gis-viewer/)
3) SONRIS = Strategic Online Natural Resources Information System (Louisiana - https://www.sonris.com/)
4) Texas GLO = Texas General Land Office (https://www.glo.texas.gov/land/land-management/gis/index.html)
5) BOEM = Bureau of Ocean Energy Management, U.S. Department of Interior (https://www.boem.gov/oil-gas-energy/mapping-and-data).
6) Subscription databases included IHS Enerdeq, IHS Petra, Lexco OWL7 (data from subscription databases are not published in this paper).

4. General Approach

The following sections will present the specific evaluation and results of oil and gas infrastructure re-use for CCS. Using the data sources summarized in Table 1, the authors utilized the following general steps to evaluate infrastructure:

1) Develop screening criteria to narrow larger datasets.
2) Use “analog sites” to focus on specific assets for deeper evaluation/case studies.
    a. Analog sites are locations that are representative of potential CO_2 storage sites that would be attractive for CCS projects (favorable geology based on initial data, proximity to a high density of CO_2 sources) and can serve as a proxy for other similar regions within the GoM. The focus of the GoMCarb project and associated work of the authors was initially in the near-shore GoM, though expansion to deeper waters is discussed later in this paper as a potential next area of study. As such, two initial analog sites were selected in the High Island region in state waters offshore of Texas – High Island Blocks 10L (HI-10L) and 24L (HI-24L).
    b. Oil and gas infrastructure near analog sites represent potentially higher value re-use assets since they are in close proximity to viable source and sink locations (i.e., higher likelihood for project development). Therefore, the analog sites serve to focus the screening results further on specific assets.
3) Develop a “workflow” or series of steps required to assess existing oil and gas infrastructure for re-use. To the extent possible, identify steps where decisions or investments were required.

The preceding general approach is fully illustrated for pipelines, which represent the assets with the most readily available/complete datasets and were most amenable to evaluation without access to private data from owners/operators on individual assets. As noted previously, platforms and wells will be discussed briefly in this paper – the authors have developed additional analyses for these assets for the GoMCarb partnership.

5. Pipeline Re-use Assessment

The pipeline re-use assessment in this section will focus on data from federal waters (i.e., data obtained via the BSEE database). The evaluation follows the major steps outlined in Section 4.

5.1. General Considerations and Screening Criteria Development

5.1.1. Pipeline Operating Pressure

To provide context for the screening evaluation, some general considerations for offshore transport of CO_2 in pipelines are reviewed. CO_2 is generally transported as a gas or supercritical/dense phase fluid in a pipeline, with many implications for the design and capacity of the pipeline. Most importantly, when CO_2 is transported as a gas, the density of CO_2 is much lower than that of a supercritical fluid and the quantity of CO_2 that can be transported for a given pressure difference over the pipeline is reduced significantly. The critical point for CO_2 (1,070 psia/73.7 bar, 87.8°F/31°C) defines the pressure and temperature above which CO_2 is a supercritical fluid. In particular, the critical pressure is a significant operating threshold – as long as CO_2 remains above the critical pressure, the CO_2 cannot reach gas phase conditions – it will only transition between a supercritical fluid and "dense" phase liquid, without a discontinuity in fluid properties such as density. Therefore, CO_2 pipelines are ideally operated above the critical pressure.

In practice, CO_2 is not a pure fluid and impurities in the CO_2 impact the properties, including the critical point for CO_2 and can create the risk of a true two-phase fluid regime in transport depending on the level of impurities. Therefore, the CO_2 source and any processing prior to entering the pipeline are critical aspects of defining hydraulic performance in a CO_2 pipeline.

The CO_2 operating conditions must be explicitly considered when assessing a pipeline, be it new construction or re-use of an existing pipeline. In particular, a safety margin (e.g., 10%) below the pipeline maximum allowable working pressure (MAWP) defines an upper limit for the CO_2 transport pressure and may dictate the CO_2 transport phase and/or pipeline capacity. Pipelines in the U.S. are often classified as ANSI Class 600 (MAWP = 1,480 PSIG @ 100°F) or ANSI Class 900 (2,220 psig @ 100°F), though the pressure rating of any individual pipeline should be verified. Natural gas pipelines are often Class 600 while a new CO_2 pipeline is more likely to be Class 900 or higher. Therefore, re-using an existing natural gas pipeline may limit the amount of CO_2 transferred due to the limit on the inlet pressure and the potential that CO_2 must be transported as a gas instead of a supercritical fluid. Table 2 compares the impact of the pipeline class and associated operating pressure on CO_2 capacity for a short-distance pipeline which allows transport as supercritical CO_2 for both cases.

Table 2. Comparison of Supercritical CO_2 Transport in Class 600 vs. Class 900 pipelines

Case	**Inlet Pressure (psig)**	**CO_2 Flow (Mt/year)**
Class 900	2,000	~3.2
Class 600	1,400	~1.8

Notes: 8", 5-mile pipeline. Outlet pressure >1,200 psig to stay above critical pressure

As the table indicates, even when maintaining supercritical CO_2 in the pipeline, the CO_2 capacity of the Class 600 line is nearly half of the capacity of an equivalent Class 900 line. For longer distances, the Class 600 line may need to move CO_2 in the gas phase and the capacity would be even more severely limited (e.g., as in the NPC report [8]).

An additional consideration for re-use of pipelines in the offshore setting is the higher density of supercritical CO_2 (vs. natural gas) and the change in elevation of the pipeline from the source to the sink. Since the CO_2 is transported offshore and the pipeline will generally follow the slope of the seafloor, a CO_2 column, or static head, will develop from the CO_2 source (near sea level) to the pipeline termination (water depth at the injection site). This CO_2 column has a weight which is reflected as increased static pressure in the pipeline. Therefore, while there will be dynamic pressure losses in the pipeline as CO_2 is transported, the pressure in the pipeline may increase due to the static head. This creates the risk of over-pressuring the line, particularly if the line is being operated close to its MAWP.

In summary, defining operating pressure is an important criterion to identify pipelines that are likely to have sufficient potential for re-use.

5.1.2. Age of Pipelines

The authors consulted literature, subject matter experts, and pipeline broker/operators to develop an understanding of the design life of pipelines. Expected lifetimes varied based on the source of information, ranging from 60 to 85 years. Note that the lifetimes cited are ideal or maximum expected lifetimes since age alone does not define the life of a pipeline. The specific details of each pipeline (damage/repairs, state of cathodic protection, corrosion, etc.) are the true determining factors for the pipeline life. For the screening evaluation, the authors started by limiting the search for lines that were less than approximately 40 years old (leaving a minimum of 20 years of useful life and up to 45 years of useful life based on the ideal expected lifetime range).

5.1.3. Shore Crossings

One potential hidden value of the re-use of existing pipelines is that a new shore crossing is not required when transporting CO_2 from an onshore source to offshore storage location. Shore crossings represent both an added cost and regulatory/environmental risk. Existing pipelines may have been installed when different regulatory standards were in place and the same shore crossing location may not be possible or practical for an identical new line. As such, the authors prioritized pipelines with a shore landing/crossing as part of the screening to identify “key segments” for more detailed study.

5.1.4. Active vs. Inactive Pipelines

The GoM includes many lines that are actively transporting oil and gas but even more lines that are inactive (includes abandoned in-place, proposed abandonment, and out of service lines). Lines that are inactive represent a potential near-term re-use opportunity and the owner/operator may be motivated to re-purpose the asset rather than carry any decommissioning costs or liability. However, inactive lines may have been out of service for some time with limited recent data on the condition of the line, may have transferred owners, or may have been partially decommissioned (e.g., authors were told that some inactive lines are filled with uninhibited seawater, which prevents further use of the line, at the end of service). These factors may make an inactive line risky or completely unsuitable for re-use. Active lines, on the other hand, will tend to be newer, likely have better/current records, and may allow for careful planning for the transition to CO_2 service. They may not be available for near-term re-use, however. Therefore, active and inactive screening cases were both evaluated to illustrate the difference in opportunities.

5.2. Screening Evaluation

The screening evaluation was initiated by retrieving all offshore existing federal pipeline data available in the BSEE public database. This yielded data on more than 20,000 independently catalogued pipeline “segments”. In some cases, multiple branches of a single large pipeline network would each have an independent identification and be classified as a segment in the database. In order to narrow this database further, the authors applied the screening criteria in Table 3 (some of which were discussed in preceding sections).

Table 3. Existing Pipeline Re-use Screening Criteria

Parameter	Criteria	Purpose
Diameter	≥ 8”	Identify “large” pipelines to support CO_2 capacities on the order of 1Mt/yr or more
Maximum Operating Pressure	> 1000 psig	Eliminate low pressure lines likely unsuitable for CO_2 transport
Length	≥ 2 miles	Eliminate short interconnecting segments
Minimum Water Depth	≤ 100 feet	Focus on near-shore CO_2 storage
Age	In service after 1/1/1980	Eliminate pipelines with limited remaining useful life
Key Segments	Key segments should come onshore and pass-through Texas or Louisiana state waters offshore	Prioritize lines with shore crossing

The screening criteria represent a “coarse” filter to identify high priority lines and do not represent the only approach to identifying lines for re-use. For example, a specific project with a reservoir location identified may only focus on pipelines crossing within a certain radius of the storage site. However, the criteria in this screening are broad enough to eliminate particularly challenging or low probability lines for re-use. Table 4 provides a high-level summary of the screening results for both the inactive and active line subsets within the larger database of pipelines.

Table 4. Summary of Existing Pipeline Screening Results. Note that the screening represents a filtered approach, or cumulative screening, to determine how many lines ultimately meet all preceding criteria.

	Number of Segments	
	Inactive* Line Screening (Near-Term Opportunity)	**Active Line Screening (Lower-Risk Opportunity)**
Total	20,274	
Service Status (Inactive/Active)	11,195	5,568
8” or larger	2,335	1,676
MAOP > 1000 psig	1,927	1,451
> 2 miles long	951	755
Water Depth < 100’	520	327
In Service 1980 or later	355	Not Applied
Key Segments**	11	47
Median Diameter	*16"*	*20"*
# of Lines MAOP > 1,440 psig	*0*	*10*
*Inactive = Abandoned in place, Proposed abandonment, Out of service **Key Segments = Come onshore/near-shore (TX, LA)		

Several key observations can be developed from the high-level results summaries, alongside supporting summary statistics to further define the re-use opportunities:

- A majority of lines in the federal GoM database fall in the inactive line subset – within this subset:
  - Less than 25% of the lines meet the minimum diameter criteria (≥ 8”).
  - Only 11 lines meet all the screening criteria and qualify as “key segments”.
    - Within this group, the median diameter is 16” and none of the lines are rated above 1,440 psig.
- For the active line subset, which is slightly more than 25% of all lines in the database:

  - Approximately 30% of the lines meet the minimum diameter criteria (≥ 8”).
  - The age restriction criterion was removed – active lines tend to be newer and are expected to have better records/knowledge of condition, so the age risk was deemed lower.
  - 47 lines met the screening criteria and qualified as “key segments”.
    - Within this group, the median diameter is 20” and 10 of the lines are rated above 1,440 psig.
- For all lines meeting the size requirement (8” diameter or greater), Figure 1 presents the pressure distribution for the lines. The large majority of these lines fall in the 1,400 – 1,600 psig operating pressure range, similar to Class 600 natural gas pipelines.
- Less than half of the lines (~46%) in the entire database were put into service in 1980 or later. This reflects the age of assets in the GoM and emphasizes the importance of understanding the upper limit of the operating lifetime of the assets.
- Relaxing other very specific criteria for this screening, such as water depth or pipeline length could introduce a larger subset of lines to investigate and a larger pool of potential re-use candidates. This may be a path of future work from this study.
  - However, in reality, project developers would have more restrictive specific criteria, so there are limitations to the value of very broad/general screenings of the assets.

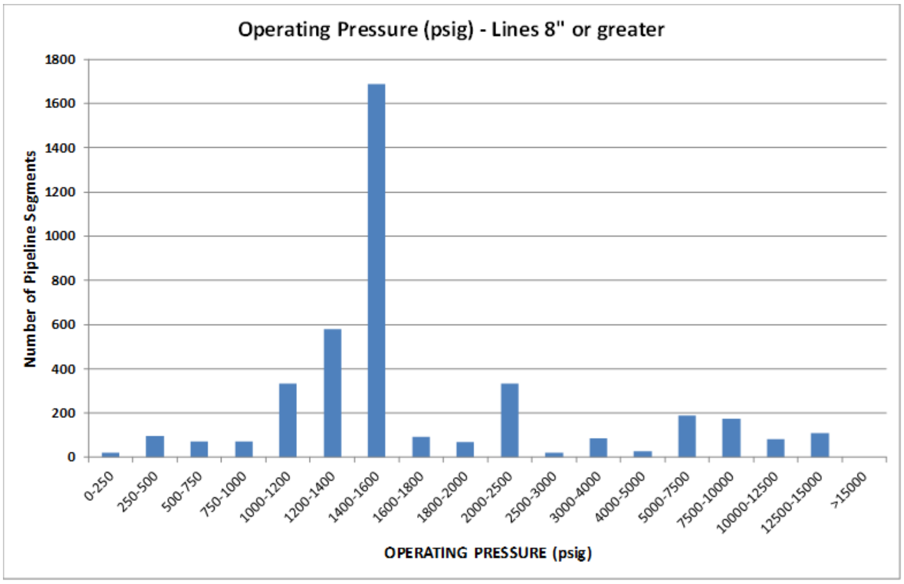

Figure 1. Pipeline pressure distribution for all pipelines ≥ 8”

It is also useful to compare the screening approach in this study to approaches used by other groups. The Re-Stream report [7], in particular, focused on pipeline re-use and performed a similar screening of a large database of pipeline assets in Europe. While both the Re-Stream report and the current paper provide screening analyses for pipeline re-use and there is some overlap in the criteria applied, the Re-Stream report evaluates some additional, more detailed technical criteria (e.g., running ductile fracture) and performs a more granular ranking of pipelines (e.g., assigns a “score” from 0 to 1 for each criterion) vs. the binary screening performed in this study. In that sense, the screening performed in this paper may be viewed as a “coarse” or initial screening while the Re-Stream screening might represent a “fine” screening or ranking that allows for more interpretation and input from the screener. For example, this study used a specific age cutoff to eliminate pipelines (when applied). In contrast, the Re-Stream report applied a “penalty” to lines older than ~30 years. The ranking or continuum of values for screening criteria keeps more of the pipelines in the study and allows for some weighting of multiple criteria when considering re-use. For example, a line may be penalized for being older, but may be ranked more highly for pressure rating. In this sense the Re-Stream approach attempted to perform a more holistic screening/ranking of pipeline assets. The trade-off in this approach is that the scale and value assigned to each parameter may become subjective or assign implied weights to one category vs. another making it difficult to differentiate pipelines with relatively similar "rankings". In that case, the ranking may collapse to an elimination of outliers and focus on "high performers" that may look similar to the coarse screening completed in this work. However, the Re-Stream approach is informative and could represent a logical next level of detail to follow the screening evaluation performed for this paper.

Finally, the results of the screening, in particular the key segments that were identified, represented the starting point for a more detailed evaluation of specific pipelines and the development of a re-use workflow.

5.3. Case Studies and Re-Use Workflow

The key segments identified in the preceding screening alongside the use of one of the analog sites (HI-10L) as a proxy CO_2 storage location facilitated the evaluation of specific pipelines of interest. Table 5 presents four pipeline networks identified from the inactive line screening (i.e., near term opportunities) that were evaluated in more detail as part of developing a "workflow" for re-use.

Table 5. Four Pipeline Networks of Interest near HI-10L, offshore of Texas – from inactive line screening

Region/ Location	Line ID	Last Owner	In Service Date	Size	MAOP (psi)	Length (miles)	Water Depth (feet)	Status
Texas (High Island)	4073 4074 5381 4613[1] 4590[1]	Williams TRANSCO	12/13/1979 1/28/1980	12" 24"	1392 - 1440	84 (system length)	43-75	Proposed Abandonment (4613, 4590) & Active (4073, 4074, 5381)
Texas (High Island)	5958[2]	Renaissance Offshore	5/28/1981	8"	1440	16	39 - 50	Out of Service
Texas (Galveston)	7199[3] 3489[4]	Williams Black Marlin	12/1/1984	16"	1367	24	48-61	Proposed Abandonment
Texas (High Island)	3493[4] 5895[5]	Panther Interstate Pipeline Energy	12/17/1981	16"	1200 (working pressure)	26	35 - 51	Pending Abandonment

Notes:

1) Segments 4613 and 4590 were not identified as key segments because they do not approach the shoreline individually, but are part of a larger network (including active segments 4073 and 5381) that does access the shoreline.
2) Segment 5958 was eliminated in the screening analysis due to the pressure criteria (< 1000 psig). The data from BSEE database indicated a MAOP of 500 psig. Further investigation as part of the case study revealed the line had been derated from a higher initial MAOP.
3) Segment 7199 was not identified as a key segment because it does not approach the shoreline individually, but is part of a larger network (including segment 3489) that does access the shoreline.
4) Segments 3489 and 3493 were not included as key segments because of an in-service date before 1980 (1967 and 1977, respectively).
5) Identified as a key segment.

The authors contacted pipeline operators (in some cases) and other industry experts as part of the case study evaluation. Some of the details of the case study evaluation are included in the notes in Table 5. The primary goal of the case studies was to develop a workflow for re-using the pipelines – this included identifying publicly available data on specific pipelines (and gaps in data), identifying key risks and analyses required to re-use specific lines, identifying regulatory, legal, and technical hurdles to re-use, and understanding best practices (if any) used in the oil and gas industry that may be applicable for re-use as CO_2 pipelines. Details of each step in the workflow and development of the workflow are not covered here. However, Figure 2 presents the major steps of the pipeline re-use workflow alongside some of the specific activities included in each step and an order-of-magnitude example cost to complete the proposed activity/test/evaluation as part of the workflow. The workflow also identifies key decision points throughout the workflow where the re-use of the line may be abandoned.

The costs that are presented in the figure are only meant to provide an order-of-magnitude example of the cost to gather some of the requisite data on a candidate pipeline. The costs do not include any transaction costs, user fees/purchase costs, repair costs, or permits that may also be associated with the re-use of the specific pipeline. Instead, the goal was to provide an approximate understanding of the level of investment required simply to make an informed decision on the condition of the pipeline and suitability for re-use. It should also be noted that, while the workflow is presented generically in Figure 2, each re-use evaluation will be unique. For example, detailed records on the condition and recent testing of a pipeline may reduce the need for additional testing/investment in the proposed workflow.

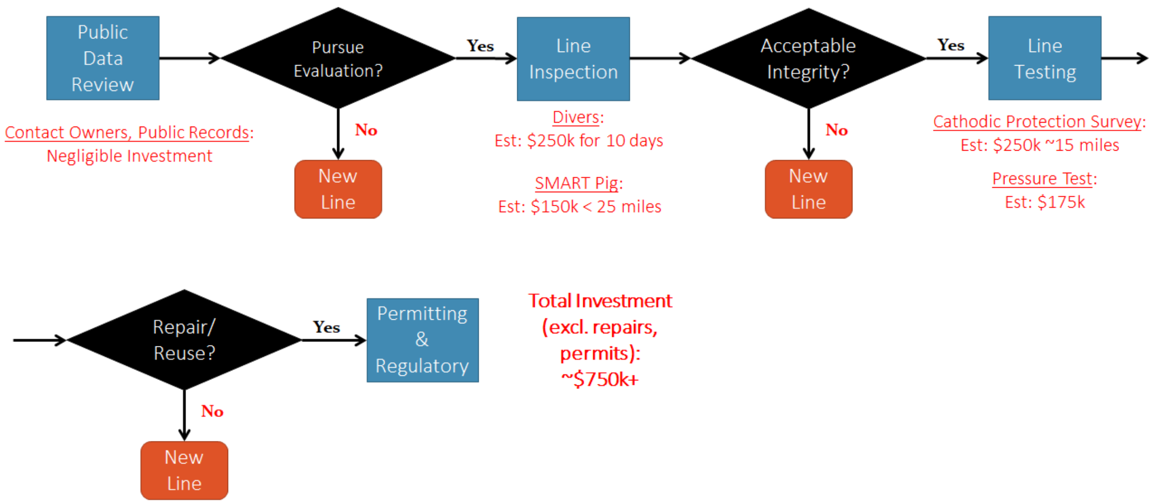

Figure 2. Pipeline re-use workflow

5.4. Summary of Pipeline Re-Use Evaluation

The screening evaluation approach yielded insights regarding the potential scale of the re-use opportunity for pipelines in the GoM and highlighted specific challenges (e.g., large number of inactive lines, low pressure lines). In addition, the case study that followed facilitated the development of a re-use workflow highlighting critical decisions, information needed, and investments to assess re-use of specific assets.

However, the evaluation in this paper is limited in the sense that any re-use evaluation will be project and asset specific. For example, an important consideration for pipeline re-use evaluation is the structure of the project itself. In other words, the feasibility to re-use an existing pipeline is not simply binary (i.e., meets the needs of the project or does not meet the needs). The following are examples where pipelines could be part of a broader, more flexible project solution for CO_2 transport:

1) Phased project/investment approach: CCS projects may develop over time, adding new sources, raising additional capital for expansion, etc. The Northern Lights project in Europe is an example of a phased CCS project where the CO_2 transportation solution will progress with the overall project (i.e., building out new pipeline capacity over time). An existing pipeline can be part of this sort of phased approach – for example, an existing pipeline with a limited capacity or limited useful life could be used in the initial stages of a project, deferring the costs of a new pipeline until the CCS project is further developed (e.g., generating revenue) and either requires more capacity or needs to replace the existing line as it approaches the end-of-life.
2) Incremental Capacity: An existing pipeline may not be able to handle all of the capacity requirements for a CCS project, particularly if the existing line capacity is limited by pressure or diameter. However, an existing line could handle part of the capacity, allowing for a smaller new pipeline to take-up any residual capacity. This approach would need to be vetted carefully as there are certain fixed costs associated with installing a new pipeline and the savings from a smaller new pipeline may not offset the risk or complexity associated with re-using an existing line in parallel.
3) Existing Pipeline as Part of a System: In some cases, an existing pipeline could potentially serve as one part of a pipeline system. For example, an existing pipeline could be used to get from onshore to offshore for some distance and a new pipeline section could be constructed for a shorter distance to a preferred injection site location. This approach would be very case specific.

In short, screening of pipelines is most effective for removing clearly infeasible or risky lines. Defining screening criteria too narrowly or interpreting the results too narrowly can lead to missed opportunities for project and asset specific opportunities for re-use. Therefore, the re-use evaluation presented here will ideally provide context and information needed to develop a more detailed and specific evaluation for projects considering the re-use of existing pipelines.

6. Platform Re-Use Overview

The authors have performed high-level evaluations of platform re-use as well. The following criteria were identified as most important for platform re-use:

- Location/proximity to CO_2 injection site: Unlike pipelines, which may represent a major capital cost center for CCS projects, are generally subject to more complex regulatory/permitting processes (e.g., shore crossings, right of way), and can potentially be re-used in a piecemeal fashion (i.e., combine an existing pipeline section with a new pipeline section), platforms are unlikely to drive the location of CO_2 storage or/injection and cannot be readily re-used if they are not in relatively close proximity to the preferred injection site.
- Age/General Condition: Subject matter experts indicated to the authors that platforms beyond 30 years old represent a much higher risk of structural integrity issues. To truly assess the potential lifetime of a platform, inspections of the platform would be required since information on the condition of platform is not readily available. To the extent prior inspection reports are available, they may not be of sufficient detail to assess lifetime extension.
    - The age of a platform can also yield insight into the standards and regulations in place at the time of construction (e.g., specific edition of API RP 2A). Past studies (e.g., [9]) have indicated the standards and regulatory requirements (e.g., inspection requirements) in place for a given platform were strong predictors of the extent of damage suffered during storms, for example.
- Topsides Space and Weight Handling Ability vs. Requirements: In cases where CO_2 is not being used for EOR, the topsides requirement for CO_2 injection should be fairly limited – slots will be required for new injection wells and limited equipment may be required in some cases (heater, booster compression). However, both the assessment of the topsides requirement and the ability of the platform to support the new

requirements are specific to each project/platform, require detailed technical data on the platform, and may require modification of the existing platform.

- Regulatory/legal considerations: Is there a process to transfer liability/decommissioning responsibility and is there an asset owner willing to engage in the process?

High level review of platform data in federal waters indicate the vast majority of existing platforms are off of the coast of Louisiana (92%) and that few of these platforms were installed after 2000 (~371). Therefore, a significant part of the existing stock of platforms in federal waters are already approaching the "high risk" end of useful life age identified by experts. The authors also reviewed platform types by location, age, and water depth to identify general trends across the GoM (Figure 3).

Structure Type	Number	% of Total (Total = ~1,850)	Average Depth (ft)	Average Age (years)
Caisson	455	24.6%	41	39
Well Protector	13	0.7%	53	84
Fixed Leg Platform	1332	71.9%	131	41
Compliant Tower	3	0.2%	1,467	28
Mobile Production Unit	1	0.1%	2,200	13
Mini Tension Leg Platform	4	0.2%	3,024	20
Tension Leg Platform	14	0.8%	3,378	19
SPAR Floating Production	18	1.0%	4,380	17
Submersible Floating Produ	11	0.6%	5,695	22
FPSO	2	0.1%	8,930	9

Min
Max

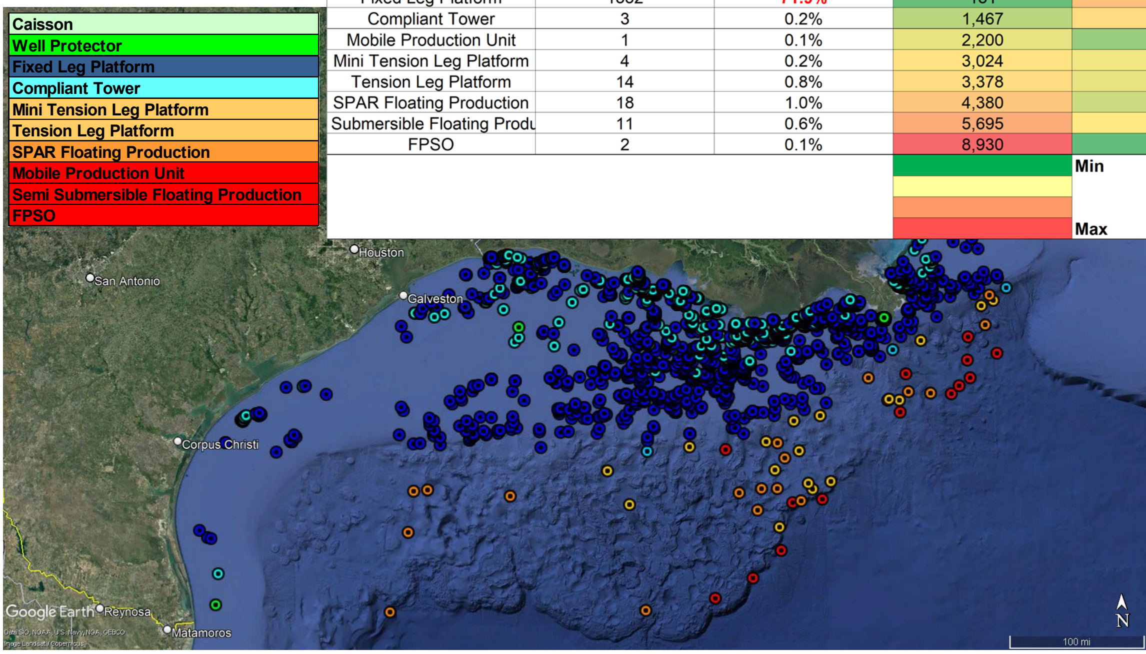

Figure 3. Platform mapping and classification in GoM federal waters

The most notable trend from the figure and associated table is the inverse relationship between water depth and age – newer platforms are generally further from the shore in deeper waters, consistent with the trend in oil and gas production over time in the GoM. Therefore, CCS projects that target locations further offshore may be more likely to benefit from existing infrastructure and may also be more incentivized to re-use the infrastructure as the cost of any new infrastructure will be higher than near shore/shallow waters. Future work by the authors will include a focus on assets in deeper waters.

In sum, when considering the critical requirements for platform re-use (e.g., condition of the platform, topsides requirements), it becomes apparent that "screening" of platforms is limited and platforms are best suited for a case-by-case evaluation for specific injection locations and projects.

7. Well Re-Use Overview

The authors used the aforementioned analog sites (HI-10L and HI-24L) to assess the type of data available regarding wells and to develop potential screening criteria. Examples of screening and classification criteria included wellbore status (e.g., active, plugged, orphaned), completion date (age), and availability of key well integrity reports (plugging report, cement bond log, pressure tests, caliper logs).

Wells pose unique challenges both from an evaluation perspective and potential re-use perspective. Even between the two analog sites studied by the authors, the data available and status of wells varied considerably. For example, HI-24L included a significant number of orphaned wells (40% of all wells), which represent high-risk assets with incomplete information/data. In contrast, HI-10L did not include any orphaned wells. In addition, a major limitation in evaluating wells are potential gaps and inconsistencies in data, particularly for older wells. The authors found inconsistencies between databases for wells, including in fundamental information such as well location. The focus on specific analog sites makes it impossible to define the prevalence of these sorts of data issues for all existing wells in the GoM – however, given the number of wells, it seems reasonable to expect other instances of inconsistency when attempting to review data on existing wells. Therefore, obtaining owner's records of wells or other reliable corroborating data for wells is essential to making any assessment of wells near a potential storage location.

Others have concluded that re-use of wells for CO_2 injection is not likely and that new wells will be needed [10] . However, existing wells represent a risk for CO_2 leakage – therefore, any discussion of evaluating existing wells, assessing well integrity, etc. may well be driven by the need or requirement to assess leakage risk vs. a desire to potentially re-use the well. In the event re-use is an option for a specific project, any consideration of well re-use for the project should be part of a more holistic well management strategy.

8. Conclusions

This paper presented an evaluation of existing oil and gas infrastructure in the U.S. Gulf of Mexico for potential re-use in CCS applications. The paper assessed the scale of the potential opportunity (e.g., via screening of data), identified key information/decisions/investments required to assess re-use (e.g., via case studies and workflow development), and identified gaps in knowledge and/or potential next steps to facilitate further development of infrastructure re-use assessment in the GoM.

The primary focus of the paper was re-use assessment of existing pipelines due to accessibility of critical screening data and ability to evaluate data in a meaningful way to assess re-use potential. Development of "coarse" screening criteria (size, operating pressure, length, age, water depth, shore landing/crossing) facilitated screening more than 20,000 individual pipeline segments in the federal waters down to less than 60 candidate lines that merited more detailed evaluation. The size of existing pipelines was the biggest eliminating factor in the screening with less than 30% of all lines meeting the minimum size criteria ($\geq$ 8" diameter). In addition, as with all infrastructure evaluated in this paper (pipelines, platforms, wells), age of infrastructure represented a specific risk – less than half of all existing pipelines are less than 40 years old. Finally, the operating pressure range of existing lines span a wide range but are concentrated between 1,400 – 1,600 psig, similar to Class 600 natural gas pipelines, potentially limiting the capacity of existing pipelines to carry CO_2. Active pipelines provided a larger number of viable candidates than inactive lines despite inactive lines making up the majority of all pipelines. Viable active lines also had a higher median size (20" vs. 16") and more "high" pressure lines (10 vs. 0 over 1,440 psig) than inactive counterparts. The screening evaluation identified specific candidates that allowed for a more detailed evaluation of re-use and the authors were able to define a high-level workflow for re-use of existing pipelines, including the type of testing and data required, order of magnitude example investment costs to assess re-use, and key decision points in the process.

Finally, despite the limitations implied by the screening, additional candidates for re-use may be identified by relaxing specific screening criteria for project specific cases. Furthermore, project structures that stage or phase investment or pair existing and new assets may be able to make use of existing pipelines in a more narrow or short-term role where the pipeline may otherwise have been excluded from consideration.

A brief review of platforms and wells highlighted the limitations in making generalizations about these types of infrastructure or performing a precise screening of the assets. Ongoing work to evaluate platforms and wells in different regions of the GoM will seek to identify trends in these assets by looking at a subset of assets across a range of locations and conditions in the GoM rather than forcing arbitrary screening criteria on the full dataset.

Future work will focus on defining the additional information and investments that would be required to assess re-use fully for project development. This activity is distinct from performing the actual evaluation of re-use viability for specific assets. Evaluating specific assets does not necessarily further broad conclusions about infrastructure re-use due to the asset and project specific nature of re-use evaluation, and, in fact, may lack meaning without the context of a specific project (i.e., projects define risk thresholds and economic criteria to make decisions). Instead, by focusing on the process of evaluating infrastructure for re-use, the authors seek to define the level of investment required to assess re-use, identify gaps in the regulatory/legal framework, and identify places where specific subject matter expertise and asset-specific data are needed. This framework should provide value to any project considering re-use of an existing asset. To facilitate this activity, the authors will broaden the screening and review of assets to include deeper waters and review a broader cross-section of infrastructure in the GoM. The re-use assessment and value proposition for re-use may vary by location and associated infrastructure available in that location, so broadening the review of assets should avoid bias towards the conditions in the near shore environment.

Acknowledgements

The authors acknowledge funding from the United States Department of Energy (U.S. DOE) National Energy Technology Laboratory (NETL) via the GoMCarb partnership (DE-FE0031558). The authors would also like to acknowledge the technical guidance and project leadership of the University of Texas Bureau of Economic Geology (UT BEG) during the course of the research and evaluation that are the basis for this paper.

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OFFSHORE OIL AND GAS INFRASTRUCTURE REUSE FOR CCS: OPPORTUNITIES AND CHALLENGES IN THE U.S. GULF OF MEXICO

Darshan Sachde, Katherine Dombrowski, Darrell Davis, Ray McKaskle, Joe Lundeen

Gulf of Mexico Partnership for Offshore Carbon Storage (GoMCarb)

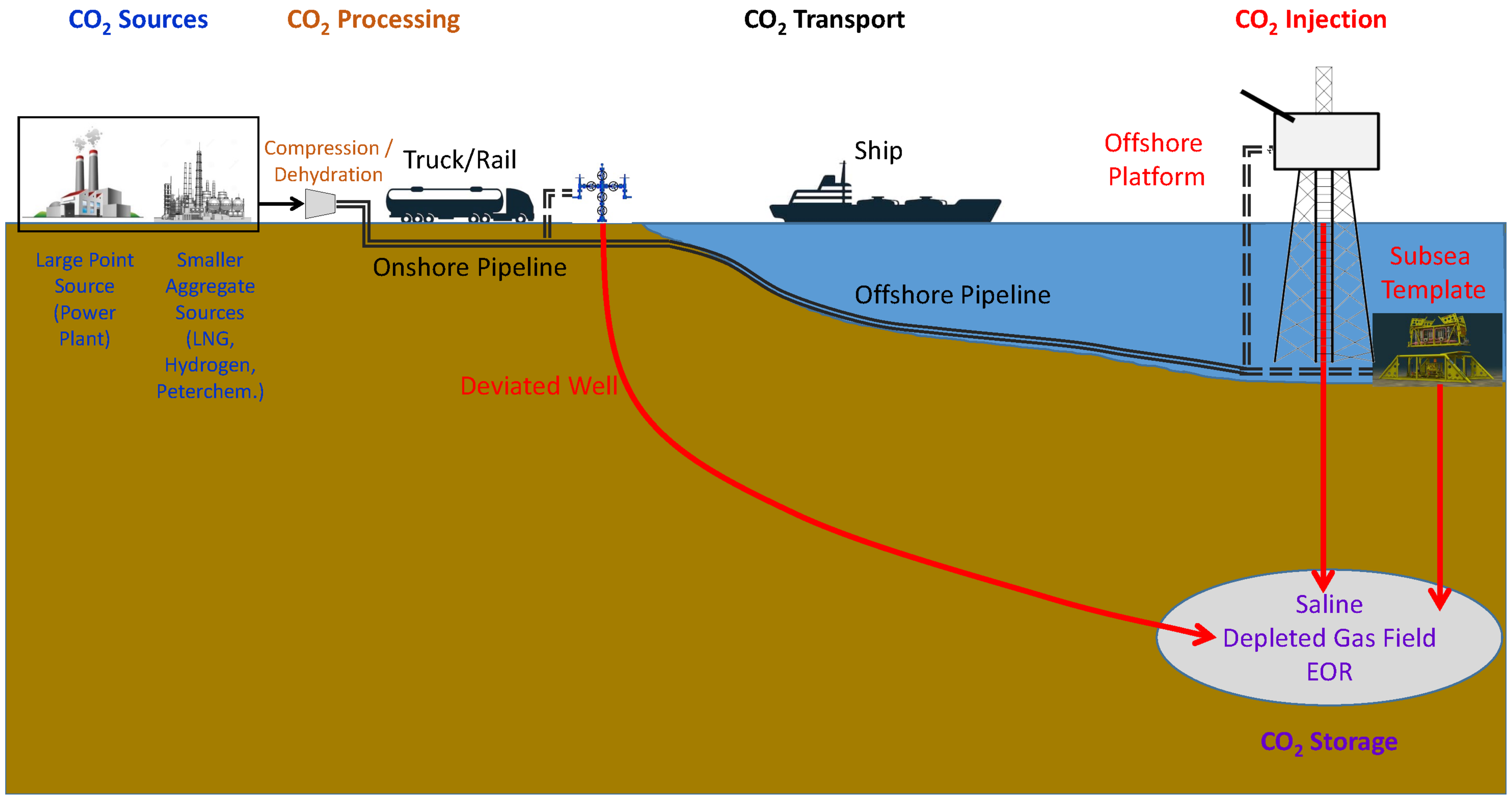
Objectives:

Define **opportunities, data gaps, challenges, and processes required** for reuse of oil and gas infrastructure for CCS in the U.S. Gulf of Mexico

Project Methodology

1. SCREEN to define opportunity.
2. CASE STUDIES to identify data gaps and challenges.
3. WORKFLOWS to define processes required to assess re-use.

Near-Offshore CO_2 Transport and Storage Options

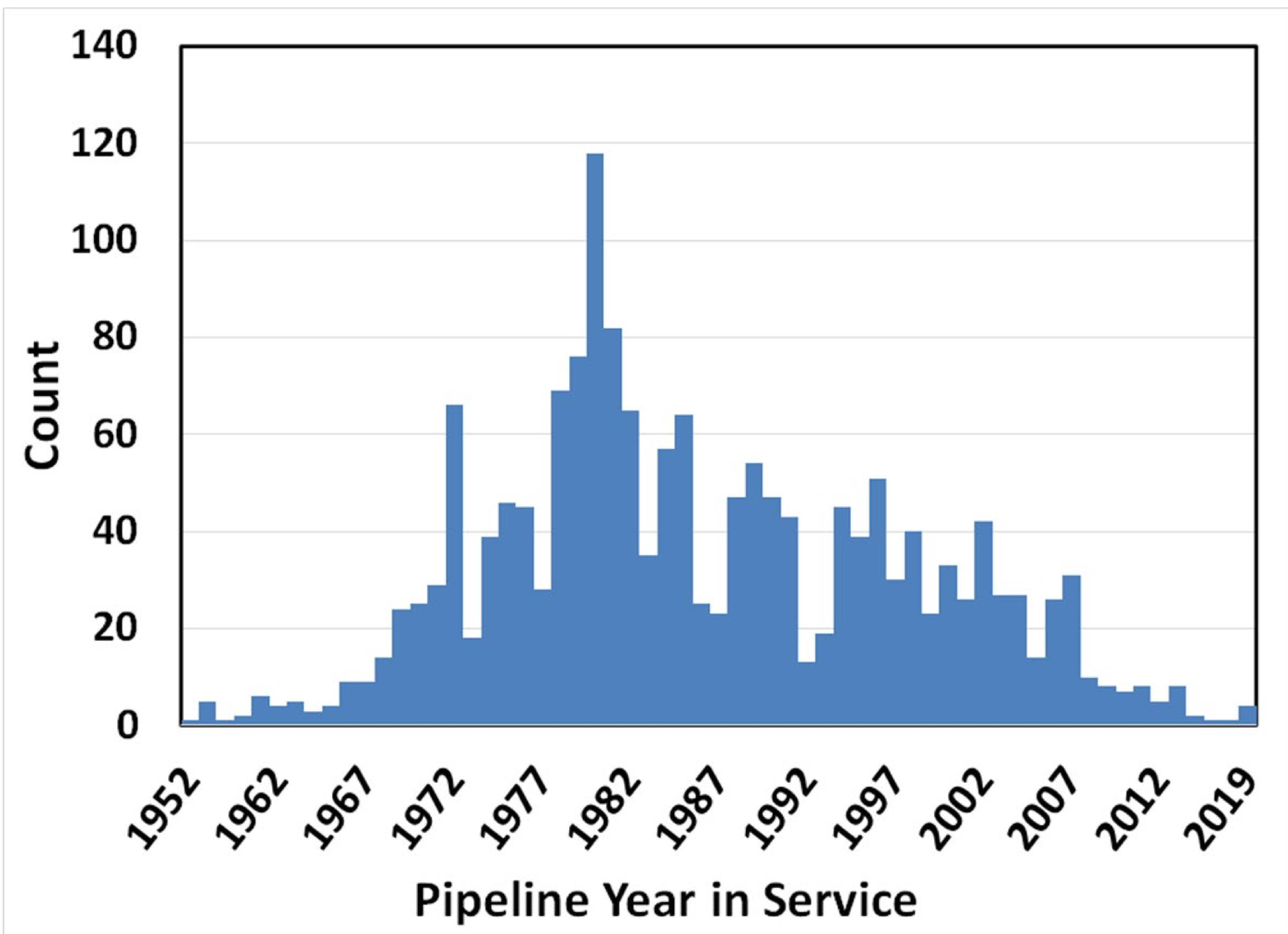


Pipeline Re-use Considerations

1. Size/Capacity of Pipelines
2. Pipeline Operating Pressure
3. Age of Pipelines
4. Shore Crossings
5. Condition/Risk of Re-use
6. Proximity to Source & Sink

Pipeline Age Distribution

Inactive Lines, D ≥ 8" + MAOP > 1,000 psig

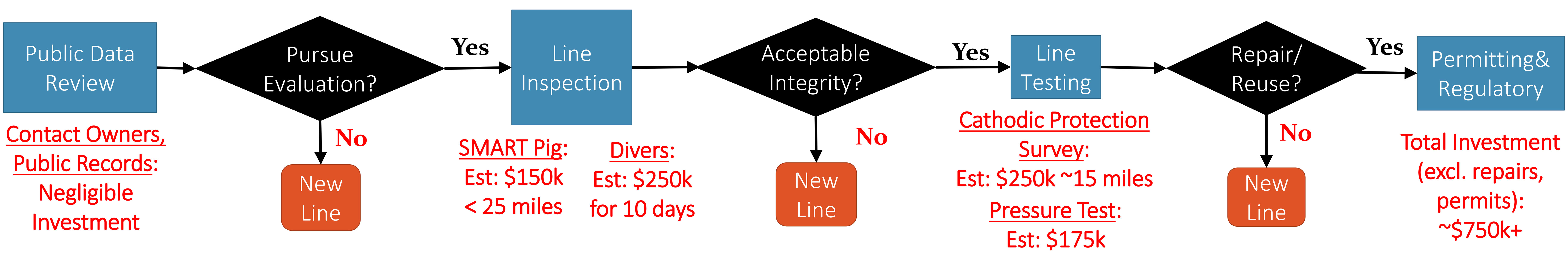


U.S. Federal Water Pipeline Screening

	Inactive* Line (Near-Term Opportunity)	Active Lines (Lower-Risk Opportunity)
TOTAL	11,195	5,568
D ≥ 8"	2,335	1,676
D ≥ 8" + MAOP > 1000 psig	1,927	1,451

*Inactive = Abandoned in place, Proposed abandonment, Out of service

Example Pipeline Re-use Workflow



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OFFSHORE OIL AND GAS INFRASTRUCTURE REUSE FOR CCS: OPPORTUNITIES AND CHALLENGES IN THE U.S. GULF OF MEXICO

Darshan Sachde, Katherine Dombrowski, Darrell Davis, Ray McKaskle, Joe Lundeen

Platform Re-Use Considerations

1. Location/ Water Depth / Proximity to CO_2 Injection Site
2. Age/General Condition
3. Topsides Space and Weight Handling Ability vs. Requirements
4. Regulatory/Legal Considerations (e.g., transfer of liability)

Existing Platforms: Structure Type and Age vs. Water Depth

Structure Type	Number	% of Total (Total = ~1,850)	Average Depth (ft)	Average Age (years)
Caisson	455	24.6%	41	39
Well Protector	13	0.7%	53	84
Fixed Leg Platform	1332	71.9%	131	41
Compliant Tower	3	0.2%	1,467	28
Mobile Production Unit	1	0.1%	2,200	13
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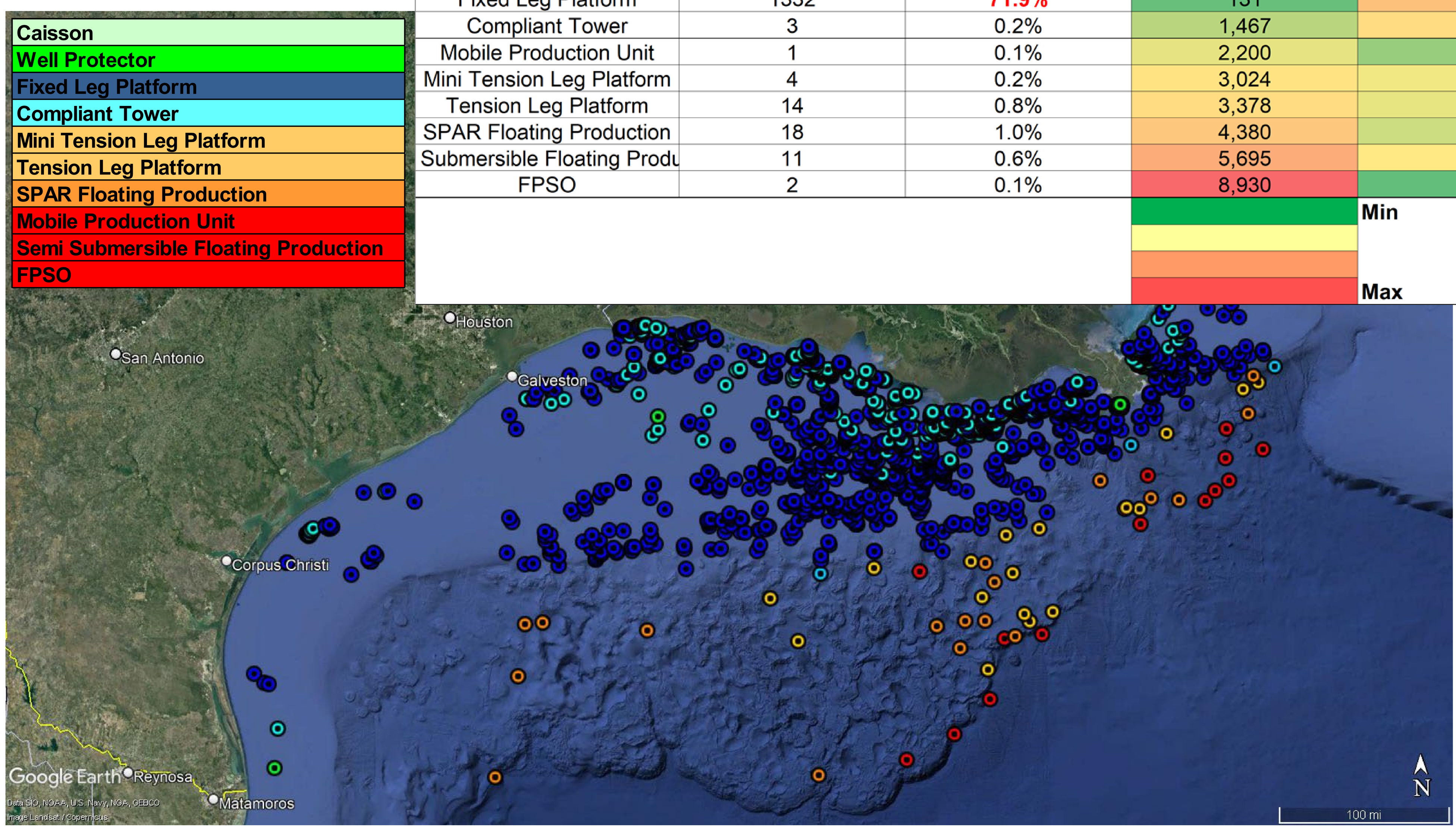
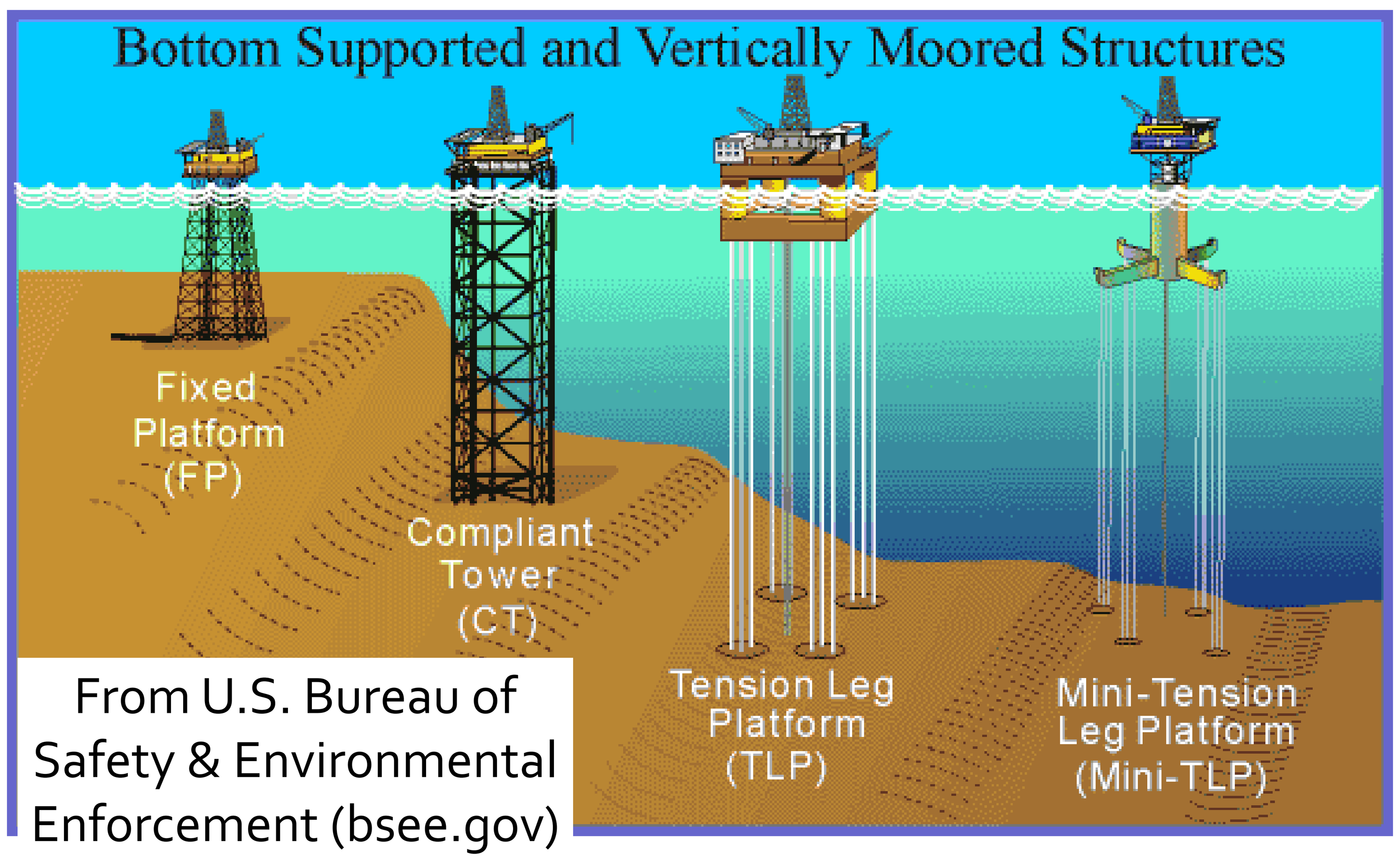
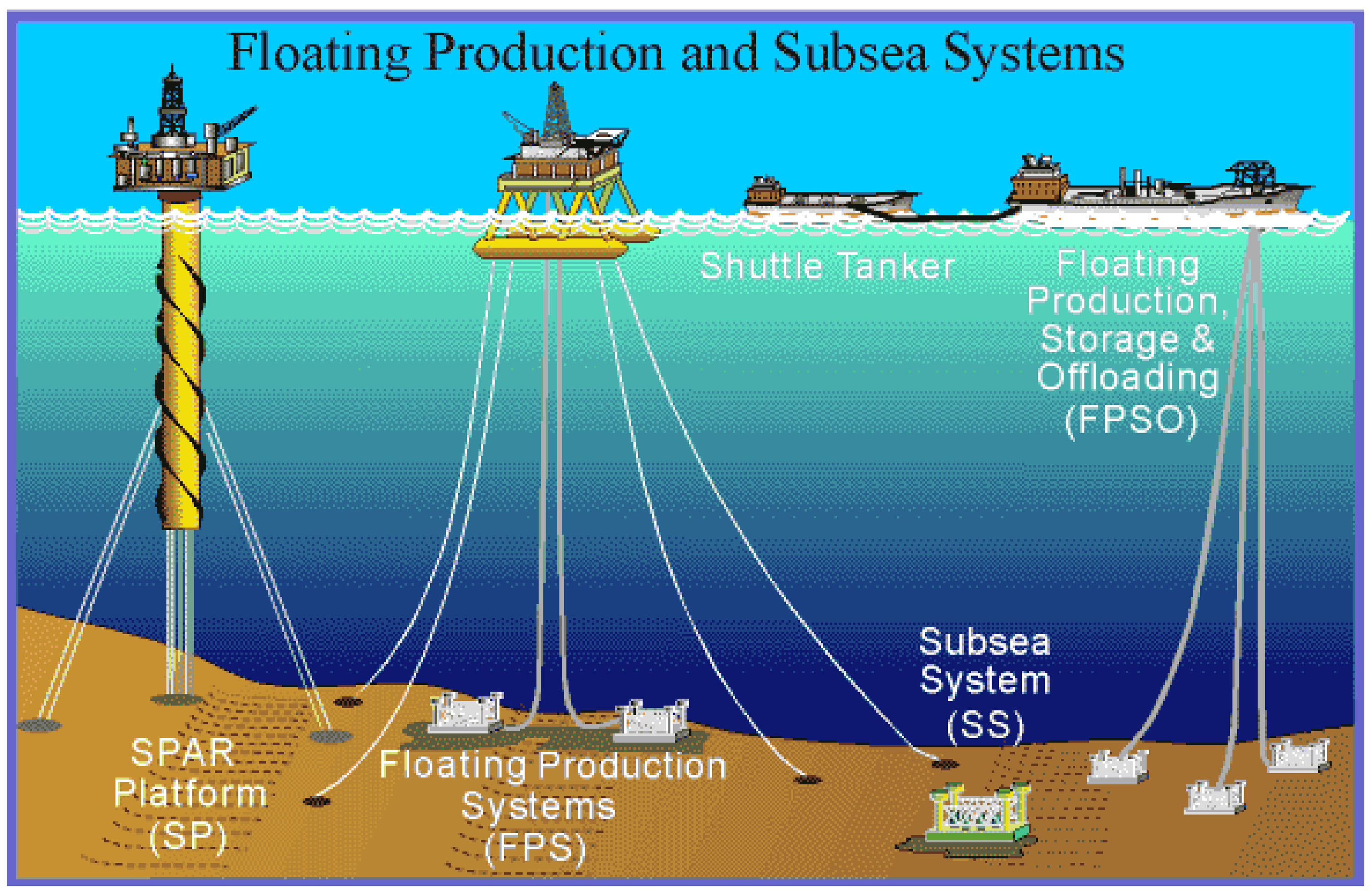
Submersible Floating Produ	11	0.6%	5,695	22
FPSO	2	0.1%	8,930	9
			Min – Max	



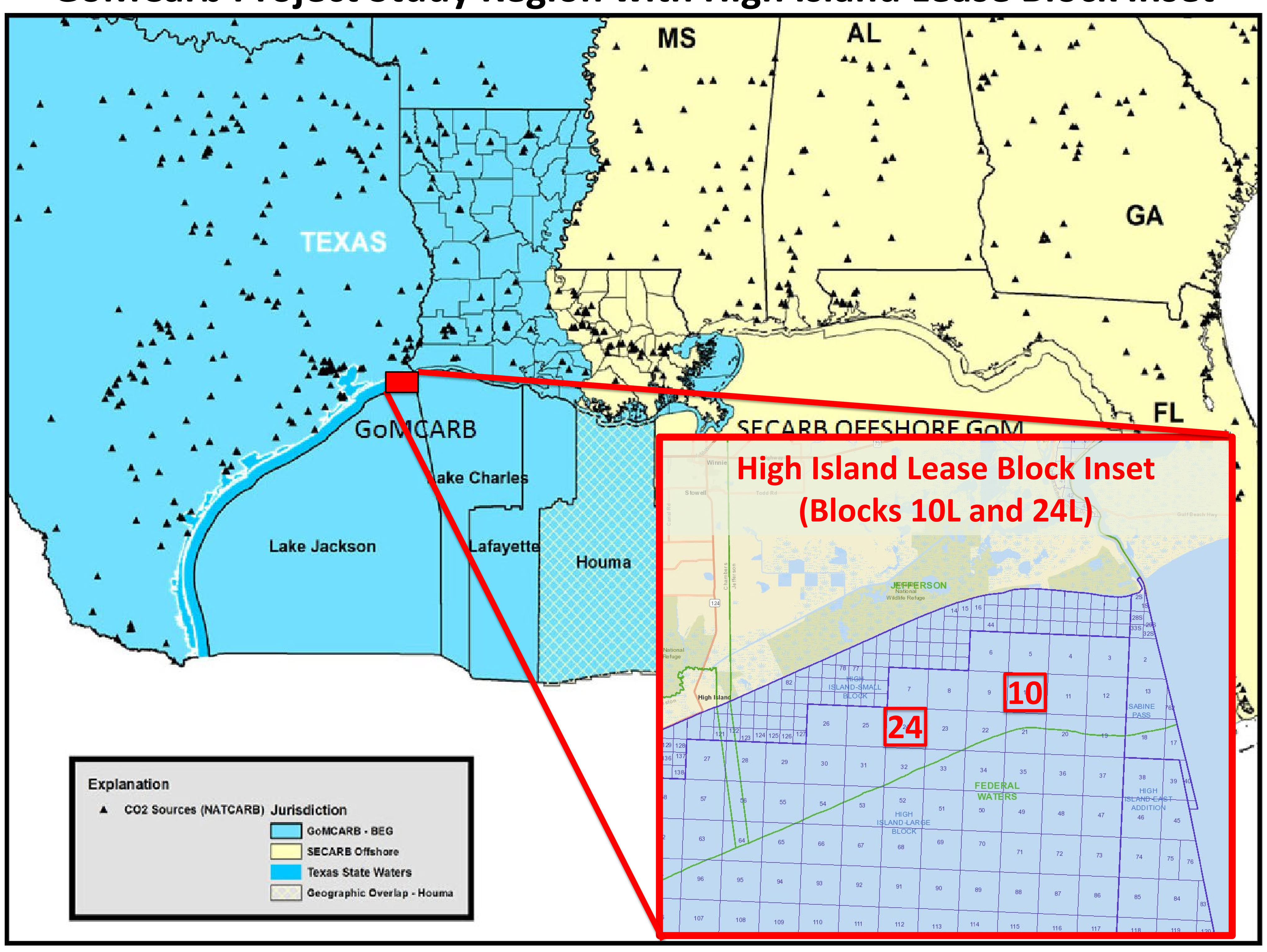




Well Re-Use Considerations

1. Wellbore status
2. Completion date
3. Availability of key well integrity reports
4. Risk for leakage or opportunity for re-use?

GoMCarb Project Study Region with High Island Lease Block Inset



Review of wells in analog sites (HI-10L and HI-24L)

- Analog sites = tractable dataset, not general trends across GoM
- Limited active O&G production @ analog sites
- Older wells = higher risk (all > 20 years old in HI-10L & 24L)
- Orphaned wells = high risk (~40% of wells in HI-24L)
- Data Gaps and Limitations
  - Inconsistency between data sources
  - Limited detailed records (3 of 73 wells had "key" reports - plugging, cement logs, pressure tests, caliper logs)

Overall Conclusions & Future Work

1. Re-use opportunities exist **but**:
   a) Assets in U.S. GoM are older & risk of re-use will increase with time as more assets are "retired".
   b) Re-use will be project and site-specific. Example: Phased/staged re-use of existing pipeline with a new pipeline.
2. Data gaps for condition of existing assets (especially wells) represent a potential risk/cost for CCS projects offshore.
3. Future work:
   a) Broader "sweep" of infrastructure across GoMCarb region, including deeper waters (newer assets).
   b) Identify trends in re-use opportunity by region.
   c) Define approach & potential costs to perform more detailed assessments of infrastructure (i.e., cost of information for investment decisions).