Gulf of Mexico Offshore Wind Transmission

Literature Review and Gaps Analysis: Environmental Considerations, Community Readiness, and Infrastructure

Angel McCoy, Rebecca Green, Dave Corbus, Clara Houghteling, Chloe Constant, Matthew Kotarbinski, Nicholas Riccobono, Caitlyn Clark, and Cris Hein

National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
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Technical Report
NREL/TP-5000-89642
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List of Acronyms

BOEM	United States (U.S.) Department of the Interior Bureau of Ocean Energy Management
BSEE	U.S. Department of the Interior Bureau of Safety and Environmental Enforcement
DOE	U.S. Department of Energy
EA	environmental assessment
EERE	Office of Energy Efficiency and Renewable Energy
EIA	U.S. Energy Information Administration
EMF	electromagnetic fields
EPA	U.S. Environmental Protection Agency
ERCOT	Electric Reliability Council of Texas
FERC	Federal Energy Regulatory Commission
GW	gigawatt
HFTO	Hydrogen and Fuel Cell Technologies Office
IRA	Inflation Reduction Act
LNG	liquified natural gas
m/s	meters per second
MISO	Midcontinent Independent System Operator
NCCOS	National Centers for Coastal Ocean Science
NOAA	National Oceanic and Atmospheric Administration
NREL	National Renewable Energy Laboratory
OCED	Office of Clean Energy Demonstrations
OCS	Outer Continental Shelf
POI	point of interconnection
SERTP	Southeastern Regional Transmission Planning

Executive Summary

The ability to effectively and efficiently connect offshore wind energy resources in the Gulf of Mexico to end users in Florida, Alabama, Mississippi, Louisiana, and Texas requires coordinated transmission planning to ensure that electric transmission facilities can adequately support future offshore development.

The Gulf of Mexico has substantial wind resources with two wind energy projects planned in state waters (Baurick 2023), one project leased in federal waters (BOEM n.d.[b]), and plans for more leasing in the U.S. Department of the Interior's Bureau of Ocean Energy Management (BOEM) federal pipeline. Most of the region's interest in offshore wind development to date has been in the central and western portions of the Gulf of Mexico (Louisiana and Texas) in federal and state waters, where the wind resource is the highest in the region. The shallow shelf and deep ocean waters are appropriate locations for fixed-bottom and floating offshore wind technologies, respectively. The total technical energy potential in this area of the Gulf is more than 1,500 gigawatts (GW), which represents 37% of the total offshore wind technical energy potential across the entire United States (Lopez et al. 2022). Even though offshore wind energy development in the Gulf region has lagged development along the Atlantic and Pacific coasts—partly because of hurricane risks and the Gulf's relatively lower wind speeds—*the unique features of the Gulf* along with BOEM's leasing activities (BOEM n.d.[b]) and the State of Louisiana's planning goal for 5 GW of offshore wind (Climate Initiatives Task Force 2022) make offshore wind energy in the Gulf of Mexico attractive.

Transmission studies specific to offshore wind have not been performed for the region. Such research would benefit future regional transmission planning to adequately meet future energy needs.

The oil and gas industry already has infrastructure and workers positioned in the Gulf of Mexico; therefore, new offshore wind energy projects could be supported through shared infrastructure and workforce. Future transmission planning should consider the Gulf of Mexico's highly productive ecosystem, diverse coastal communities, considerable existing infrastructure, and heavy industrial foundation. Transmission solutions should be tailored to regional environmental concerns to minimize impacts to wildlife, habitat, and coastal resources and should include local communities in their planning efforts.

In this report, an offshore wind transmission literature review and a gaps analysis are conducted for the Gulf of Mexico, similar to federal activities in the Atlantic and West Coast regions (Bothwell et al. 2021; Pacific Northwest National Laboratory n.d.). The previous two gap analyses focused on transmission activities and informed the *Atlantic Offshore Wind Transmission Study* (Brinkman et al. 2024) and the West Coast Offshore Wind Transmission Study (Pacific Northwest National Laboratory n.d.). This report not only summarizes available information and gaps related to Gulf of Mexico offshore wind transmission planning as of July 2024 but also captures environmental considerations, community readiness, and regional infrastructure that are critical and unique to transmission planning for offshore wind energy in the region.

Significant knowledge gaps were identified while reviewing existing literature:

- **Current long-term transmission expansion plans from regional independent system operators and utilities have not accounted for offshore wind development in the Gulf of Mexico.** Proactive and coordinated transmission analyses would improve assessments of the onshore and offshore transmission build-out for long-term offshore wind deployment needs in the Gulf of Mexico. This includes analyzing points of interconnection, transmission technologies, and onshore options to evaluate their relative feasibility, cost, reliability, and resilience impacts.
- **Siting considerations (including physical, environmental, and ocean co-use, among others) to inform coordinated offshore wind transmission routing have not been identified in published literature to date.** Research is needed to identify environmental risks associated with the siting of future offshore wind transmission cables in the region, including sensitive habitats, seafloor hazards, and coastal areas that are susceptible to climate change (among many other factors), with a focus on developing solutions to avoid, minimize, and mitigate the identified risks.
- **There is a lack of focused community and workforce engagement to incorporate the priorities of diverse Gulf stakeholders regarding opportunities for planned offshore wind transmission.** The Gulf of Mexico is culturally and demographically diverse. While each offshore wind energy and transmission project should conduct project- and location-specific engagement and impact assessments, case studies that interview community members and examine the complex environmental, cultural, and economic landscapes of key offshore wind resource areas could lay the groundwork for future studies and engagement.
- **Partnerships, industry engagement, and research would inform how offshore wind transmission development fits into the energy generation portfolio in the region and serves energy end uses and future needs of coastal industries in Gulf Coast states.** The Gulf of Mexico region has a well-established oil and gas industry. Generation and transmission expansion modeling should be conducted to understand the role of offshore wind and how expansion can leverage existing infrastructure in the region. In addition, research would improve understanding of evolving energy end uses and future needs of coastal industries.

Since 2022, the U.S. Department of Energy (DOE) and BOEM have been hosting convening workshops in coordination with the Atlantic Offshore Wind Transmission Study. These broad stakeholder activities have led to an associated action plan (DOE and BOEM 2024) for addressing near-, medium-, and long-term offshore wind transmission challenges for the Atlantic Coast. Entities specific to the Gulf of Mexico region (for example, the Midcontinent Independent System Operator, the Electric Reliability Council of Texas, Entergy Louisiana, the existing oil and gas industry, and local leadership) should be involved through a similar central convening effort. Through such forums, as well as coordinated offshore wind transmission studies in the Gulf, realistic pathways toward the maximum net benefits of Gulf of Mexico offshore wind transmission can be identified.

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1 Purpose

Connecting offshore wind energy resources in the Gulf of Mexico to end users in Florida, Alabama, Mississippi, Louisiana, and Texas (herein, the Gulf of Mexico or "region") requires proactive and coordinated transmission planning to ensure that electric transmission facilities can adequately support future offshore development. There are also unique regional considerations, including the environment, community readiness, and existing infrastructure.

The Gulf of Mexico has substantial wind resources in both shallow shelf waters and deeper waters off the shelf where fixed-bottom and floating offshore wind technologies, respectively, would be most appropriate (Lopez et al. 2022). Most interest in the region in offshore wind development to date has been in the central and western portions of the Gulf of Mexico (Louisiana and Texas) in federal and state waters, where the wind resource is the highest (Musial et al. 2020).

As a companion study to other U.S. Department of Energy (DOE) literature reviews and gaps analyses in the offshore wind transmission space—the *Atlantic Offshore Wind Transmission Literature Review and Gaps Analysis* (Bothwell et al. 2021) and the *West Coast Offshore Wind Transmission Literature Review and Gaps Analysis* (Douville et al. 2023)—this literature review and gaps analysis for the Gulf of Mexico synthesizes the publicly available information to date.

The overarching objectives of this report are to survey publicly available offshore wind transmission analyses and research specific to the Gulf of Mexico, including environmental, community readiness, and infrastructure considerations; identify gaps in the body of literature; and inform potential future investments in transmission planning analysis and stakeholder convenings, which may guide the development of offshore wind transmission to realize its maximum value and minimum impact. The report is organized as follows:

- Background on offshore-wind-related activities to date (Section 2)
- Gulf of Mexico transmission analysis (Section 3)
- Environmental sensitivities (Section 4)
- Coastal communities and ocean co-use (Section 5)
- Regional infrastructure (Section 6)
- Diverse energy end uses and coastal industries (Section 7)
- Gaps assessment based on the existing public literature (Section 8)
- Role for convening in the region (Section 9)
- Conclusions (Section 10).

2 Background

In a 2020 study commissioned by the Bureau of Ocean Energy Management (BOEM) within the U.S. Department of the Interior, the National Renewable Energy Laboratory (NREL) assessed offshore wind resources in the Gulf of Mexico to quantify the region's technical and economic potential (Musial et al. 2020).

Offshore wind energy in the Gulf of Mexico has real and significant technical energy potential: 696 gigawatts (GW) of capacity from fixed-bottom wind turbines and 896 GW of capacity from floating wind turbines, which represents 37% of the total offshore wind technical energy potential across the entire United States (Lopez et al. 2022).

The average wind speed in the Gulf of Mexico is lowest in the east, off the coast of Florida, at around 7 meters per second (m/s), and highest in the west, off the coast of Texas, at almost 9 m/s (Musial et al. 2020). Figure 1 shows the results of a wind resource dataset created for the Gulf of Mexico (Bodini et al. 2023), with detailed wind speed information at a 5-minute resolution from the years 2000 to 2020. The model reveals that the highest average wind speeds in the Gulf of Mexico Call Area,[1] measured at 160 m above sea level, occur in the western part of the region near Corpus Christi, Texas, at 8.8 m/s. Wind speeds tend to decrease moving eastward, with the lowest speeds of around 7 m/s found in the eastern part of the Call Area, south of New Orleans. Unlike wind behavior in many coastal areas in the United States, wind speed in the Gulf of Mexico does not consistently increase with distance from the shore. In fact, as shown in Figure 1, the highest wind speeds are found near the coast in Texas state waters.

[1] A Call Area refers to potential areas identified by BOEM for public comment during the Call for Information and Nominations stage to explore interest in commercial wind energy leasing in that area.

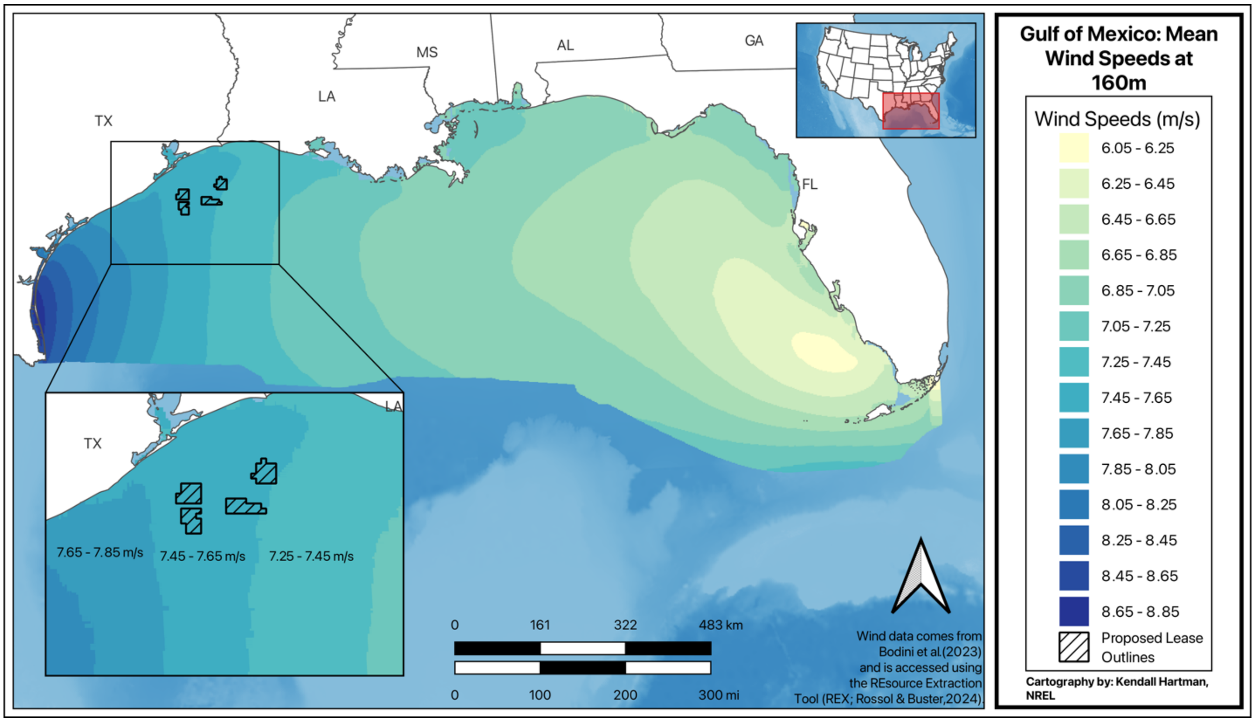

Figure 1. Mean wind speeds at 160 m elevation over the period 2000–2020.

Illustration by Kendall Hartman, NREL

The study concluded that a single offshore wind project could support approximately 4,470 jobs and $445 million in gross domestic product during construction and an ongoing 150 jobs and $14 million annually. The findings were based on technical offshore wind resource potential, levelized cost of energy estimates, and a summary of net value. The study found that the shallow-water resources in the Gulf of Mexico, existing supply chain for the oil and gas industry, and mild climate are all advantages for the development of offshore wind energy in the region.

2.1 Gulf of Mexico Lease Sale Activities

Planning for offshore wind energy development in the Gulf of Mexico has been ongoing for several years. In 2017, BOEM commissioned NREL to conduct a study of offshore renewable energy potential in the region, which yielded promising results for the future of offshore wind energy. Texas and Louisiana rank third and fourth, respectively, in state-by-state offshore wind energy potential. Each state has more than 200 GW of wind energy potential from its respective coast to the exclusive economic zone boundary 200 nautical miles offshore at the conservative installation density of 3 megawatts per square kilometer. Florida, Alabama, and Mississippi each has less than 50 GW of technical offshore wind energy potential (Musial et al. 2020).

Through an interagency agreement with the National Oceanic and Atmospheric Administration (NOAA) National Centers for Coastal Ocean Science (NCCOS) Marine Spatial Ecology Division, BOEM funded an ecosystem-wide spatial suitability model to inform selection of wind energy areas in federal waters in the Gulf of Mexico. Fourteen potential wind energy areas were identified as the most suitable. After several rounds of assessment and model configuration, a precision siting model was developed to maximize the number of lease areas for the two wind energy area options of highest interest (Randall et al. n.d.).

In 2020, former Louisiana Governor John Bel Edwards asked BOEM to form a Gulf of Mexico Intergovernmental Renewable Energy Task Force, which was established and held its first meeting in 2021 (BOEM n.d.[a]). The task force is a partnership of federal, Tribal Nation, state, and local agencies tasked with coordinating renewable energy planning activities on the Outer Continental Shelf (OCS) of the Gulf of Mexico. In 2021, BOEM announced an offshore wind leasing path through 2025, which included the Gulf of Mexico, along with other regions, in fulfillment of the Biden-Harris administration's goal to deploy 30 GW of offshore wind by 2030 (BOEM 2021a). In April 2024 a new leasing path was announced that updates the 2021 path and includes several rounds of auction (BOEM 2024a).

On May 25, 2023, BOEM published a Final Environmental Assessment (EA)[2] that considered potential environmental consequences of site characterization activities (i.e., biological, archaeological, and geological and geophysical surveys and core samples) and site assessment activities (i.e., installation of meteorological buoys) associated with issuing wind energy leases in the Call Area of the western and central Gulf of Mexico (BOEM New Orleans Office 2023). Following the issuance of a Finding of No Significant Impact, BOEM published a Final Sale Notice for the first lease sale in the Gulf of Mexico (BOEM 2023). The Final Sale Notice included a stipulation for transmission planning with consideration given to coordinated systems. The notice states, "The Lessee must—to the extent that it is technically and economically practical or feasible—consider the use of cable corridors, regional transmission systems, meshed systems, or other mechanisms for transmission facilities proposed in a construction and operations plan (COP)" (BOEM 2023). A wind energy lease sale was held on Aug. 29, 2023, and RWE Offshore US Gulf LLC won the auction for the Lake Charles Lease Area; there were no bids on the two Galveston lease areas (BOEM n.d.[b]).

BOEM proposed a second offshore wind energy auction for four areas offshore Louisiana and Texas totaling 410,060 acres (Figure 2). BOEM published a Proposed Sale Notice in the Federal Register on March 21, 2024 (BOEM 2024b).

[2] This was in compliance with the National Environmental Policy Act, which requires that federal agencies assess the environmental effects of their proposed actions prior to making decisions.

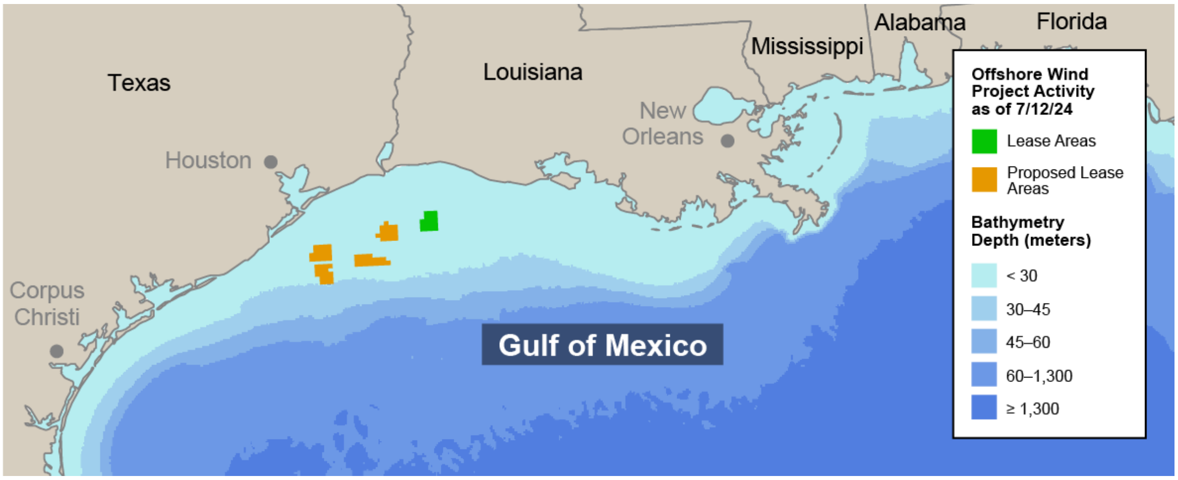

Figure 2. Gulf of Mexico final wind energy areas and lease options for the second auction.

Illustration by John Frenzl, NREL

2.2 State Activities

Economic drivers and state policies are important factors in determining the success of the offshore wind industry in the Gulf of Mexico. In addition to federal waters, Louisiana has supported offshore wind energy development in its state waters, with multiple developers currently in negotiations with the state. In 2022, Louisiana passed Act 443/H.B. 165 (Louisiana State Legislature 2022), which allows leases in state waters for wind energy production up to 25,000 acres. It also allows the state to receive a share of revenues from projects and updates the state's authority to accept project bids. Louisiana has a state planning goal of 5 GW of offshore wind energy generation by 2035 and a near-term goal to prioritize offshore wind strategic planning for outreach, workforce, and impacts assessments (Climate Initiatives Task Force 2022). The Louisiana Climate Action Plan also contains an action to develop a regional long-range transmission infrastructure plan that would benefit offshore wind development. The near-term action is to assess infrastructure needs across the state to plan for renewable connectivity. The goal is a 30% increase in transmission infrastructure by 2030 and a 100% increase by 2050 (Climate Initiatives Task Force 2022).

Alabama, Mississippi, and Louisiana all actively participate in the BOEM Intergovernmental Renewable Energy Task Force meetings. Offshore wind transmission considerations have been a topic of discussion at all Task Force meetings to date, as evidenced in the summaries provided online for each meeting (BOEM n.d.[a]).

3 Gulf of Mexico Transmission Analysis

Offshore wind in the United States has the potential to play a critical role in transitioning the nation to a clean energy future while improving the power system's reliability and resilience and providing economic opportunities. Transmission planning in the Gulf of Mexico region is complex, as it crosses different regions and regulatory structures. For the successful deployment of offshore wind energy, transmission planning needs to be conducted well in advance of wind energy development to allow for interproject and interregional coordination. At the onset, transmission planning requires a clear understanding of the available wind resource and development potential, a quantification of costs, identification of points of interconnection (POIs), and leadership across all jurisdictional levels.

3.1 State and Utility Offshore Wind Development Activities

Offshore wind energy development can be influenced by several factors, including state energy goals and mandates; regional integrated resource plans; and partnerships between industry (e.g., utilities and developers) and other stakeholders.

To date, offshore wind development in the United States has primarily been driven by individual states and their policies. Louisiana's goal to add 5 GW of offshore wind generation by 2035 is an important step for offshore wind energy in the region. It is the only significant regional offshore wind commitment to date, and it is not a mandate.

The Louisiana Public Service Commission has urged utilities to assess the costs and benefits of offshore wind energy as part of their long-term (2023–2042) resource planning (Louisiana Public Service Commission 2022). Entergy Louisiana LLC conducted their 2023 integrated resource plan (Entergy Louisiana 2022) using the Aurora capacity expansion model to select their generation mix based on the latest cost and resource data (e.g., offshore wind costs were sourced from NREL's 2021 Annual Technology Baseline [NREL 2021]). They conducted three future scenarios, which they called Capacity Expansion Optimized Portfolios. Although these scenarios contained solar energy and land-based wind energy, none contained offshore wind energy. Similarly, offshore wind energy was also not selected in integrated resource plans conducted by Texas utilities. The primary sources of energy generation in Texas have historically been natural gas, coal, wind, and solar power, with land-based wind playing a significant role in the state's renewable energy capacity (Wooley 2023).

Vestas' Steelhead Americas and Mitsubishi-owned Diamond Offshore Wind signed agreements with the state of Louisiana to explore development in state waters (Baurick 2023). Louisiana state waters begin at the coast and extend 3 nautical miles. Diamond Offshore Wind, Entergy Louisiana, and Entergy New Orleans have signed a memorandum of understanding to evaluate and potentially develop wind power generation in the Gulf of Mexico (Scardigli and Sabatini 2022). This agreement aims to bring wind power to the Louisiana coast and strengthen economic development in the region. The memorandum of understanding outlines a legal framework for collaboration between Entergy and Diamond Offshore Wind to work on potential offshore wind energy demonstration projects in Louisiana state waters. The focus will be on evaluating grid interconnection and determining the optimal size and locations for future offshore wind development. In March 2023, Entergy Louisiana also signed a memorandum of understanding with RWE AG (an offshore wind developer that currently leases OCS lease area OCSG-37334) to explore similar development opportunities in the Gulf of Mexico (Hannan and Tirone 2022).

3.2 Offshore Wind Transmission Planning and Analyses

Transmission planning in the Gulf of Mexico is conducted in three main ways:

1. The Electric Reliability Council of Texas (ERCOT): ERCOT manages the flow of electric power to about 90% of the state of Texas and is not Federal Energy Regulatory Commission (FERC) jurisdictional (i.e., does not involve interstate commerce). Transmission activities are regulated by the Public Utility Commission of Texas. ERCOT conducts a coordinated bottom-up transmission planning process, reviewing the plans of individual transmission planning entities within their region.
2. The Midwest Independent System Operator (MISO): MISO is a FERC-regulated regional transmission operator that extends from Minnesota to the Gulf of Mexico, including parts of Texas, Louisiana, and Mississippi. Additional regulation occurs at state and local levels. MISO conducts top-down transmission planning that addresses the needs of utilities throughout their region.
3. Individual utilities in the Southeast: The southeastern portion of the United States is not part of an organized electricity market. The utilities in Florida, Alabama, and parts of Mississippi are regulated by FERC and state authorities. They plan transmission individually and coordinate regionally and inter-regionally through Southeastern Regional Transmission Planning (SERTP).

Offshore wind transmission planning has been identified in several recent state plans, federal COP approvals, and intergovernmental proceedings for the Gulf of Mexico. The Louisiana Climate Action Plan contains an action to develop a regional long-range transmission infrastructure plan to increase state grid infrastructure, including infrastructure supporting offshore wind energy (Climate Initiatives Task Force 2022). As stated in Section 2.1, the BOEM Final Sale Notice for the first lease sale (BOEM New Orleans Office 2023) includes a stipulation for transmission planning that requires developers to consider cable corridors, regional transmission systems, meshed systems, or other mechanisms for transmission facilities. Participants in BOEM's Intergovernmental Renewable Energy Task Force meetings (BOEM n.d.[a]) have inquired about offshore wind transmission, including the siting and design of the transmission grid, BOEM's transmission planning process, modeling of transmission costs, the opportunity to use oil and gas infrastructure as a conduit for offshore wind transmission, considerations for transmission via electricity versus a hydrogen pipeline, and using existing nearshore transmission corridors to potentially minimize environmental impacts.

Transmission system operators and planners are engaged in long-range transmission planning for their respective regions. Offshore wind energy should be included in resource and transmission planning studies to capture resource diversity benefits and ensure that the supporting transmission infrastructure is coordinated.

Offshore wind energy is in the early stages of development in the Gulf of Mexico, and it **has not been** included in any of the transmission planning studies to date; as explained in this report, it will be important to include offshore wind energy in the future.

BOEM commissioned NREL to conduct a study (Fuchs et al. 2023) to identify a set of plausible POIs for offshore wind development in the Gulf of Mexico, centered around the Texas and Louisiana coasts. The POIs were identified based on multiple technical criteria, such as distance to the offshore platform, voltage levels, network topology, existing transmission ratings, and related information. The study results indicated that interconnecting offshore wind in the Gulf of Mexico is feasible because there are several plausible POIs near the coast with 230-kilovolt or greater high-voltage transmission lines. Many of the lines will require significant upgrades to handle gigawatt-scale power injections into land-based grid infrastructure, like other U.S. offshore wind regions (Fuchs et al. 2023). NREL identified 25 plausible POIs and calculated a least-cost path for onshore cable routes. The POIs were selected because they met the criteria of having one or more transmission lines, where one of which is at least 230 kilovolts.

4 Environmental Considerations

Transmission planning requires an understanding of constraints within the physical and biological environments and an evaluation of environmental and ocean co-use considerations. A complete discussion of the potential environmental considerations of offshore wind development is beyond the scope of this report. In brief, offshore wind energy development activities include geotechnical, geophysical, biological, and benthic habitat surveys to inform the baseline understanding of the physical and biological environment in the region. Environmental surveys consider the impacts during initial site construction and throughout the life of the wind energy project, including operation, maintenance, and decommissioning of wind turbines, transmission cables, and offshore and onshore substations.

4.1 Wildlife and Habitat

The Gulf of Mexico is home to diverse wildlife and habitats, including seabirds, marine mammals, sea turtles, fish, and other species. In addition, there is a large network of Marine Protected Areas in the Gulf of Mexico covering a range of designations (e.g., national marine sanctuaries, wildlife refuges, national seashores) (Marine Protected Areas n.d.). Surveying, construction, operation, maintenance, and decommissioning activities related to offshore wind energy development may affect marine species and habitats in several ways, such as direct collision with infrastructure, displacement, habitat disturbance, increased underwater noise, vessel traffic, increased electromagnetic fields, and entanglement (Tethys n.d.). Of these, habitat disturbance, electromagnetic fields, and entanglement may occur from the presence of transmission cables between wind turbines and from wind turbines to shore (Tethys n.d.).

Transmission cables can alter the benthic environment (the area on or near the seabed) during and after construction (Responsible Offshore Development Alliance 2022). The introduction of transmission cables can potentially change the physical and chemical properties of the sediment, displace some invertebrate species, and create new habitats. The latter may increase biodiversity, but it can also lead to the establishment of invasive species, particularly if a hard substrate—such as rocks placed around foundations to prevent erosion—is introduced into a soft-sediment environment like that of the Gulf of Mexico (Jenkins 2011). Benthic disturbance from laying seafloor cables tends to be localized and temporary, and biological and physical conditions typically recover within a few years. Changes to biodiversity from the presence of cables can occur throughout the life of the project.

Transmission cables are sources of electromagnetic fields (EMF) and heat. Additional EMF may alter the behavior of some species, such as sharks, sea turtles, and lobsters, that use naturally occurring electrical and magnetic fields for navigating and foraging (Hutchison et al. 2021). However, EMF decays quickly with distance from the cable. Thus, effects to populations are not expected, and EMF is unlikely to act as a barrier to movement (BOEM n.d.[c]). Heat generated by the cables can raise the water temperature within 2 feet by as much as 10°C to 20°C, but it is unclear what, if any, impact this has on the local environment or species. Burying cables can limit the potential exposure to heating effects, and EMF impacts are considered during the National Environmental Policy Act analysis (BOEM n.d.[c]).

Unique to floating offshore wind projects, where wind turbines are mounted on top of floating structures instead of attached to the seabed, suspended interarray cables (cables that connect wind turbine generators to an offshore substation), export transmission cables (cables that connect an offshore substation to the landfall site and points of interconnection to the electrical grid), and backbone transmission cables (cable line that connects two or more wind farms) create a potential for primary or secondary entanglement, particularly for sharks, marine mammals, sea turtles, and diving birds (Copping and Hemery 2020). Primary entanglement occurs when wildlife becomes entangled with the cable itself. Secondary entanglement occurs when wildlife becomes entangled in marine debris, such as derelict fishing gear, that gets caught in the suspended cables. Buried cables eliminate the risk of entanglement but may result in temporary and localized disturbance to flora and fauna on the seafloor during installation.

Ocean planning is used to inform offshore wind energy development in the Gulf of Mexico. To support early-stage planning, BOEM collaborated with NOAA NCCOS to develop an ecosystem-wide spatial suitability model to aid the selection of wind energy areas in federal waters in the region (Randall et al. n.d.). The model includes NOAA National Marine Fisheries Service datasets for protected resources and species protected under the Endangered Species Act and Marine Mammal Protection Act. A total of 23 protected resource data layers were combined in the model and included considerations for various species of dolphins, whales, manta rays, sea turtles, and fish (Farmer et al. 2023). Fourteen potential wind energy areas were identified as the most suitable areas within the Call Area based on the model configuration, which provided significant consideration for both natural resources and other ocean industries.

In 2023, BOEM finalized an EA for commercial and research wind lease and grant issuance and site assessment activities on the OCS of the Gulf of Mexico to determine whether the issuance of leases and grants within the Call Area would lead to reasonably foreseeable significant impacts on the environment (BOEM New Orleans Office 2023). The EA analyzes the impact of issuing up to 18 leases within the Call Area, the issuance of potential project easements associated with each lease, and the issuance of grants for export cable corridors and associated offshore collector/converter platforms.

In the EA, BOEM anticipates that each lease could have up to two transmission cable routes (for connecting future wind turbines to an onshore power substation) or would use a backbone transmission system—a single, shared transmission line capable of serving multiple connections. The EA analyzed the potential affected environment and environmental consequences for the following resources: air quality; coastal communities and habitats; benthic communities and habitats; fish and invertebrates; marine mammals; sea turtles; and cultural, historic, and archaeological resources. Coastal habitats and ecosystems considered in the analysis include estuaries, wetlands, mangroves, submerged aquatic vegetation, beaches and barrier islands, and coastal coral reefs. In terms of benthic communities and habitat, example ecosystems in the Gulf of Mexico include, muddy, soft bottom; oyster reefs; coral- and sponge-dominant banks; and marine canyons. The EA considers the effects of bottom disturbance on benthic communities and habitats caused by transmission cables. The EA outlined three alternative actions, and Alternative C (the preferred alternative) was selected. It excluded OCS lease blocks located within the exterior boundaries of any unit of the National Park System, National Wildlife Refuge System, National Marine Sanctuary System, or any National Monument, as provided in Subsection 8(p)(10) of the Outer Continental Shelf Lands Act and also removed whole or partial

Topographic Features Stipulation blocks. Alternative C was selected because it would result in the avoidance of sensitive benthic habitat.[3]

In a recent report on offshore wind transmission development in the U.S. Atlantic region, DOE and BOEM called for continued study of the impacts and interactions between offshore wind transmission infrastructure and marine ecosystems (Baker et al. 2023). Additional sources of research recommendations are available in the databases created for the Atlantic and the Pacific (Tethys n.d.). Although these recommendations are for different coastlines, they are applicable to other regions like the Gulf of Mexico, because the same types of research gaps persist related to habitat, ecosystem processes, and wildlife species.

4.2 Coastal Climate, Land Loss, and Restoration Activities

Areas along the Gulf Coast have the largest estimates of sea level rise for the United States by 2050 (Sweet et al. 2022). The western part of the Gulf of Mexico has the highest extrapolated values in 2050 driven by high rates of coastal subsidence in the region. The coasts of Louisiana and Texas are projected to experience roughly 2 feet of sea level rise by 2050. Rising sea level can lead to more permanent inundation, land loss, coastal erosion, and flood exposure for coastal communities. In Louisiana, climate-related sea level rise is rapidly eroding the state's coastline, and extreme weather events threaten billions of dollars in damages every year (Törnqvist et al. 2020; Climate Initiatives Task Force 2022). The viability of transmission infrastructure in the region, particularly in coastal cities, could be affected by flood frequency, extreme rainfall events, sea level rise, more intense hurricanes, and higher storm surge from hurricanes.

Widespread restoration activities are ongoing along the Gulf Coast to counteract the effects of rising sea levels, erosion, and the impacts of the 2010 Deepwater Horizon oil spill. Louisiana's 2023 Coastal Master Plan is the fourth plan developed by the state to guide billions of dollars of investment toward achieving comprehensive coastal restoration and risk reduction goals (Coastal Protection and Restoration Authority of Louisiana 2023). Completed, ongoing, and future projects include restoration of shorelines, marshes, and barrier islands in many sensitive areas of the Louisiana coastline. For each Gulf state, NOAA maintains the Gulf Spill Restoration website, which has the status of all restoration activities since 2010 (NOAA n.d.). BOEM's Marine Minerals Program is contributing sand, gravel and/or shell resources from federal waters on the OCS for shore protection, beach nourishment, and wetlands restoration along the Gulf Coast. Sand and gravel borrow areas[4] may be incompatible with transmission siting; BOEM and the U.S. Army Corps of Engineers requested the exclusion of sand and gravel borrow areas from future transmission cable areas modeled in the *Atlantic Offshore Wind Transmission Study* (Brinkman et al. 2024). Similarly, the feasibility of potential transmission routing would also need to be considered in potentially sensitive areas that are undergoing restoration activities along the Gulf Coast. The use of existing corridors, such as those previously developed for the

[3] For more information on the specifics of each alternative considered, refer to Chapter 2 of the *Commercial and Research Wind Lease and Grant Issuance and Site Assessment Activities on the Outer Continental Shelf of the Gulf of Mexico* (BOEM New Orleans Office 2023).
[4] Sand and gravel borrow areas generally refer to the offshore geographic areas where OCS sand and gravel sources have been identified for potential use.

oil and gas industry, may offer an opportunity to minimize further environmental disruption related to future transmission routing associated with offshore wind development in the region.

5 Ocean Co-Use and Coastal Communities

The Gulf of Mexico's geographic characteristics, environmental characteristics, and people have made the region economically productive and culturally rich. Many industries, such as shipping, commercial fishing, and oil and gas production, have thrived in the area for decades, leading to the diverse use of the area's marine and coastal resources. The military is active throughout the Gulf region. In addition to commercial and military activities, the Gulf also supports a variety of noncommercial uses, including environmental conservation, recreational and subsistence fishing, shrimping, and oyster harvesting. These are just a few examples of how the Gulf's demographically diverse population uses its waters and coastline for a variety of cultural practices, often continuing traditions that stretch back decades, centuries, or, in the case of Tribal Nations and indigenous communities, millennia. Any of the varied and long-standing uses of the Gulf's seabed and shorelines may have implications for developing offshore wind energy transmission, requiring careful consideration of the area's unique cultural, environmental, and economic contexts.

5.1 An Overview of Ocean Co-Use

The Gulf sustains a wide variety of "ocean co-uses," meaning multiple, concurrent uses of the marine environment. Some established uses are commercial, such as shipping, fishing industries, and resource extraction, while others are noncommercial, such as recreation, subsistence fishing, and marine research and conservation. Though not yet established in the Gulf, expanded uses could include offshore aquaculture and renewable energy generation, including wind energy and water power generation. As the United States' primary offshore source of oil and gas, the Gulf already accounts for about 97% of the nation's OCS extraction administered by BOEM. The region's marine mining, dredging, and sand leases to coastal sites are also managed by BOEM through its Marine Minerals Program (BOEM n.d.[d]). Beyond BOEM's activities, the Gulf of Mexico waters are subject to a variety of uses by other federal agencies, including the U.S. Department of Defense, and by diverse nongovernmental stakeholders with commercial, recreational, and cultural interests.

The Gulf's coastlines, wetlands, and marine habitats have been the focus of many conservation and environmental protection and restoration efforts. These efforts often aim to protect the region's biodiversity—the Gulf's wetlands, coastal waters, and marine habitats are home to more than 15,400 species (Felder and Camp 2009). There has been substantial research on the effects of past offshore energy development on these species, perhaps most notably on the effects of the Deepwater Horizon oil spill in 2010 (McKinney et al. 2021). Researchers and conservationists recognize that Gulf species exist in complex dynamics with offshore energy infrastructure. Many of the structures constructed for oil and gas extraction, for instance, have become heavily populated marine habitats, and the U.S. Department of the Interior Bureau of Safety and Environmental Enforcement (BSEE) works with state governments to convert defunct structures into artificial reefs under the Rigs-to-Reef program (BSEE n.d.[a]).

Leveraging the region's biotic productivity, commercial and recreational fisheries in the Gulf of Mexico generate millions of dollars per year and are regulated at both the state and federal levels. With perhaps one of the largest ocean use footprints of all Gulf users, the U.S. Department of Defense maintains several major military bases and many smaller military installations along the Gulf Coast, conducting extensive airspace and maritime activities.

Additionally, the U.S. Environmental Protection Agency's (EPA's) Ocean Disposal Map displays the 98 sites currently designated for ocean disposal of specified materials under the Marine Protection, Research and Sanctuaries Act (EPA 2024). There are more than 30 ocean dumping and disposal sites located in the Gulf of Mexico.

Some of these uses would be able to exist in the same waters as offshore wind energy developments (including transmission), while others may preclude offshore wind transmission development in certain high-use, restricted, and/or protected areas. Transmission construction activities can impact ocean co-users through increased vessel traffic and disturbance of the seabed sediment during cable laying and burying (or in some cases, cable mattressing, which means covering the cables with concrete barriers). For instance, companies and individuals who fish for commerce, subsistence, or recreation could be impacted by seabed disruptions that cause some marine animals to avoid the area during the construction period. Research indicates that these sediment disruptions are generally short-lived (Green et al. 2022).

Impacts to ocean co-use can often be avoided, minimized, or mitigated by siting wind projects—and thus associated offshore transmission needs—away from high-use zones and by timing construction periods during other industries' "off seasons" to the extent possible. For example, in the Vineyard Wind 1 Record of Decision document, the U.S. Army Corps of Engineers anticipates that "the project will adhere to time of year restrictions in Nantucket Sound provided by fisheries agencies to reduce impacts to vulnerable life stages of fish, crustaceans, and mollusks that could be present in the area" (BOEM 2021b). Offshore wind siting analyses have focused on avoiding conflicts with ocean co-uses and avoiding, minimizing, and/or mitigating impacts whenever practicable. As mentioned in Section 4.1, a spatial suitability model developed by BOEM and NOAA NCCOS factored in existing fishing and vessel traffic patterns to determine which zones of the Call Area were least likely to create conflicts with other industries and uses.

5.2 Human Communities and Environmental Contexts

Offshore wind transmission development projects are major infrastructure projects with both offshore and onshore implications. Developers need to analyze the potential impacts not only to marine habitats and species but also to the Gulf Coast's human residents with their diverse uses of Gulf waters and coastlines. The Gulf of Mexico is the fastest-growing coastal region in the United States. By 2017, a total of 15.8 million people were living in counties along the Gulf of Mexico—a population increase of more than 25% from 2000 (U.S. Census Bureau 2019). Home to major metropolitan areas like Houston, Texas; New Orleans, Louisiana; and Tampa, Florida, the Gulf Coast is also racially, ethnically, and culturally diverse, with Black, Latino, Native American, Cajun, Creole, and immigrant communities. In many cases of offshore wind energy development in other regions, perspectives on offshore wind plants and their related infrastructure vary across communities; local acceptance will be key to the advancement of offshore wind in the Gulf region.

Industrial and energy development are major sources of employment and economic activity in the region, generating billions of dollars of revenue annually. However, they have also contributed to severe environmental degradation, pollution, and negative health outcomes for the communities nearby, often called "fenceline" and "frontline" communities or "sacrifice zones," that are disproportionately Black and low-income (Climate Initiatives Task Force 2022).

Although offshore wind transmission infrastructure is different than the historical development of other industries, past experiences raise a need for sensitivity to legacies of environmental injustice and highlight the importance of awareness, avoidance, minimization, and mitigation of potential environmental or other impacts of offshore wind transmission system development on frontline communities.

As both urban and rural areas along the coast are increasingly subject to the impacts of climate change, new climate contexts may compound historically entrenched health and environmental inequities. Due to their geography, Gulf Coast communities are at an elevated risk of flooding, excessive heat, natural disasters, and infrastructure failures. Tribal Nations are also often on the front lines of environmental justice issues. In some cases, past coastal infrastructure development, including for energy generation, has appeared to exacerbate the impacts of climate change by increasing communities' vulnerability to coastal erosion (Carter et al. 2018). Managing these risks has become a central component of environmental and energy planning for federal, Tribal Nation, state, and local governments along the Gulf Coast. Many of these efforts are salient to both transmission infrastructure planning and broader community health outcomes.

Louisiana's Climate Action Plan, for instance, seeks to improve statewide health and environmental equity through broad decarbonization and disaster preparedness. Expanded renewable energy infrastructure (including offshore wind energy and long-term transmission capabilities), wildfire and flood mitigation, and reduced industrial emissions are central to Louisiana's plan (Carter et al. 2018). Due to the Gulf of Mexico's high industrial capacity, industrial emissions account for 66% of Louisiana's total greenhouse gas emissions, compared with 17% for the United States as a whole. Reducing industrial emissions, potentially through low- and no-carbon hydrogen development, is one way the state's Climate Action Plan aims to slow the impact of climate change while directly improving health outcomes for frontline communities. Transmission development related to offshore wind energy could potentially complement goals to increase the resilience of local Gulf of Mexico electric grids or stimulate clean hydrogen production.

The impact of offshore wind transmission on shorelines and communities must be taken into consideration when planning development. For example, some concerns raised by other communities that have experienced offshore wind transmission development include installation activities causing disruption to the ocean environment and their use of it; disruption and potential visible impacts at the cable landfall site; disruption from installation of the onshore cabling; and lasting visual and noise impacts from any onshore substation expansion or development (Yale.edu n.d.). Understanding the local cultural and historical context and planning for early engagement with local communities as part of broader transmission planning can help ensure concerns and potential impacts can be addressed and that development happens in an equitable manner.

5.3 Workforce and Industry Considerations

Since the inception of the United States' offshore wind industry, Gulf Coast companies have directly supported its development, including the first projects on the Atlantic Coast. With their manufacturing and servicing capabilities, Louisiana companies are well-positioned to support offshore wind development and were integral in the design, fabrication, and construction of the Block Island Wind Farm in Rhode Island (Office of Energy Efficiency and Renewable Energy

[EERE] 2017), the first commercial U.S. offshore wind farm. The country's first wind farm service ship is being built in Louisiana for the New England energy service provider Eversource and the developer Ørsted to operate and maintain wind farms in the northeastern United States; the ship is being built by Edison Chouest Offshore, a company that traditionally builds ships for offshore oil and gas operations (Setyawan 2023). The first U.S.-made offshore substation was fabricated in Texas by Kiewit Offshore Services (Durakovic 2023), and the first U.S.-flagged wind turbine installation vessel is being built in Brownsville, Texas, for Dominion Energy to support multiple wind farm installations along the Atlantic Coast. The Southeastern Wind Coalition, Greater New Orleans Inc., the Center for Planning Excellence, and The Pew Charitable Trusts released a Louisiana offshore wind supply chain assessment detailing the readiness for offshore wind in the Gulf and its existing capacity for development (Xodus 2024). The experience of Gulf Coast companies positions them to further support the manufacturing, servicing, and transmission of offshore energy in the Gulf.

The Gulf of Mexico supports several existing industries that may have transferable skill sets for offshore wind transmission development. Compared with national averages, the region employs high numbers of natural resource, construction, and machine maintenance workers. The Gulf of Mexico also sustains two of the world's largest ports, at Houston, Texas, and New Orleans, Louisiana, and a multi-billion-dollar shipping industry. It also supports a culturally and economically significant commercial fishing industry that produces about 15% of total U.S. fish landings (which are the catches of marine fish that are brought into ports). With its extensive oil and gas industry, the Gulf Coast also houses 47% of total U.S. petroleum refining capacity and 51% of total U.S. natural gas processing plant capacity, employing thousands of workers (U.S. Energy Information Administration [EIA] 2023a).

While much of the current workforce could help build and maintain offshore wind transmission, it is also important to understand if transmission development could temporarily or permanently disrupt existing industries that are regional sources of employment. For instance, without careful siting and mitigation, construction of offshore transmission infrastructure could temporarily disrupt vessel traffic or alter the behavior or location of species in marine fisheries (Green et al. 2022).

BOEM collaborates on siting studies that analyze vessel traffic related to the shipping and fishing industries, among many other types of co-use. BOEM has also published fact sheets on the potential impacts of offshore wind development on fisheries and vessel traffic, as described in Section 5.1. In January 2022, BOEM also held four sector-specific Gulf of Mexico fisheries workshops aimed at collecting information that would be helpful in avoiding and mitigating the potential impacts of offshore wind transmission development on both commercial and recreational fishing (BOEM n.d.[c]). These efforts have been supplemented by collaborative research projects and engagement with marine research and fishery management institutions. Strategies for investigating and mitigating potential impacts to the fishing and shipping industries were also discussed in a series of meetings held by BOEM's Gulf of Mexico Intergovernmental Renewable Energy Task Force.

Though still a large source of employment, oil and gas extraction has reduced its demand for labor over the past decade as a result of increases in efficiency and automation. Between 2015 and 2019, oil and gas companies laid off 55,000 employees, or 28% of the total workforce. Oil and gas employment has become generally less stable on the Gulf Coast as more workers experience periods of unemployment (Milliken Biven and Lindner 2023). In light of these fluctuations, a survey of oil and gas workers indicated considerable interest in programs to transition displaced workers to other fields and job opportunities, which could include wind energy jobs (Milliken Biven and Lindner 2023).

Although efforts can be made to retrain and recruit a local workforce, as with any large infrastructure project, offshore wind transmission development may potentially have the need to utilize external work crews from other places. In a study commissioned by BOEM, NREL estimates that a single offshore wind project, including transmission development, has the potential to create 4,470 construction jobs and 150 full-time operations jobs (Musial et al. 2020). Transmission development would specifically require work for manufacturing and shipping the cables, trenching or horizontal directional drilling of cable routes and landfalls, laying cables, burying or mattressing cables, and providing other support activities. As mentioned in Section 2, several shipyards that have typically supported oil and gas infrastructure are pivoting to meet the demands of offshore wind installation, as the large-scale infrastructure previously developed for oil and gas production is well-suited to offshore wind industry needs. Furthermore, companies in the southern United States and Gulf of Mexico region are well-represented in work related to offshore surveying and electric substations and cables, capturing about 23% of the contracts tracked by the Oceantic Network, an ocean-based renewables industry association (Saul 2023). Matching the region's available workforce to wind energy labor needs is a source of emerging economic potential that warrants further location- and industry-specific research.

6 Regional Infrastructure

The Gulf of Mexico region has an established infrastructure network that consists of extensive pipeline and electric transmission, developed through legacy oil and gas industries. The existing infrastructure could support offshore wind energy development and transmission deployment in the Gulf to produce electricity for regional use and for the creation of downstream products like hydrogen and ammonia.

The direct and indirect infrastructure from the oil and gas industry in the Gulf of Mexico has the potential to support onshore and offshore renewable energy operations. This infrastructure includes ports, manufacturing facilities, vessels, pipelines, platforms, transmission and distribution corridors, hydrogen networks, and geological gas storage, among other components. Through direct use or through retrofit and expansion (DNV n.d.), the existing infrastructure could support offshore wind development, electricity transmission, and other clean energy technologies (like clean hydrogen production) (EERE 2022). Furthermore, Gulf Coast states have established renewable energy infrastructure from land-based wind, solar photovoltaics, and battery industries.

This section focuses on Texas, Louisiana, and Mississippi, given their activities in the central and western Gulf of Mexico, the presence of legacy energy industries, and planning for offshore wind development in this region.

6.1 Electrical Infrastructure

The existing electrical infrastructure in the Gulf will require additional reinforcements to accommodate substantial offshore wind development. The DOE *National Transmission Needs Study* (Grid Deployment Office 2023) identifies transmission infrastructure limitations, congestion, and interconnection capacity constraints; grid and transmission reliability considerations; and resiliency adaptation. For the Texas region, the *National Transmission Needs Study* recommends a significant increase in transmission deployment to meet the needs of projected generation and demand growth (Grid Deployment Office 2023); this is without consideration of the potential future integration of offshore wind into the grid.

According to the *Offshore Wind Market Report: 2023 Edition* (Musial et al. 2023), the forecasted pipeline capacity of offshore wind energy in the Gulf of Mexico is 4,885 megawatts. Although it remains uncertain how much exact transmission capacity might be needed to support offshore wind deployment in the Gulf, offshore wind potential is helping drive future transmission deployment needs (Musial et al. 2023). Thus, offshore wind transmission infrastructure expansion is needed for greater system reliability and resiliency as renewable energy is added to the grid.

6.2 Oil and Gas Infrastructure

As a major source of oil and gas production, the Gulf of Mexico has the most extensive offshore oil and gas infrastructure in the country, which could be leveraged or transitioned to support the development of offshore wind (BOEM n.d.[e]). On the Gulf of Mexico seafloor, there are more than 26,000 miles of pipelines (roughly 8,600 of which are actively used) and 1,862 platforms (National Centers for Environmental Information 2011; U.S. Government Accountability Office

2021; BSEE n.d.[b]). The Gulf Coast states have waterways and terminals for import and export of liquefied natural gas (LNG).

Additionally, about 97% of abandoned pipelines, equating to 18,000 miles, remain on the Gulf of Mexico's seafloor (U.S. Government Accountability Office 2021). Pipeline infrastructure could be leveraged for clean hydrogen transmission and distribution, especially when integrated with offshore wind to directly transport renewable fuels. Existing pipeline infrastructure could be repurposed for specific hydrogen applications or blending hydrogen into existing natural gas pipelines. A technical report commissioned by DOE's Hydrogen and Fuel Cell Technologies Office (HFTO) and co-authored by NREL, Sandia National Laboratories, and Pacific Northwest National Laboratory reviewed the state of hydrogen blending technology to provide direction for future hydrogen blending research. The report explores material, economic, and operational factors that must be considered, including summaries of studies that developed relevant mathematical models used to study how blending hydrogen impacts the operation of natural gas transmission and distribution infrastructure (Topolski et al. 2022). DNV published a white paper that discusses the current research and latest developments around hydrogen pipelines and outlines a process to assess the safety and feasibility of repurposing onshore pipelines for hydrogen (DNV n.d.).

At the end of 2021, 573 platforms had been decommissioned and converted into artificial reefs (BSEE n.d.[a]). Furthermore, the repurposing of platforms has been researched, including for applications like electrolysis, freshwater production (Leporini et al. 2019), and offshore wind energy (Braga et al. 2022). This research is outside the geographic scope of offshore wind in the Gulf of Mexico and does not focus specifically on platform redesign for substations; therefore, more research is required.

6.3 Ports and Vessels

Because of the established supply chain for ports and vessels from legacy industries, the Gulf Coast can expand port and vessel capabilities to support offshore wind energy and transmission deployment throughout the Gulf of Mexico. Two ports in Texas have been identified as capable of supporting offshore wind development (Musial et al. 2023). Port Ingleside in Corpus Christi Bay, Texas, can support the construction of offshore substations. Three locations supporting vessel construction in Louisiana have also been identified as suitable for offshore wind support—one announced and two under construction (Musial et al. 2023). There are seven fabricators and shipbuilders located in Texas, Louisiana, Mississippi, and Alabama whose primary capabilities include the fabrication of complex structures; shipyard improvements; and procurement, construction, installation, and maintenance services to support offshore wind and transmission deployment in the Gulf Coast region (Musial et al. 2020).

7 Energy End Uses

As already noted, energy use in Gulf Coast states has been shaped by the states' vast fossil fuel resources and coastal location. State governments, system operators, and the oil and gas industry have planned, built, and maintained an extensive transmission network to transport these natural resources to residential, commercial, and industrial users. Each state has high-capacity port infrastructure that supplies the world with energy commodities and has access to extensive geologic storage for commodities such as crude oil and natural gas. Furthermore, underground caverns may be a viable long-term storage method for hydrogen (Papadias and Ahluwalia 2021). As energy demand and supply shift, the Gulf Coast is positioned to adapt to future needs.

Renewable energy is rapidly growing in the region, adding complexity to the region's existing transmission capacity. Renewable energy sources have been integrated into the transmission mix, aided by incentives from the Inflation Reduction Act (IRA). For example, in the Energy Infrastructure Reinvestment Program under Title 17 of Section 1706, the IRA guarantees loans to projects that retool, repower, repurpose, or replace energy infrastructure that has ceased operations (Loan Programs Office n.d.). Combining hydrogen generation capabilities with land-based wind and/or solar energy or with offshore wind facilities has led to the development of hybrid power plants. Using multiple generators and storage devices can increase the capacity factor of a renewable power plant and provide opportunities for offshore wind projects in the Gulf of Mexico (Dykes et al. 2020).

7.1 Petroleum and Refining

The Gulf Coast states are large producers of crude oil products. Those products supply petrochemical industries and fuel the transportation sector. Louisiana is home to the nation's only deep-water oil port where oil imports are stored in underground and aboveground storage facilities with a capacity of more than 70 million barrels (EIA 2023b). Louisiana's 15 oil refineries make up almost one-sixth of the refining capacity in the United States. Mississippi's oil production has been in decline in recent years, yet the state derives more than one-third of its energy use from petroleum (EIA 2023c). Texas consumes the most petroleum in the United States by volume and is third in volume per capita (EIA 2023d). Regardless of each state's capacity, the oil pipelines between these states are critical infrastructure that ensure energy is accessible for end users and coastal industries. Altogether, the region contributes significantly to the domestic Strategic Petroleum Reserve and the international oil and gas economy.

Since hydrogen is a necessary feedstock to some refining processes, more than 6 million tons of hydrogen is consumed annually by U.S. oil refineries (Ruth et al. 2020). Steam methane reformation is typically used to produce hydrogen and contributes 9 kilograms of carbon dioxide per kilogram of hydrogen. Therefore, by integrating zero- or low-carbon hydrogen, the oil refining industry can potentially reduce its carbon dioxide emissions by up to 54 million tons annually. The demand for hydrogen by Texas' refining industry is projected to be 2 million tons in 2035 and 1.6 million tons in 2050 (Ati et al. 2022). However, if oil demand decreases, then this demand for low-carbon hydrogen will likely diminish.

7.2 Natural Gas

Given the maturity of the natural gas industry in the Gulf of Mexico, states in the region rely on natural gas power plants to provide between two-thirds and three-quarters of their electricity demand. Texas is the nation's largest natural gas consumer, accounting for nearly 15% of the total use in the United States (EIA 2023d). Natural gas infrastructure requires significant energy to ensure its reliability. Nearly twice the amount of natural gas delivered to residential and commercial users is spent producing, processing, and distributing the natural gas. Texas is also home to nearly 850 billion cubic feet of underground natural gas storage, which is almost 10% of the total underground storage capacity in the United States. Louisiana has 19 underground storage sites, which accounts for 8% of the nation's storage capacity (EIA 2023e). These caverns store oil and natural gas in preparation for domestic transmission and to support the Strategic Petroleum Reserve. Mississippi has virtually no natural gas production compared to Texas or Louisiana. Therefore, the natural gas pipelines that connect Mississippi's extensive underground storage and natural gas processing plants to Texas and Louisiana allow Mississippi to export up to 1.5 billion cubic feet of LNG per day (EIA 2023c).

7.3 Industrial Sectors

The industrial sector in the Gulf Coast consumes more energy in the form of electricity and natural gas than the transportation, residential, and commercial sectors. Some of the major industries outside oil and gas are ammonia, iron and steel, and cement. The Gulf Coast is also home to a wide range of advanced manufacturing that supports the aerospace and defense industries. Today, ERCOT recognizes data centers and crypto mining as large load centers. Therefore, the reliability of energy and commodities are important to businesses in the region. Additionally, the Center for Houston's Future and McKinsey & Company released a report that envisions Houston as the epicenter of low-carbon hydrogen supply. It highlights the ample supply of renewable energy as well as the 900 miles of hydrogen pipeline infrastructure along the Texas coast.

Figure 3 depicts the major industries that emit carbon dioxide across Texas and Louisiana (Ati et al. 2022). Each circle is color-coded according to the industry, and the size represents the carbon emissions in million tons per annum. The 2019 data represented in the figure were aggregated from the EPA's FLIGHT database and a proprietary database from McKinsey & Company (Ati et al. 2022).

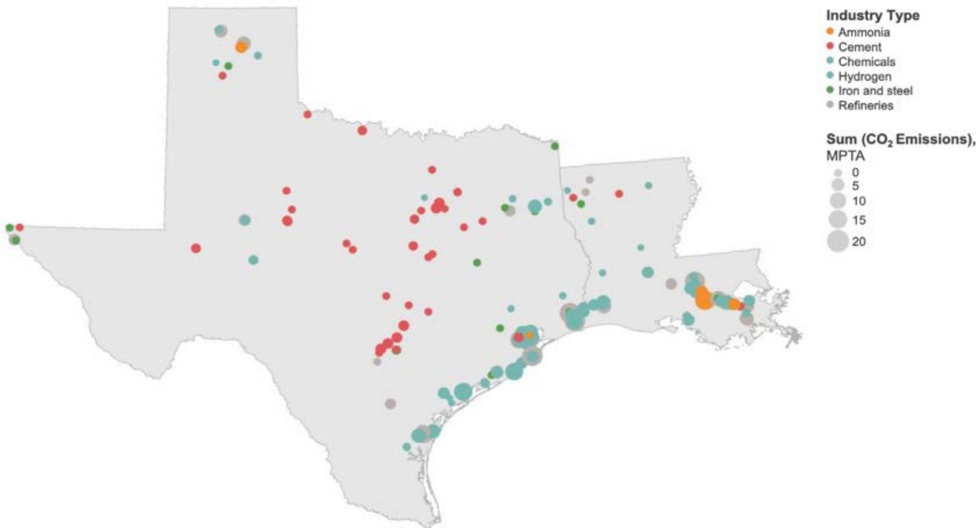

Figure 3. Major carbon dioxide (CO_2) emitters in Texas and Louisiana's industrial sectors in 2019. Each color represents a different type of industry, and the size of the marker indicates the million tons per annum ("MPTA") of CO_2 emissions.

Image from Ati et al. (2022), Exhibit 22

- **Ammonia:** Southern Louisiana has a high concentration of ammonia plants, as shown in orange in Figure 3. Large commodity holding companies such as CF Industries have announced plans to utilize the state's geologic storage for carbon-capture projects, but the plans are still in the front-end engineering design phase and have yet to break ground in new facilities or plant expansions (Louisiana Economic Development 2023).
- **Iron and Steel:** According to the Mississippi Development Authority, Mississippi and Louisiana collectively are home to nearly 50 iron and steel manufacturers, as well as 10 iron foundries. The presence of these commodities also supplements a myriad of advanced manufacturing applications, such as aircraft, biomedical products, light- and heavy-duty vehicles, marine vessels, agricultural machinery, and construction equipment, among others. Additionally, Texas also has 100 iron and steel mills and 22 iron foundries, mostly near Houston. Between the three states, iron foundries and steel mills generate $2.3 billion in annual revenue. Texas has plants that remove oxygen from iron ore or other iron-bearing materials in the solid state, known as direct reduction plants, using natural gas to produce steel with fewer carbon emissions. If steel producers mix low- or zero-carbon hydrogen into this process, Texas could be a leader of U.S low-carbon or green steel (Ati et al. 2022).
- **Cement:** Cement facilities in Texas are sparsely distributed throughout central Texas, as shown in red in Figure 3. Depending on future transmission capacity, Texas' cement industry could benefit from the wind and solar resources in West Texas and the Gulf of Mexico. CEMEX, a cement and building material manufacturer, has demonstrated hydrogen-injected cement processes to reduce carbon emissions (CEMEX 2022). While CEMEX has yet to implement the technology in the United States, future hydrogen hubs see their presence in Texas as pivotal to decarbonizing the cement industry.

7.4 Exports and Imports

Along the Gulf Coast, there are nine major seaports dedicated to oil imports and exports. Connected to these ports are the highest concentrations of offshore oil platforms, onshore oil refineries, and shale basins in the United States. The established infrastructure and operations in this region could enable the exporting of clean hydrogen or ammonia for industrial feedstocks.

U.S. LNG exports doubled between 2020 and 2022, when expanded infrastructure came online. Two ports in Louisiana, Sabine Pass and Cameron LNG, now handle more than 60% of these exports (EIA n.d.). Although this economic benefit can be traced to increased global demand, the magnitude of the growth shows what can be achieved with infrastructure investments. Port logistics and operations are large energy consumers given the schedule of cranes, lifts, light- and heavy-duty vehicles, freight, and vessels. Funding from DOE's "CarbonSAFE Phase II – Storage Complex Feasibility" funding opportunity was awarded to the Port of Corpus Christi, Texas, along with universities and energy companies, to improve procedures to assess onshore and offshore carbon dioxide project sites safely, efficiently, and affordably within a storage complex at a commercial scale (Office of Fossil Energy and Carbon Management 2023).

7.5 Hydrogen Production, Storage, and Hubs

Hydrogen is used by many industries, such as steel, ammonia, and cement. Hydrogen is commonly produced from fossil fuels by "cracking" hydrocarbons with extreme heat and pressure into pure hydrogen while releasing carbon dioxide. By including carbon capture and storage in the process, the produced hydrogen is classified as low-emission hydrogen. However, producing hydrogen by splitting water molecules through electrolysis results in a lower life cycle emissions intensity.

Qualified clean hydrogen is defined as hydrogen produced "through a process that results in a lifecycle greenhouse gas emissions rate of not greater than 4 kilograms of CO_2e per kilogram of hydrogen." Hydrogen production though the electrolysis of water, using renewable energy, has a very low carbon intensity, and one of the lowest life cycle emissions among varying types of integrated energy systems (HFTO 2023a). Therefore, the coupling of offshore wind energy development and hydrogen production is a unique low-carbon-intensity integrated energy hydrogen production system that is of increasing interest to research and industrial sectors. DOE has set ambitious goals for reducing the costs to producing hydrogen, like the Hydrogen Shot goal of reducing the cost of carbon-free hydrogen to $1 per kilogram in one decade (HFTO 2021). The DOE has also published a U.S. National Clean Hydrogen Strategy and Roadmap exploring opportunities for clean hydrogen to contribute to national decarbonization goals across multiple sectors of the economy (HFTO 2023b). Hydrogen production from renewable energy is one of the key pathways for clean hydrogen production to pursue to meet these ambitious goals, and offshore wind energy offers a unique opportunity for hydrogen production in the Gulf region.

Hydrogen has been identified by the Biden-Harris administration as a potential catalyst to decarbonize hard-to-abate sectors, including steel manufacturing, chemical processes, and long-haul transportation (Satyapal et al. 2023). These sectors are examining how to leverage existing infrastructure while reducing their carbon footprint, such as blending hydrogen with natural gas in existing or retrofitted pipelines.

The region also benefits from the potential to use low-cost, salt dome geological storage for hydrogen, primarily in Texas, Louisiana, and Mississippi, which plays favorably into the economic viability of producing low-cost, carbon-free hydrogen when paired with renewable energy generation.

In October 2023, the Biden-Harris administration endorsed the increasing focus on clean hydrogen in the Gulf of Mexico by selecting the Gulf Coast Hydrogen Hub (Office of Clean Energy Demonstrations [OCED] n.d.[a]) for the $8 billion Regional Clean Hydrogen Hubs program under the Bipartisan Infrastructure Law (OCED n.d.[b]). Positioned near Houston and along the Texas Gulf Coast, this hub will leverage the area's existing natural gas pipelines and geological salt caverns. It also presents a potential avenue for more electric transmission deployment that could indirectly support the integration of offshore wind due to the anticipated increase in production capacity and demand associated with the Gulf Coast Hydrogen Hub.

When paired with wind energy, hydrogen production can take advantage of policy incentives for wind, as well as unlock additional tax benefits under the federal tiered emissions intensity Clean Hydrogen Production Tax Credit, also known as provision 45V. Therefore, within an offshore wind-to-hydrogen system, both the wind and hydrogen production components of the facility can qualify for tax credits that could be stacked, potentially reducing the levelized cost of hydrogen produced (EERE 2023). The hydrogen could be produced at offshore wind facilities and used to meet demand in the Gulf region. Clean hydrogen from offshore wind can connect renewable electricity to hard-to-abate industries[5] and decarbonize traditional hydrogen production, but most large-scale projects are still in demonstration phases (International Energy Agency 2021).

The hydrogen shift in the Gulf of Mexico will come at the directive of individual states. Louisiana's Climate Action Plan identifies plans to use clean hydrogen to aid in decarbonizing its heavy emitting industries. The plan notes that due to the nascence of this strategy, research and development are needed to meet Louisiana's 2050 net-zero goal (Climate Initiatives Task Force 2022). Mississippi announced a clean hydrogen project with Hy Stor Energy that proposed to use the state's vast underground geologic storage to store hydrogen generated from renewable energy sources (Mulder 2023). In 2021, Hy Stor Energy announced that it expects to build a $3 billion clean hydrogen complex (Hy Stor Energy 2021).

The region near Houston, Texas, produces and consumes a third of the nation's hydrogen along with 50% of the country's pipelines to transmit hydrogen (Ati et al. 2022). The Houston hydrogen hub, led by HyVelocity Inc., recently received DOE funding to jump-start the low-carbon hydrogen economy and accelerate innovation in the region. The funding is expected to help plan and develop large-scale clean hydrogen production as well as support projects such as low-carbon ammonia, underground storage, pipeline transmission, and refueling stations for the transportation sector. HyVelocity Inc. envisions creating 35,000 construction jobs and 10,000 permanent jobs, as well as reducing carbon dioxide emissions by 7 million tons per year (OCED n.d.[a]).

[5] The steel, power, chemical, cement and refining industries are considered hard-to-abate because it is difficult to lower their greenhouse gas emissions.

8 Gaps Assessment

The existing available literature on topics related to Gulf of Mexico offshore wind transmission and siting was reviewed for this report. Based on this review, a series of topics emerged as areas where future action is needed to inform coordinated offshore wind transmission solutions in the region.

In general, the region is just beginning to consider offshore wind transmission planning, and there are few existing studies directly related to this topic. The *Assessment of Offshore Wind Energy Opportunities and Challenges in the Gulf of Mexico* (Fuchs et al. 2023) and the *2023 Integrated Resource Plan* from Entergy Louisiana (2022) are the best available resources on this topic. Stakeholders on BOEM's Intergovernmental Renewable Energy Task Force (BOEM n.d.[a]) have also identified the need for more research in this area.

Essential gaps in information include:

- Identification of viable transmission cable routes from offshore wind energy generation to POIs
- In-depth POI analyses to include available capacity, reliability, stability, and resiliency analysis
- Determination of the feasibility, compatibility, and cost-effectiveness of transmission technologies, such as high-voltage alternating current or high-voltage direct current technology to interconnect offshore wind generators
- How equity and energy justice considerations can be integrated into future transmission planning and design decisions.

A transmission expansion study should include offshore transmission scenario analyses. Analyzing offshore transmission operations requires understanding the underlying design assumptions that are informed through independent preliminary studies. Comprehensive system impact analyses assess the land-based and offshore transmission options to evaluate the relative feasibility, cost, reliability, and resilience benefits of different transmission options. Essential information includes numerous years of weather data over varying time scales in which all the weather-based generation resources are coincident with load to capture interdependencies, variability, and uncertainty over the range of expected outcomes; co-optimization of transmission with necessary existing generation and storage technologies to holistically compare integrated alternatives that capture generation and transmission trade-offs; transmission contingency analysis to identify system upgrades that maintain transmission facility thermal and voltage limits, promote efficient flow, and maintain reliability according to North American Electric Reliability Corporation (NERC) requirements (NERC 2023); and resilience analysis that considers potential weather events and potential common mode failure scenarios caused by interdependencies.

Current long-term transmission expansion plans have not accounted for offshore wind development in the Gulf of Mexico. On May 14, 2024, FERC issued Order No. 1920, a transmission grid rule that requires transmission operators to conduct and periodically update long-term transmission planning over a 20-year time horizon to anticipate future needs (FERC 2024). It will be important to evaluate the impact of future offshore wind deployments on local and regional power system operations. No studies have evaluated this within the ERCOT, MISO, and SERTP transmission areas and the utilities operating within those areas. It is essential to ensure that the development of the necessary offshore and onshore transmission infrastructure is coordinated, and that the power generated from offshore wind facilities can be efficiently transmitted to users and load centers.

Since the Gulf of Mexico is dominated by industrial loads in many locations, most powering the oil and gas sector, it is important to evaluate these loads and how they may be affected as energy use patterns shift. While the region has one of the most developed energy infrastructures in the world, transmission gaps exist, and these gaps need to be addressed for the successful deployment and integration of additional transmission capacity into the U.S. electricity grid. Many offshore wind connections to the onshore transmission system require upgrades at the POI due to the significant amount of power being brought onshore, so characterizing the existing POIs is important for offshore wind transmission planning. Improvements in the surrounding grid infrastructure are required to ensure the grid can reliably support long term offshore wind generation growth and associated transmission infrastructure.

Siting considerations (including physical, environmental, and ocean co-use, among others) to inform coordinated offshore wind transmission routing have not been identified in published literature to date. Research is needed to identify environmental risks associated with the siting of future offshore wind transmission cables in the region, including sensitive habitats, seafloor hazards, and coastal areas that are susceptible to climate change (among many other factors), with a focus on developing solutions to avoid, minimize, and mitigate the identified risks. While ocean planning was performed to inform current wind energy areas in the Gulf of Mexico, discussions have not yet been held with stakeholders to characterize the types of environmental siting layers that would be appropriate for offshore wind transmission routing associated with multiple wind facility buildout scenarios in the region into the future. Governments and stakeholders need to be convened from several sectors, including federal agencies, Tribal Nations, state agencies, the public, academia, consultants, and other interested parties, to provide information on sensitive wildlife and habitat and specific cable routing opportunities and constraints.

In a recent report on offshore wind transmission development in the U.S. Atlantic region, DOE and BOEM called for continued study of the impacts and interactions between offshore wind transmission infrastructure and marine ecosystems (Baker et al. 2023). For example, there is limited information on the disturbance levels of different cable installation tools and methods and how each can be used appropriately in different environments to mitigate seafloor disturbance. To address research gaps, the report suggested ongoing monitoring throughout the life cycle of projects, with long-term studies documenting any habitat or behavioral impacts due to introduced thermal or EMF sources, and conversion of bottom type resulting from flow or current changes from introduced structures. Additional sources of research recommendations are available in the databases created for the Atlantic and the Pacific (Tethys n.d.). Although these recommendations are for different coastlines, they can be applied to other regions, including the Gulf of Mexico, because similar research gaps persist related to habitat, ecosystem processes, and wildlife species.

Climate risk and restoration activities should also be considered as a factor in these siting discussions given the major role that they play along the Gulf Coast and their potential impacts on siting transmission infrastructure. To minimize environmental disturbance, further analysis of the feasibility of using existing energy corridors (e.g., oil and gas pipeline corridors, nearshore transmission corridors) for siting future offshore transmission lines is needed.

Focused community and workforce engagement is needed to incorporate the priorities of diverse Gulf stakeholders regarding opportunities for planned offshore wind transmission. The Gulf of Mexico is culturally and demographically diverse. While each offshore wind energy and transmission project should conduct project- and location-specific engagement and impact assessments, case studies with the scope to interview community members and examine the complex environmental, cultural, and economic landscapes of key offshore wind resource areas could lay the groundwork for future studies and engagement. This research could build on wind energy social acceptance literature previously developed in other geographies. In October 2023, Oregon State University began investigating attitudes toward offshore wind (Baumhardt 2023); similar studies have been done on the Atlantic Coast such as a BOEM-funded study on values and implications in recreation and tourism (Parsons and Firestone 2018). Additionally, more information is needed on location-specific workforce transition. Research is needed to understand how possible employment dislocations and/or career transitions impact residents as the local skilled workforce supporting the oil and gas industry enters the offshore wind development and transmission industry. The transition and need will occur at the regional level, so more research can identify additional training and educational support that is needed to fill specific roles. Matching the region's available workforce to wind energy labor needs is a source of emerging economic potential that warrants further location- and industry-specific research.

Partnerships, industry engagement, and research would better inform how offshore wind transmission development fits into the energy generation portfolio in the region and to understand evolving energy end uses and future needs of coastal industries in the Gulf Coast states. Capacity expansion modeling should be conducted to understand the role of offshore wind and how expansion can leverage existing infrastructure in the Gulf of Mexico region. Participants in BOEM's Intergovernmental Renewable Energy Task Force meetings have specifically referred to the opportunity to use existing oil and gas infrastructure for transmission (BOEM n.d.[a]). Public-private partnerships or private industry partnerships would be required to identify whether opportunities exist for repurposing. This information will inform long-term offshore wind transmission scenarios that provide coordinated solutions tailored to regional needs. Scenarios should include the influence of the IRA and increased hydrogen production in the region. Understanding how IRA infrastructure policies and DOE investment influence renewable energy innovation and adoption may shape end-user energy demands. The role of hydrogen in the region could impact the type of offshore wind transmission solutions that are most suited to regional needs. Finally, a holistic understanding based on combining hydrogen generation capabilities with hybrid offshore wind power plants could help to inform opportunities for transmission development in the Gulf of Mexico.

9 Role for Convening

In addition to analytical efforts aimed at addressing the gaps in Gulf of Mexico offshore wind transmission-related planning and research, the guidance of studies by and circulation of findings among active participants and stakeholders in the areas of transmission planning; technology advancement and standardization; economics; environmental impact; siting and permitting; and policy development are necessary to drive impact.

On the Atlantic Coast, DOE and BOEM have followed this model by hosting a series of convening workshops and a Tribal Nation dialogue, which have been conducted in coordination with, though distinct from, the Atlantic Offshore Wind Transmission Study. The convening workshops have spanned the topics described above with decision makers from federal agencies, Tribal Nations, state agencies (public utility commissions, state energy offices, state environmental and natural resource agencies, etc.), independent system operators and regional transmission operators, consumer advocates, electric reliability organizations, and current BOEM leaseholders.

The broader offshore wind stakeholder community has also been engaged in this effort to hone a set of recommendations and an associated action plan (DOE and BOEM 2024) for addressing near-, medium-, and long-term offshore wind transmission challenges for the Atlantic Coast, with broader national relevance as well. A similar convening effort is underway for the West Coast. State and transmission operator guidance on study approaches and interpretation of findings within the context of public policy and transmission planning processes would inform decision criteria. Additionally, coordination between regionally specific entities (for example, MISO, ERCOT, Entergy Louisiana, the existing oil and gas industry, and local leadership) would also be reinforced through a central convening effort. Through such forums, realistic pathways toward the maximum net benefits of Gulf of Mexico offshore wind transmission can be identified, worked toward, and achieved.

10 Conclusion

This document summarizes the best publicly available information regarding environment, community readiness, and infrastructure with respect to offshore wind transmission planning in the Gulf of Mexico. Coupling the oil and gas industry with new offshore wind initiatives and the goals of the IRA presents a significant opportunity to advance coordinated transmission planning and siting in the Gulf of Mexico. Since 2014, Gulf Coast companies have played an important role in the growth of the U.S. offshore wind industry, supporting in numerous ways the first offshore wind projects being built on the Atlantic coast. Given this regional expertise, and skills transitioned from the oil and gas industry, the Gulf of Mexico is well-poised to build and support offshore wind projects in its own waters. There is significant offshore renewable energy potential in the region that is suitable for both fixed-bottom and floating offshore wind technologies.

Topics related to offshore wind transmission have been raised in Gulf of Mexico regional stakeholder meetings and are recognized as important considerations for economical and responsible development. Some topics have been informed by lessons learned during offshore wind development in other regions of the United States. Offshore wind transmission studies have not been performed in the Gulf of Mexico region and are needed to inform effective regional transmission planning and coordinated transmission solutions that are responsive to regional needs and future energy uses. The siting of future offshore wind transmission needs to account for the unique setting of the Gulf of Mexico region with its highly productive ecosystem, diverse coastal communities, considerable existing infrastructure, and heavy industrial base. Environmentally informed transmission siting solutions should be tailored to the region to minimize impacts and should be based on the best available science pertaining to sensitive wildlife, habitat, and coastal resources. In terms of coastal human communities, the region is culturally and demographically diverse, and community members need to be engaged throughout the transmission planning processes.

Finally, the substantial existing oil and gas infrastructure and heavy industrial base need to be considered, respectively, as conduits for offshore wind transmission and to inform scenarios for transmission and hydrogen pipelines, among other considerations.

Collaborative efforts and coordination on offshore wind development and transmission planning across government jurisdictions (i.e., federal, Tribal Nation, state, local) and all stakeholders in the Gulf of Mexico region will help to inform future investments and long-term renewable energy build-out that helps meet evolving decarbonization and clean energy goals.

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