Challenges and Opportunities for Floating Offshore Wind Energy in Ultradeep Waters of the Central Atlantic

Walt Musial, Angel McCoy, Daniel Mulas Hernando, Stein Housner, George Hagerman, and Kendall Hartman

National Renewable Energy Laboratory

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5000-90608
August 2024

Challenges and Opportunities for Floating Offshore Wind Energy in Ultradeep Waters of the Central Atlantic

Walt Musial, Angel McCoy, Daniel Mulas Hernando, Stein Housner, George Hagerman, and Kendall Hartman

National Renewable Energy Laboratory

Suggested Citation

Musial, Walt, Angel McCoy, Daniel Mulas Hernando, Stein Housner, George Hagerman, and Kendall Hartman. 2024. *Challenges and Opportunities for Floating Offshore Wind Energy in Ultradeep Waters of the Central Atlantic*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-90608. https://www.nrel.gov/docs/fy24osti/90608.pdf.

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Contract No. DE-AC36-08GO28308

Technical Report
NREL/TP-5000-90608
August 2024

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

NOTICE

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Wind Energy Technologies Office. The views expressed herein do not necessarily represent the views of the DOE or the U.S. Government.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

U.S. Department of Energy (DOE) reports produced after 1991 and a growing number of pre-1991 documents are available free via www.OSTI.gov.

Cover Photos by Dennis Schroeder: (clockwise, left to right) NREL 51934, NREL 45897, NREL 42160, NREL 45891, NREL 48097, NREL 46526.

NREL prints on paper that contains recycled content.

Acknowledgments

The authors would like to thank the Bureau of Ocean Energy Management reviewers of this report including Mark Jensen, Seth Theuerkauf, David MacDuffee, Emily Hildreth, Marty Heinze, and Jennifer Draher. We also thank the National Renewable Energy Laboratory internal reviewers Nicola Bodini, Amy Robertson, Brian Smith and Paul Veers. The study also benefited from the feedback and comments received from the external peer reviewers including Josh Kaplowitz (Locke Lord), Sam Beirne (Maryland Energy Agency), and Tom Noyes (State of Delaware). Sheri Anstedt (National Renewable Energy Laboratory) provided editing and communications support and John Frenzl provided graphics support.

Disclaimers

List of Acronyms

AHTS	anchor handling tug supply (vessel)
API	American Petroleum Institute
Area ID	Area Identification
BOEM	Bureau of Ocean Energy Management
BSEE	Bureau of Safety and Environmental Enforcement
COP	Construction and Operations Plan
CTV	crew transfer vessel
CVOW	Coastal Virginia Offshore Wind
DNREC	Delaware Natural Resources Environmental Control
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
ft	feet
GW	gigawatt
HVDC	high-voltage direct current
IEC	International Electrotechnical Commission
km	kilometer
LCOE	levelized cost of energy
m	meter
mi	mile
m/s	meters per second
MW	megawatt
NOAA	National Oceanic and Atmospheric Administration
NOW-23	2023 National Offshore Wind data set
NOWRDC	National Offshore Wind Research and Development Consortium
NREL	National Renewable Energy Laboratory
OCS	Outer Continental Shelf
OREC	Offshore Renewable Energy Credit
PSN	Proposed Sale Notice
ROD	Record of Decision
s	second
SAP	site assessment plan
WEA	Wind Energy Area
WTIV	wind turbine installation vessel

Executive Summary

This study, funded under an interagency agreement between the U.S. Department of Energy's National Renewable Energy Laboratory and Bureau of Ocean Energy Management (BOEM), is intended to provide BOEM with key information to inform their decision-making about current and future offshore wind energy leasing in the Central Atlantic region of the United States. The report will also benefit state governments, developers, research institutions, and the public who are seeking technical and market-based information about the unique aspects of offshore wind energy development along the Outer Continental Shelf (OCS) of this region of the United States.

The study provides a broad, top-level assessment of the key challenges and opportunities that are unique to offshore wind energy development in the Central Atlantic region. Specific BOEM Call Areas from the first round of planning in the Central Atlantic region (hereafter referred to as Central Atlantic 1 Call Areas) are shown in Figure ES-1. The research is based on the most current technology, deployment, and stakeholder information available to the National Renewable Energy Laboratory (NREL). The topics include assessing the physical environment; current leasing status and major stakeholder issues; state and federal energy policy; an assessment of future leasing requirements based on state targets; status and limitations of the technology; and supply chain status. The primary intent is to inform the readers about the prospects for deploying offshore wind energy in the designated deep-water Call Areas known as E and F, as identified by BOEM. The report makes recommendations regarding development in these regions.

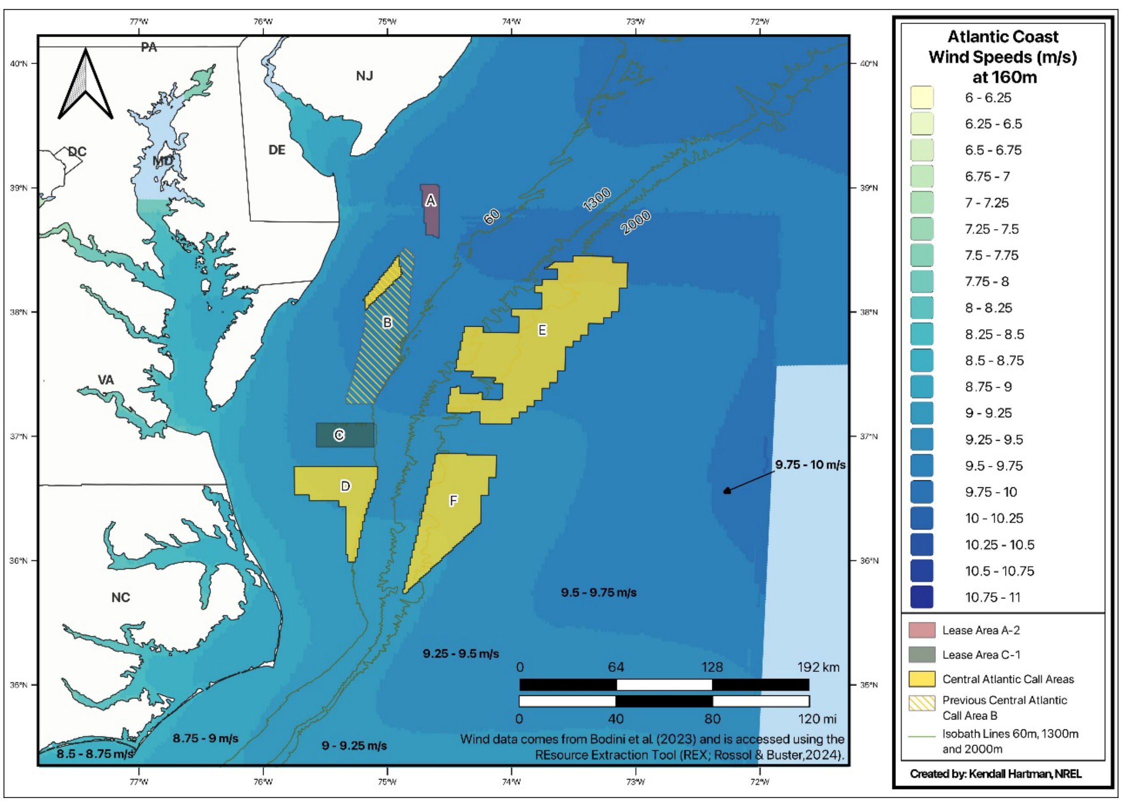


Figure ES-1. Central-Atlantic 1 Call Areas and lease areas showing annual average wind speeds.
Image by Kendall Hartman, National Renewable Energy Laboratory (NREL)

Figure ES-1 also provides a heat map of the wind resources of the Central Atlantic 1 Call Areas. These areas have annual average wind speeds ranging from about 9 meters per second (m/s) to 10 m/s. The annual average wind speed in Call Area E ranges from about 9.4 m/s in the south to 9.8 m/s in the north. In Call Area F the average wind speeds range from about 9.2 m/s to 9.4 m/s.

Nine lease areas are available for development on the OCS off the coast of Delaware, Maryland, Virginia, and North Carolina, and a Final Sale Notice (FSN) to auction two additional lease areas, FSN OCS-A 0557 (also named "A-2") and FSN OCS-A 0558 (also named "C-1") has been announced by BOEM (BOEM 2024c). An additional research lease (OCS-A 0497) has already been developed for the 12-megawatt Coastal Virginia Offshore Wind pilot project. These lease areas, the projects under development, final leases areas, and the Central Atlantic 1 Call Areas are shown in Figure ES-2.

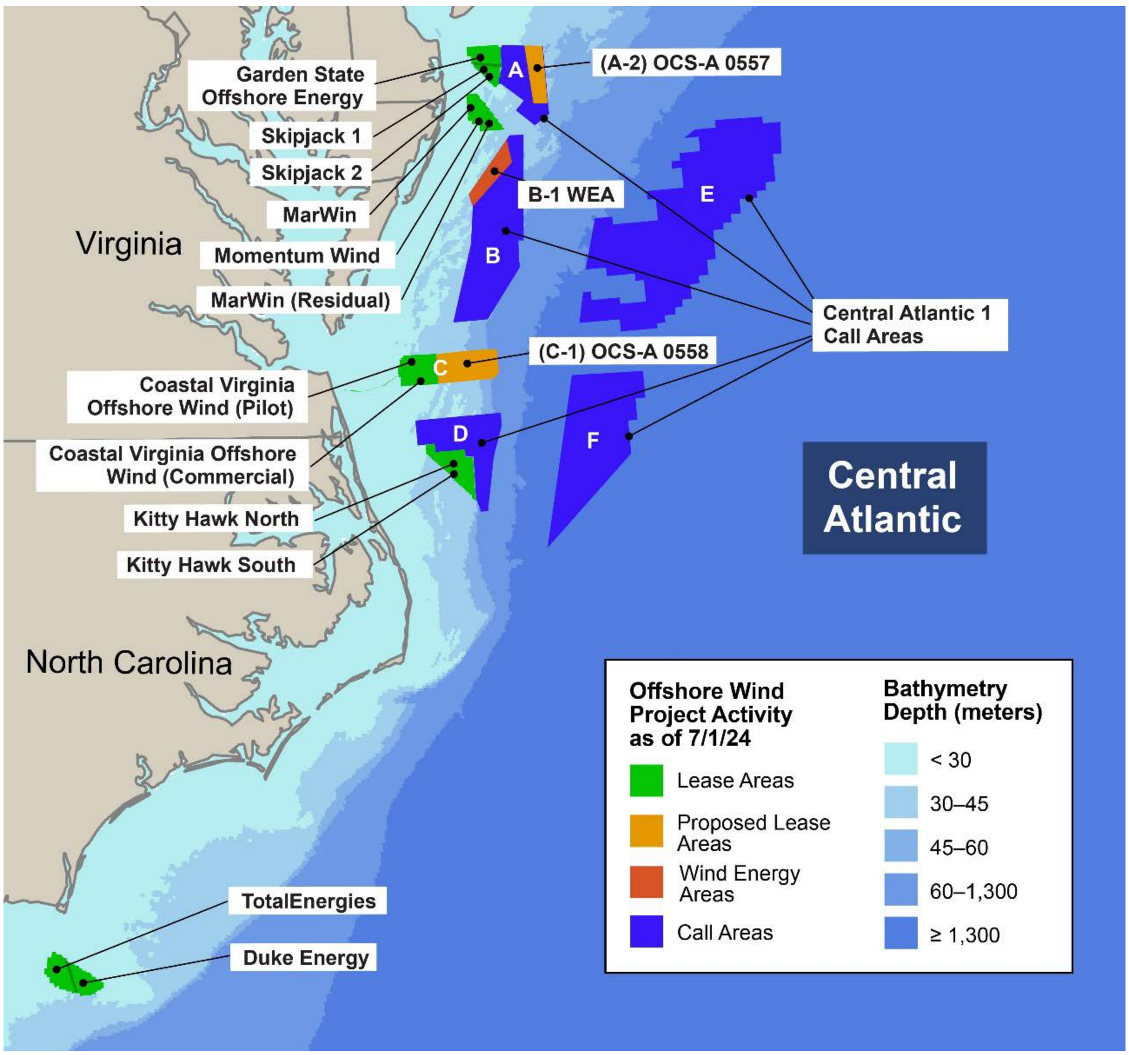


Figure ES-2. Map of existing and final lease areas for the round 1 auction in the Central Atlantic and remaining WEA and Call Areas. *Map by John Frenzl, NREL*

Most of the space within the Central Atlantic 1 Call Areas in Figure ES-2 have some degree of conflict with other ocean users, such as the military and U.S. Coast Guard vessel routing (See

Section 3.2). As a result, the total area of the final lease areas for Round 1 of the Central Atlantic is insufficient to support the long-term needs for offshore wind energy development based on state goals. The authors investigated Call Areas E and F in ultradeep water[1] as possible locations for future leasing. However, use conflicts are evident within these Call Areas as well, and they are less attractive from an offshore wind development perspective due to high technical risk and greater distance from shore (See Section 5).

The Central Atlantic 1 planning area is comprised of four Central Atlantic states including Delaware, Maryland, Virginia, and North Carolina which is closely aligned with the NREL study area for this report. State policy is the primary market driver of offshore wind energy development in the Central Atlantic 1 region as it is in the rest of the country. Within this four-state area, there are over 20 gigawatts of state policy mandates or planning targets for offshore wind energy. Accounting for the existing lease areas and the final lease areas in the upcoming auction in 2024, this study determined that about 2,233 square kilometers of additional lease area would be needed in these four Central Atlantic states, using a power density metric of 4 megawatt/square kilometer. To make enough ocean space available to meet these targets, BOEM will need to conduct additional marine spatial planning and site suitability analysis, possibly for a Central Atlantic Round 2 auction scheduled for 2026. Future site suitability analysis and marine spatial planning by BOEM should examine options in both the shallower waters of the shelf and the ultradeep waters located in Call Areas E and F. Central Atlantic Round 2 planning may also consider expanding the regional planning area to possibly include areas off southern New Jersey.

Federal policy is not the primary market driver but the 2022 Inflation Reduction Act that was signed into law during the COVID pandemic has enabled many early offshore wind energy projects to move forward while helping the offshore wind industry secure domestic jobs and infrastructure as it matures.

Ultradeep Technology Challenges

There are several technical challenges of floating offshore wind energy in ultradeep waters (depths greater than 1,300 meters), like Call Areas E and F, which would increase the design uncertainty and risk relative to the shallower floating lease areas of California, the Gulf of Maine, and Oregon with depths ranging from 200 m to 1,300 m. Even at these shallower depths, significant technical uncertainty is present because all floating wind energy experience globally has been in shallower water (around 200 meters) and deployed at the pilot scale (less than 100 megawatts). This technical risk can be mitigated by the industry gaining commercial floating wind experience at these shallower sites, and by developing and demonstrating technology solutions that address the specific concerns related to ultradeep waters (see Section 5).

Hurricane risk is an additional concern in the Central Atlantic region and may increase with distance from shore in Call Areas E and F. For this region, we recommend that the optional design features described in the annexes of the International Electrotechnical Commission

---

[1] Ultradeep water is defined as ocean area with water depths greater than 1,300 meters. Most of Call Area E and all of Call Area F are in these water depths.

standards become mandatory requirements for offshore wind energy projects. These features include tropical class (T-Class) wind turbine design ratings, battery back-up systems, and support structures built to the specification of Annex I in International Electrotechnical Commission 61400-3-1, which accounts for limit-state storms with increasing severity. Many wind turbine manufacturers and developers are already incorporating these features into their designs (Fuchs 2023).

Future Leasing Considerations

We recommend that BOEM consider the current state targets and mandates as a lower boundary for offshore wind lease requirements because state and federal net-zero decarbonization requirements in this region may call for additional offshore acreage beyond the minimum 2,233 square kilometers identified in this report. Long-term, systemwide energy planning conducted by the U.S. Department of Energy and others should include integrated net-zero energy scenarios for land-based wind, solar photovoltaics, hydroelectric, nuclear, as well as offshore wind, which are needed to inform BOEM's long-term leasing to 2050. Significant research should be conducted to demonstrate and prove ultradeep technologies, and more industry experience is needed with floating wind energy in California, Gulf of Maine, and Oregon to reasonably mitigate the technical and economic risks of floating technologies in ultradeep waters.

Table of Contents

List of Figures

List of Tables

1 Overview

Offshore wind energy leasing in the Central Atlantic region began over a decade ago. For the Central Atlantic 1 planning, this region includes Delaware, Maryland, Virginia, and North Carolina, but future planning for Central Atlantic Round 2 may be expanded to include southern New Jersey. The Bureau of Ocean Energy Management's (BOEM's) initial "Smart from the Start" initiative comprised the first commercial lease sales in Delaware (2012), Virgina (2013), Maryland (2014), and North Carolina (2017) (U.S. Department of the Interior 2010). In parallel, state policy in some states legislated mandates and targets that reflect their long-term energy requirements. As long-term state energy needs become clear, BOEM's offshore wind leasing process has continued to support state clean energy goals with available acreage.

This study, funded under an interagency agreement between the U.S. Department of Energy's (DOE's) National Renewable Energy Laboratory (NREL) and BOEM, is intended to provide BOEM with key information to inform their decision-making about current and future leasing in the Central Atlantic region. The report will also benefit state governments, developers, research institutions, and the public who are seeking technical and market-based information about the unique aspects of the offshore wind energy development along the Outer Continental Shelf (OCS) in this region.

The geographic continental shelf within these waters is characterized by a relatively shallow nearshore region (0-30 nautical miles) where conventional fixed-bottom foundation technology[2] is viable. Some of this is the acreage being offered in the upcoming lease auction scheduled for August 2024. Depths increase sharply beyond this nearshore region where emerging floating technology will be needed. Floating wind is expected to become a major part of the offshore wind energy industry because there are more limited siting options in shallower water closer to shore. Unfortunately, one of the unique characteristics of this region is that the steep drop of the continental shelf puts all the viable floating wind energy sites into ultradeep water depths of more than 2,000 meters (m), beyond where there is significant offshore energy experience (e.g., including deep water oil and gas).

1.1 Scope

This report provides a broad, top-level assessment of the key challenges and opportunities that are unique to offshore wind energy development in the Central Atlantic 1 region. It focuses on BOEM's Central-Atlantic 1 Call Areas, as shown in Figure 1. The research was a desktop study using the most current offshore wind energy technology, deployment, and stakeholder information available to NREL. The topics herein include assessments of the physical environment; current leasing status and major stakeholder issues; state and federal energy policy; future leasing requirements; technology status and limitations; supply chain status; and a summary of the key findings. The intent of this report is to inform the readers about the prospects for deploying offshore wind energy in the designated deep-water Call Areas and includes recommendations regarding development in these regions. As offshore wind is unproven at these

[2] A fixed-bottom wind turbine foundation has a direct connection to the seabed as opposed to a floating foundation which is buoyant and is attached to the seabed with mooring lines and anchors.

depths, our investigation provides mostly a qualitative assessment of the technical challenges relative to shallower sites.

1.2 Primary Resources and Relevant Research

NREL is currently conducting, and has conducted, several studies to characterize offshore wind energy resources, economics, technical challenges, and extreme conditions that are relevant to the Central Atlantic region and its deep-water sites. The authors leveraged many of these studies for this report as well as information from many other sources. In 2023, NREL completed the development of the 2023 National Offshore Wind data set (NOW-23) database that provides the resource assessment data for the Central Atlantic region presented in Section 2 (Bodini et al. 2023). Currently, NREL is conducting a new study to assess the challenges of deploying offshore wind turbines in ultradeep waters[3] (Cooperman et al. forthcoming). NREL is also engaged in an in-depth research project known as STORM, which is investigating the hurricane resilience of offshore wind turbines (Sanchez Gomez 2023). Additional information is drawn from BOEM and DOE's Energy Information Administration, as well as many other sources found in the References section.

[3] All leasing in the United States has been in waters less than 1,300 meters deep. In the Central Atlantic, water depths are 2,600 meters in Call Areas E and F, and on the Pacific Coast water depths can reach 3,000 meters just beyond the current leases. Ultradeep water is defined as waters at these depths.

2 Physical Environment

2.1 NREL Study Area Description

The NREL Central Atlantic study area for this report aligns closely with the BOEM Central Atlantic 1 planning area which includes the original Call Areas and the existing and proposed lease areas shown in Figure 1.

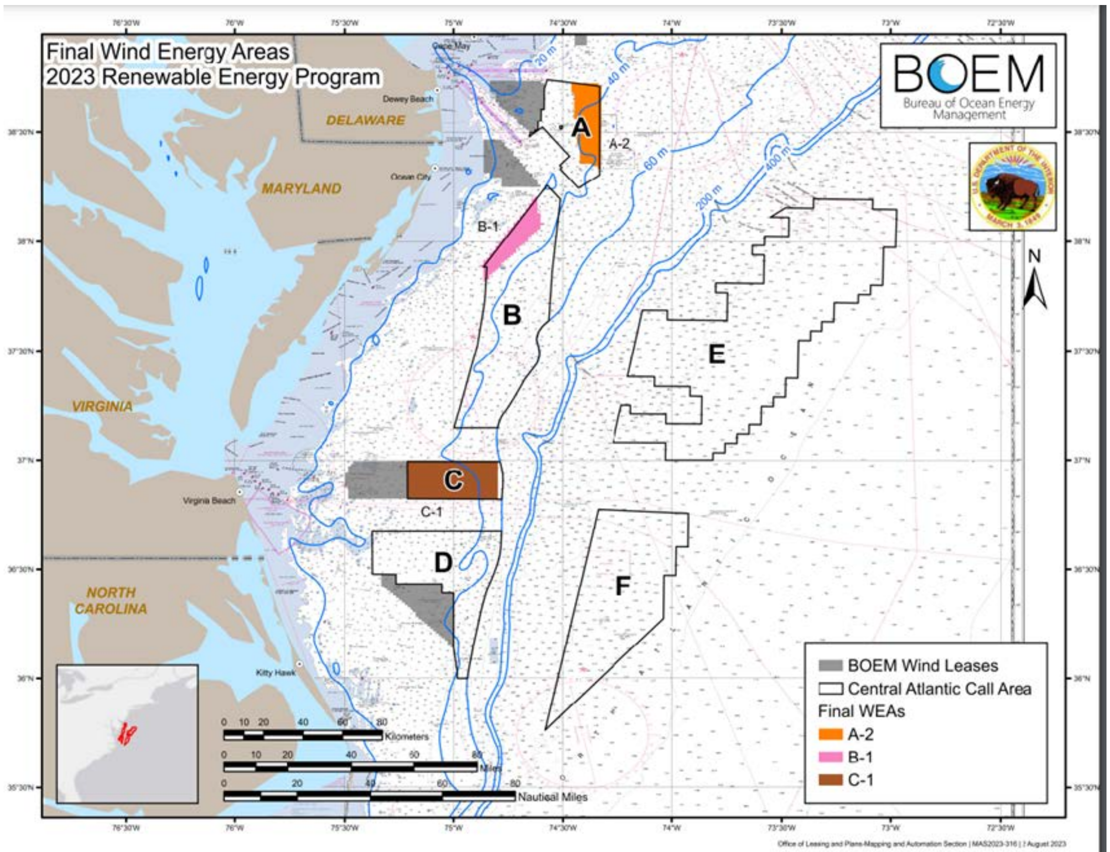


Figure 1. BOEM's Final Sale Notice map of Central Atlantic 1 wind leases and Call Areas. *Image from BOEM*

The extent of the study area is as far north as offshore Dewey Beach, Delaware, and as far south as Hatteras, North Carolina. The closest point to shore is located approximately 36 kilometers (km) (22 miles [mi]) from shore and the farthest point is about 200 km (120 mi) from shore. The study area is much larger than what is needed to meet the most aggressive offshore wind energy scenarios for decarbonization of the Central Atlantic but includes many areas that have been eliminated from consideration. We intentionally include these wide boundaries to allow for different assumptions to be used in future site identification. However, the focus of this report is on the deep-water Call Areas E and F.

2.2 Geology and Bathymetry

The NREL Central Atlantic study area is in the Mid-Atlantic Bight, a coastal region that extends as far north as Massachusetts and as far south as North Carolina. The area is situated on the OCS, with a width generally greater than 120 km (75 mi). The distance from the geographic shelf where there is a steep drop out to the Exclusive Economic Zone[4] (United Nations 1982) is about 125 mi. The shelf is made up of a mantle of sand that is about 20 m (65 feet) thick. Submarine canyons are a dominant feature of the OCS and slope of the East Coast from the Gulf of Maine to Cape Hatteras (Ross and Brooke 2012). The Mid-Atlantic Bight region is made up of 13 major canyons.[5] Canyons vary in physical structure, hydrography, and geological activity. Exposed hard substrata are common in canyons and are generally found on the upper rims, and sometimes in the base of the axis, where boulders have been deposited. The Baltimore Canyon Trough is the deepest basin along the U.S. Atlantic margin, with a width of up to 18 km (11 mi) (Minerals Management Service 2007).

Geologic and other physical hazards that may affect offshore operations off the U.S. Atlantic Coast include the scouring action of ocean currents, irregular topography, steep slopes and seabed instabilities, sedimentary erosion processes, seismic faults, major hurricanes, tsunamis, fluid and gas expulsion, and variable seabed soil types.

Water depths in the Central Atlantic 1 study area range from 30 m on the geographic shelf to 2,600 m beyond it. Figure 2 is a map of the Central Atlantic 1 region where water depths are demarcated in 100-m increments—the key features to observe in the map are the shallow regions where near-term leasing is planned (yellow), steep slopes (green), and ultradeep regions (blue).

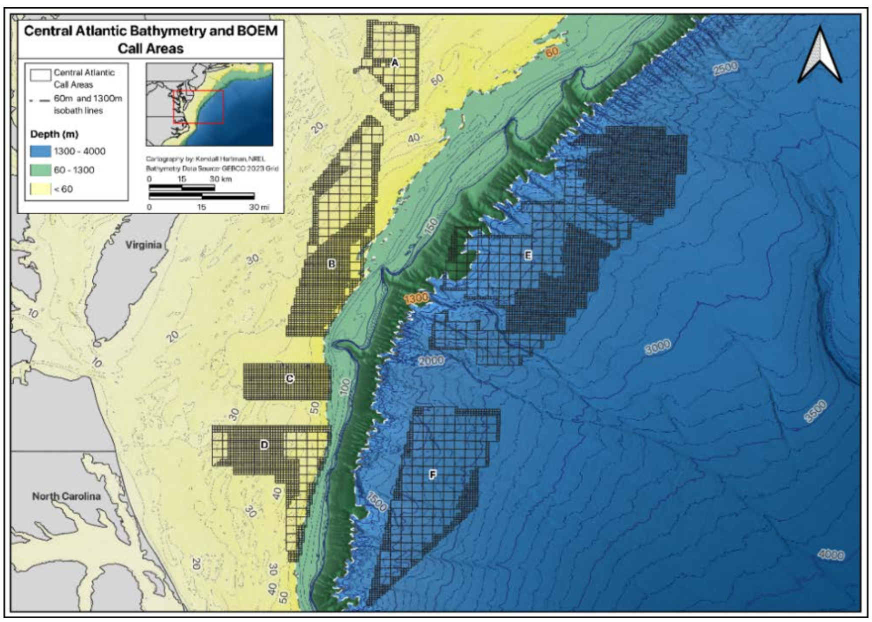


Figure 2. Map of Central Atlantic bathymetry. *Image from NREL*

---

[4] The Exclusive Economic Zone is an area beyond and adjacent to the territorial sea where the coastal state has sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources, whether living or nonliving, of the waters superadjacent to the seabed and of the seabed and its subsoil, and with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from the water, currents, and winds.
[5] Deep-sea canyons are steep-sided valleys cut into the seafloor of the continental slope, sometimes extending well onto the geographic continental shelf.

The figure shows the steep increase in water depths over a short distance. For more information regarding the suitability of subsea soils and ultradeep waters for installing offshore wind facilities, see Section 5.5.2.

2.3 Wind Resource Assessment

Wind resource data are from NOW-23 (Bodini 2023). Figure 3 displays the annual average wind speed throughout the U.S. Atlantic region and Figure 4 provides a closer look at just the Central Atlantic study area.

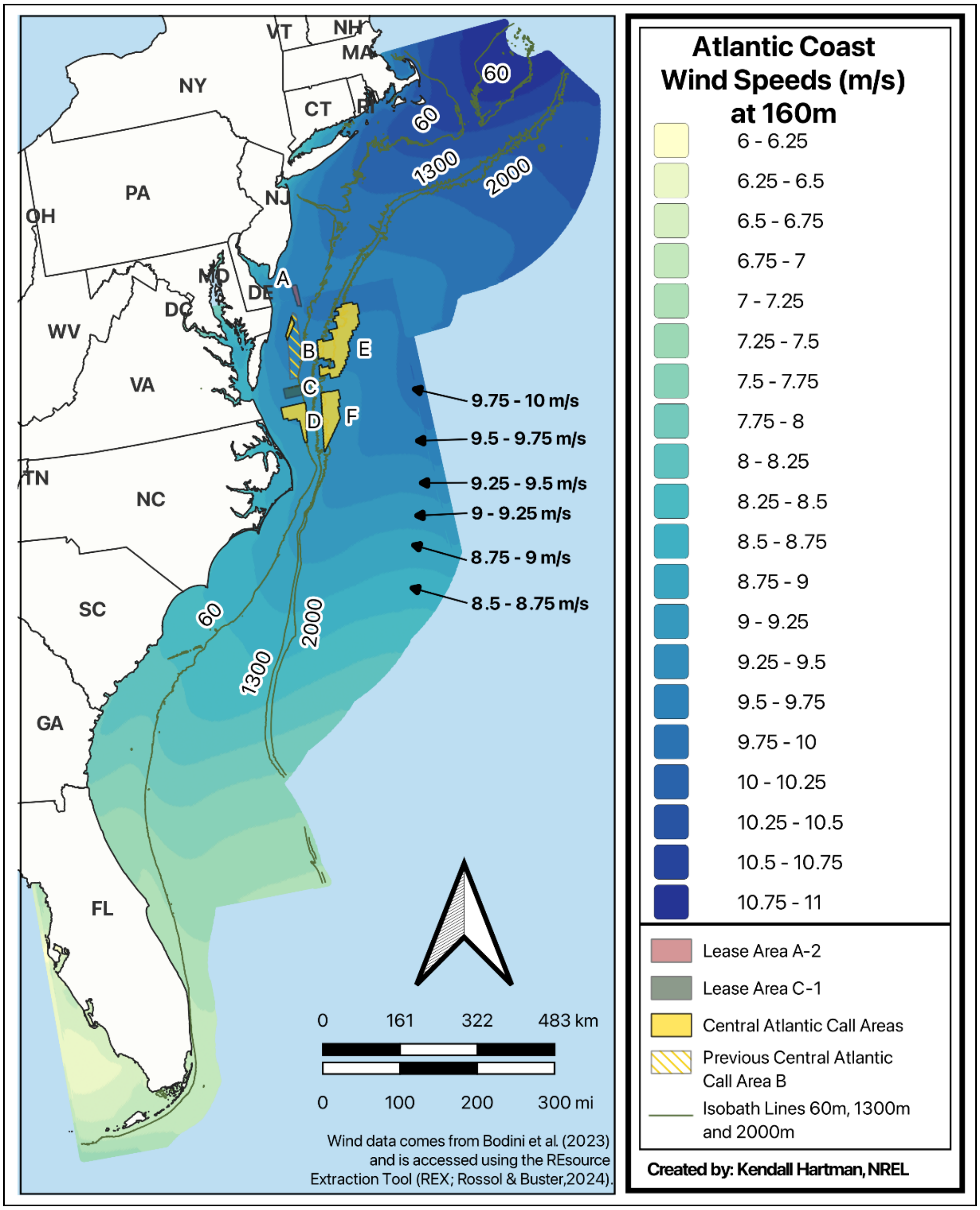


Figure 3. Atlantic wind resources showing annual average wind speeds.
Image by Kendall Hartman, NREL

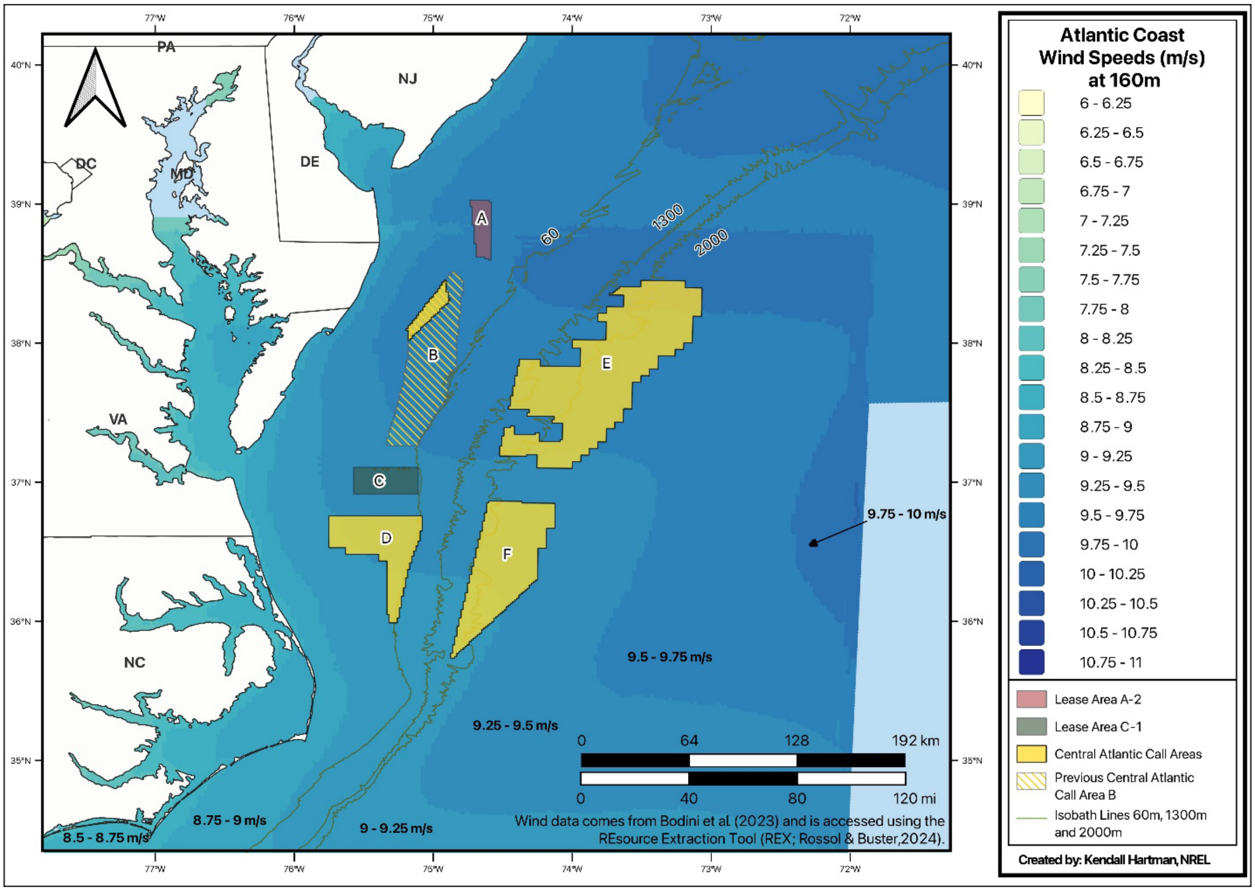


Figure 4. Central Atlantic 1 wind resources showing annual average wind speeds near the Call Areas. *Image by Kendall Hartman, NREL*

The dataset was produced using the Weather Research and Forecasting Model version 4.2.1. and regional observations. Specifically, buoy-mounted lidar observations in the Mid-Atlantic were used to validate and improve models. The Central Atlantic 1 Call Areas are in a region where wind speeds average 9 meters per second (m/s) to 10 m/s. The annual average wind speed in Call Area E is approximately 9.4 m/s in the south to 9.8 m/s in the north. In Call Area F, the average wind speed ranges from 9.2 m/s to 9.4 m/s. Our analysis of wind resource capacity distribution by water depth and distance to shore for each Central Atlantic 1 Call Area is shown in Figure 5. It shows that the highest concentration of wind resource in Call Area E is in water depths of approximately 2,175 m, between 154 km and 168 km from shore. In Call Area F, the highest concentration of wind resource is in water depths of approximately 2,180 m, similar to Call Area E, and between 120 km to 150 km from shore.

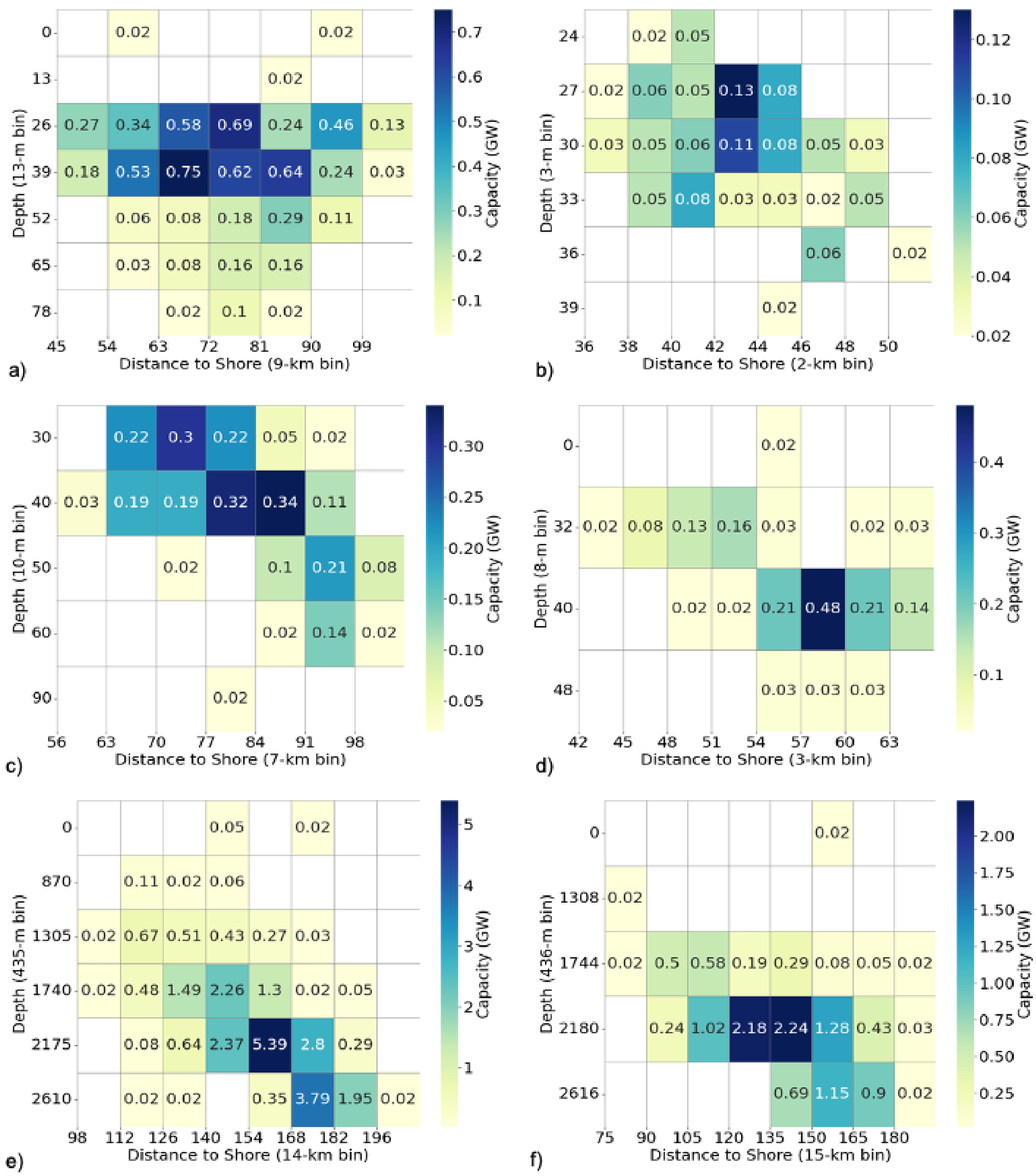


Figure 5. Wind resource capacity distribution by water depth and distance to shore for each Central Atlantic 1 Call Area designated A through F (darker cells show where the highest concentration of resource is located).

Note: GW = gigawatt(s)

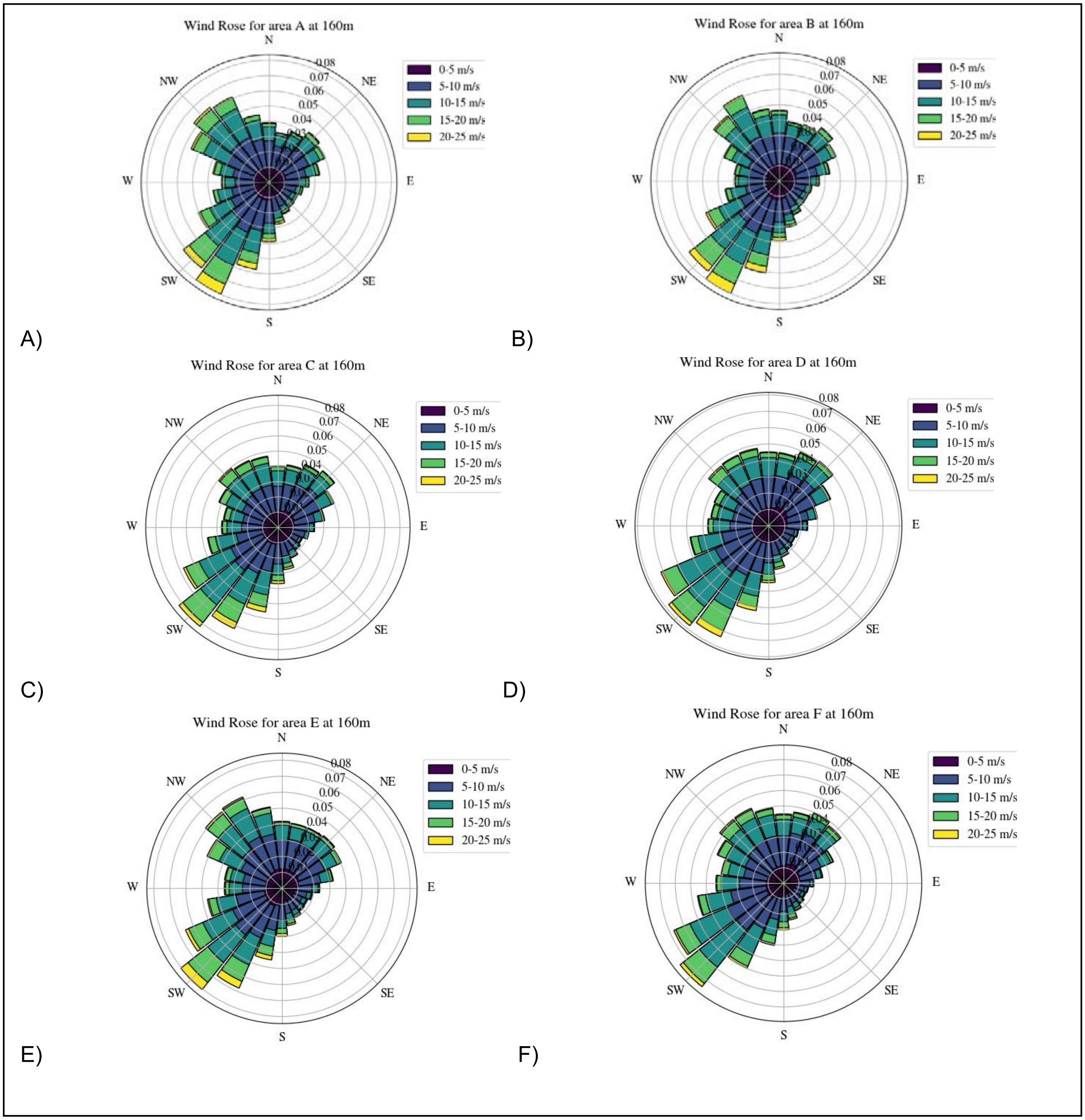


Figure 6. Wind roses for each Central Atlantic 1 Call Area, designated A through F

Wind roses are shown in Figure 6 for the centroid of each of the Central Atlantic 1 Call Areas designated by BOEM. The wind roses consistently show a strong component of prevailing wind from the southwest among all the Call Areas. Yet, some sites on the northern side of the Central Atlantic region show a weaker component of northwest wind direction.

Diurnal and seasonal data from NOW-23 are plotted in Figure 7 at the centroid of each of the Central Atlantic 1 Call Areas.

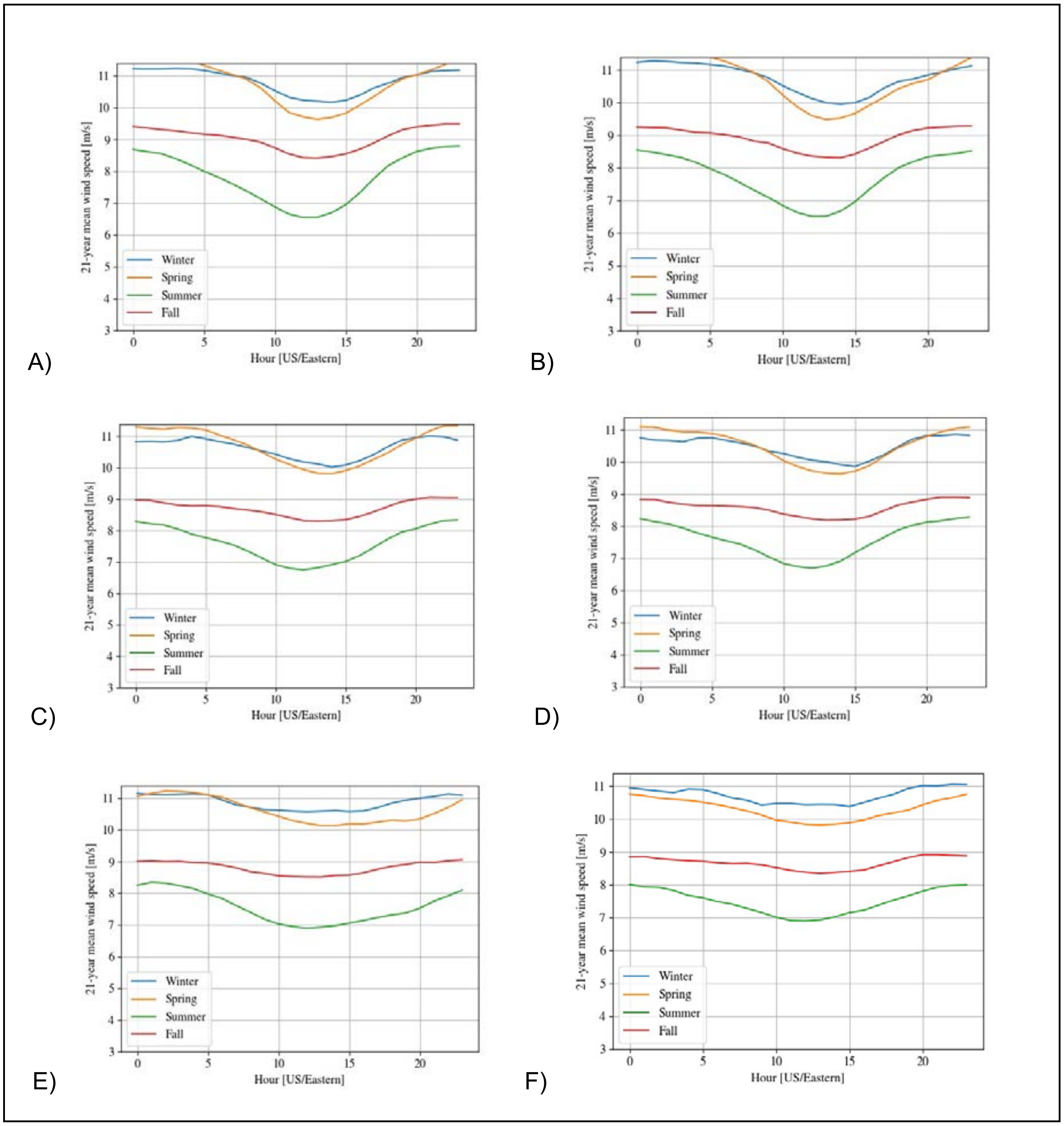


Figure 7. Diurnal and seasonal characteristics for each of the Central Atlantic 1 Call Areas designated A through F

Diurnal averages show lower midday winds consistently across all Call Areas with nighttime peaks. This pattern is consistent with many offshore wind areas in the United States and is complementary with solar energy from a load-matching standpoint, which peaks during midday. Seasonal variations show consistent winter maximum winds with summer being the lowest wind speeds. Similarly, this pattern complements solar energy resources, which peak during the summer months. These diurnal and seasonal day/night variations appear to be slightly stronger for the four Call Areas (A, B, C, and D) that are closer to shore.

2.4 Wave Climate

We characterized the average and extreme wave heights in the two ultradeep Call Areas, E and F, using the nearest available hindcast grid point stations from the U.S. Army Corps of Engineers' Wave Information Studies (USACE-WIS: https://wisportal.erdc.dren.mil). The USACE-WIS database provides long-term wave climatology for all U.S. coastal waters, using third-generation, phase-averaged wave models forced with high-resolution wind fields and mean daily ice concentration fields, and with a 43-year hindcast period from 1980 through 2022.

The WIS 2022 annual update used the European Centre for Medium Range Weather Forecasts 5 Reanalysis monthly wind and ice fields. The wind fields are enhanced by embedding all tropical cyclones and the top 10 extra-tropical storm events using kinematic procedures for the extratropical storms. The WIS 2022 hindcast shows good statistical agreement at available wave measurement evaluation sites operated by the National Data Buoy Center and Coastal Data Information Program, with domainwide biases of 0.1 m and 0.1 seconds (s), and root-mean-square errors of 0.3 m and 1.5 s, for significant wave height and mean wave period, respectively.

There are five USACE-WIS grid point stations along the shelf edge (190- to 210-m depth), just west of ultradeep Call Areas E and F. Based on aggregated month-by-month statistics over the 43-year hindcast period, the average significant wave height for these five stations ranges from 1.4 to 1.5 m, with average mean wave periods ranging from 7.5 to 7.9 s. By comparison, average significant wave height in the fixed-bottom shelf areas nearer shore range from 0.9 to 1.1 m, with mean wave periods ranging from 7.1 to 7.7 s.

As detailed in Section 5, Call Areas E and F are exposed to more frequent passage of major hurricanes, which greatly influences the extreme wave climate. The 50-year return-period significant wave heights at the five USACE-WIS shelf-edge stations range from 9.7 to 11.7 m, with 100-year significant wave heights ranging from 10.4 to 12.8 m. By comparison, extreme significant wave heights in the fixed-bottom shelf areas nearer shore range from 6.0 to 7.5 m for 50-year return periods, and from 6.5 to 8.5 m for 100-year return periods.

Because the wave climate is incrementally more severe in Call Areas E and F, the challenges related to design, installation, and operation could increase; however, the levels of wave severity do not exceed standard design practices for offshore wind turbines.

2.5 Ocean Currents

Call Areas E and F are in the so-called "Slope Sea," which is a narrow band of ocean that lies between the Gulf Stream and the geographic continental shelf edge in the Mid-Atlantic Bight. Its general circulation pattern is a closed cyclonic gyre within the upper few hundred meters of the water column.

Just west of these two Call Areas is a shelfbreak jet[6] that flows southwest, along the edge of the continental shelf, until it reaches the Gulf Stream at Cape Hatteras. The jet's current speed is directly related to the position of the Gulf Stream, which typically ranges from 150 to 300 km seaward of the shelf edge. Off North Carolina, the shelfbreak jet is strongest, with speeds of 0.30 to 0.40 m/s when the Gulf Stream is within 150 km of the shelf edge, but near zero when the Gulf Stream is 300 km away from the shelf edge (Bane et al.1988). By comparison, off New Jersey, peak shelfbreak jet speeds are in the range of 0.20 to 0.30 m/s (Forsyth et al. 2020).

Along the eastern border of Call Area F off North Carolina, the Gulf Stream flows toward the northeast, with core speeds typically in the range of 1.0 to 2.0 m/s. Its mean core position is located above the 3,350-m isobath depth contour, where the general bottom slope is about 10 m of depth change per horizontal kilometer or approximately a 1% grade. The Gulf Stream core routinely meanders ±90 km onshore and offshore from its mean position. The Gulf Stream core meander zone is largely bounded between the 2,500- and 4,000-m depth contours (Andres 2021). By comparison, the eastern border of Call Area F is along the 2,700-m depth contour, which is well within the meander zone. Therefore, Call Area F will routinely experience Gulf Stream core speeds that could be a significant challenge for both installing and operating floating wind farms.

On the other hand, Call Area E would not likely experience these core currents, because at this latitude, the Gulf Stream has diverged far enough offshore, with a mean core position 100- to 120 km away from the eastern border of Call Area E.

Both Call Areas E and F will experience the intermittent passage of warm core rings. Gulf Stream warm-core rings form in the Slope Water between the shelf edge and the Gulf Stream by the separation of a north-extending meander. The initial physical, chemical and biological properties at the cores of these 100-200-km-diameter eddies are often similar to those of their parent water mass, the Sargasso Sea. A clockwise rotating remnant of the Gulf Stream circulates around the core with surface current speeds of 50-200 cm s^{-1} (1.0-3.9 knots; Joyce, et al., 1984).

The interactions between Call Areas E and F and the Gulf Stream are unique to the deep-water sites and would not be an issue on the shallower geographical shelf.

2.6 Extreme Design Considerations

The most extreme external design conditions expected in the Central Atlantic region are from hurricanes. In this region, the severity and frequency of hurricanes are greater than at sites farther north, but a full assessment of the risk has not been completed. The National Offshore Wind Research and Development Consortium (NOWRDC) is funding a study being conducted by Northeastern University and partners at the University of Massachusetts and Clemson University called O-Wind. This research effort is investigating hurricanes in the waters off the states of Massachusetts, New Jersey, and Maryland, which are co-funding the study. Hurricane risk is addressed in more detail in Section 5.6 (NOWRDC 2024).

[6] A shelfbreak jet is a cool-water current that flows along the geographic continental shelf in a coastal current system.

3 Status of Central Atlantic Leasing

3.1 Existing Lease Areas

Nine OCS lease areas are available for development off the states of Delaware, Maryland, Virginia, and North Carolina. A Final Sale Notice (FSN) to auction two additional lease areas, OCS-A 0557 (also named "A-2") and OCS-A 0558 (also named "C-1"), has been announced by BOEM (BOEM 2024c). An additional research lease (OCS-A 0497) has already been developed and supports the 12-megawatt (MW) Coastal Virginia Offshore Wind pilot project. These lease areas, final leases areas A-2 and C-1, B-1 Wind Energy Area (WEA), and the Central Atlantic 1 Call Areas are shown in Figure 8. The map includes areas that were originally considered by BOEM under Central Atlantic first round planning as well as the existing and final leases. BOEM's assessments have revealed the potential for substantial cost increases and mitigation measures that may make offshore wind energy in these areas (e.g. B-1 WEA), difficult or not viable at this time (BOEM 2023a). Because of these challenges, the Biden administration and State of Maryland committed to accelerating review of additional areas that could support Maryland's offshore wind energy targets.

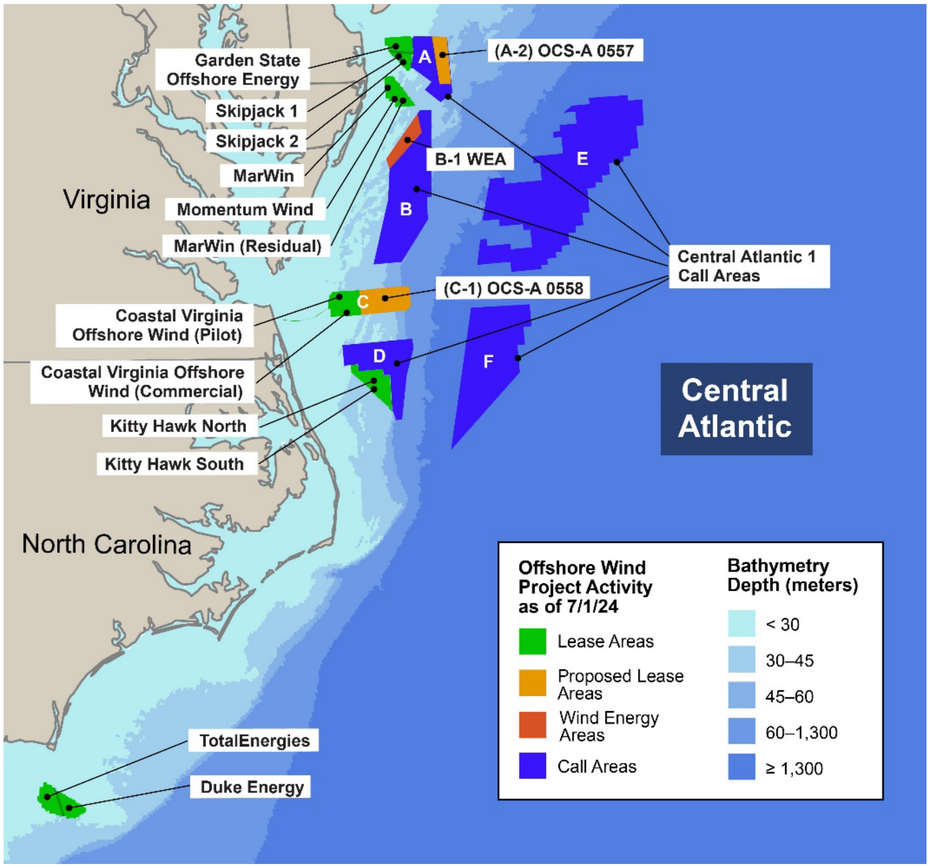


Figure 8. Map of existing and final lease areas for the round 1 auction in the Central Atlantic and remaining WEA and Call Areas. *Image by John Frenzl, NREL*

Next is a brief overview of the existing lease areas (from north to south) within the Central Atlantic region:

- **Garden State Offshore Energy I (OCS-A 0482)**. On December 12, 2016, the lease was assigned to Garden State Offshore Energy, a collaboration involving Deepwater Wind, Ørsted, and Public Service Enterprise Group. On June 12, 2018, the lease area was subdivided into two lease areas: OCS-A 0482 and OCS-A 0519. A site assessment plan (SAP) was submitted on July 12, 2018, with approval granted on December 6, 2019. The project does not have an active offtake to sell energy, nor has it filed a Construction and Operations Plan (COP). The total area of the lease is 284 km^2, and based on its proximity, could produce electricity for the states of New Jersey, Delaware, and/or Maryland.
- **Skipjack 1 and 2 (OCS-A 0519)**. Initially conceived as a 120-MW project with a capacity for up to 16 wind turbine positions, Ørsted successfully secured a bid from the Maryland Public Service Commission to expand the project's scale to 966 MW and encompass some of the available area in OCS-A-0482. In January 2024, Ørsted canceled its offtake agreement for 966 MW because of challenging market conditions, including inflation, high interest rates, supply chain constraints, and a vessel delay (Ørsted 2024; Davidson 2024). With the cancellation of the offtake agreement and based on the geographical location of the lease, there is now a possibility for this lease area to support the clean energy needs of Delaware or Maryland, as well as New Jersey. The project does not have a public COP yet.
- **Maryland Offshore Wind Project (OCS-A 0490)**. This lease area is owned by USWind and plans to install up to 121 wind turbines in an area of 323 km^2 using the GE Vernova 14.7- or 15.5-MW turbine, with a total capacity between 1,778.7 MW and 1,875.5 MW. The project includes two phases: MarWin, a 248-MW wind farm for which the State of Maryland awarded offshore renewable energy certificates (ORECs) in 2017, and Momentum Wind, comprising approximately 808 MW with additional ORECs awarded in 2021. The expected passage of HB 1296 would allow US Wind to renegotiate an increase to the amount of ORECs sold from each project, thereby enabling a corresponding increase in project capacity to meet state offshore wind energy targets (Public Service Commission of Maryland 2021). The SAP and COP were submitted in 2020, with the latest version of the COP being published on July 31, 2023. On September 29, 2023, BOEM announced the draft Environmental Impact Statement for this project with the final statement expected in the summer of 2024. Both MarWin and Momentum Wind phases have secured offtakes to supply power to Maryland. However, the future development phase has the potential to establish connections with either Delaware and/or Maryland.
- **Coastal Virginia Offshore Wind Pilot Project (CVOW-P) (OCS-A 0497)**. This is a two-turbine 12-MW pilot project situated 27 miles off the coast of Virginia Beach. Fully commissioned in 2020, the project is owned and operated by Dominion Energy. The landfall location for this project is Camp Pendleton Beach, Virginia. This pilot project is located at the OCS-A 0497 research lease area, with approximately 9 km^2 of area.
- **Coastal Virginia Offshore Wind Commercial Project (CVOW-C) (OCS-A 0483)**. This project plans to install up to 176 wind turbines and up to three offshore substations with a total capacity of 2,587 MW. The project plans to use Siemens turbines, potentially rated at either 14-MW or 14.7 MW (Siemens Gamesa 2020; BOEM 2023b). Dominion Energy submitted their initial COP on December 17, 2020, with the latest COP update on September 8, 2023. BOEM issued a Record of Decision on October 30, 2023, which confirms the planned installation of up to nine export cables, with landfall in Virginia Beach, Virginia. Dominion Energy has asserted that the $10 billion project remains on budget and began offshore construction in May 2024. Initial power generation is expected in the second half of

2025, with completion anticipated in late 2026 (Disavino 2023). This commercial project is located at the OCS-A 0483 lease area, with a footprint of 457 km^2.

- **Kitty Hawk North (OCS-A 0559)**. This proposed project is situated 27 miles east of Corolla, North Carolina. The SAP for the project received approval on April 8, 2020. The COP for Kitty Hawk North was received on December 11, 2020. The COP indicates there will be an interconnection to Virginia, yet no offtake agreements have been awarded. Therefore, the project can still opt for an interconnection to either North Carolina or Virginia, but is contingent upon a viable market pathway emerging from either state.
- **Kitty Hawk South (OCS-A 0508)**. This lease area is located 27 miles east of Corolla, North Carolina. The proposed project plans to incorporate up to 121 wind turbines. It includes the installation of up to two offshore export cables within one corridor, with potential landfall locations in Virginia Beach, Virginia, and/or southern North Carolina near Morehead City. The SAP received approval on April 8, 2020, setting the groundwork for subsequent project developments. The COP for Kitty Hawk South was received on April 14, 2022, and has been acknowledged as complete by BOEM. The lease area is 338 km^2 in size and could interconnect with either Virginia or North Carolina, as no offtake has been awarded yet.
- **Total Energies Carolina Long Bay (OCS-A 0545)**. An SAP was jointly submitted with Duke Energies Renewables Wind on November 15, 2023, and is presently undergoing review by BOEM. This lease area is situated 22 miles off the coast of North Carolina and covers an area of 222 km^2. The combined potential of this lease area coupled with OCS-A 0546 could reach up to 3 gigawatts (GW); however, the North Carolina integrated resource planning process suggests lower project capacities (Duke Energy 2022a; State of North Carolina 2024). No COP has been submitted yet for this lease area. According to the developer's projections, the anticipated project capacity is estimated to be between 1.0 and 1.2 GW (TotalEnergies n.d., 2024; Carolina Long Bay n.d.). This project does not have an awarded offtake yet. Based on geographical location, it could have an interconnection point and offtake with either North Carolina or South Carolina.
- **Duke Energy Renewables Wind (OCS-A 0546)**. This lease area is situated 22 miles off the coast of North Carolina and has an area of 223 km^2. The project has a joint SAP submitted with Total Energies (the adjacent lease area) but has not published a COP yet. According to Duke Energy, the capacity potential for this project could reach up to 1.6 GW (Duke Energy 2022b). This project does not have an awarded offtake yet. Based on its geographical location, it could have an interconnection point either in North Carolina or South Carolina.

In December 2023, BOEM published a PSN for two lease areas: A-2 (OCS-A 0557) and C-1 (OCS-A 0558; shown in Figure 8). On June 28, 2024, BOEM announced a Central Atlantic Final Sale Notice, setting a lease auction on August 14, 2024. The following provides an overview of the two final lease areas proposed for auction:

- **OCS-A 0557 (A-2)**. The total lease area is 412 km^2. It has a mean depth of 37 m and is located 49 km from Delaware Bay. Based on its geographical location, this area could potentially deliver energy to the states of Delaware and/or Maryland.
- **OCS-A 0558 (C-1)**. The total lease area is 715 km^2. It has a mean depth of 36.5 m and is located 65 km southeast of the mouth of Chesapeake Bay. Based on its geographical location, this area could potentially deliver energy to the states of Virginia and/or North Carolina.

3.2 Stakeholder Concerns

BOEM's competitive offshore wind lease issuance process begins with a Call for Information and Nominations (Call) where BOEM requests input from the public regarding areas of the OCS that should be considered and analyzed for the potential development of offshore wind energy. Comments received on the Call Area are then used to inform the Area Identification (Area ID) process. The Area ID process is used to identify areas for environmental analysis and consideration for leasing. It considers multiple competing uses and environmental concerns that may be associated with a proposed area's potential for commercial wind energy development. This down-selection process and associated stakeholder feedback are documented here: www.boem.gov/renewable-energy/state-activities/central-atlantic.

3.2.1 Stakeholder Concerns With Call Areas A Through D

Impacts to other ocean uses and the environment associated with development of the Call Areas come from noise, air emissions, lighting, habitat degradation, vessel traffic, vessel discharges, seafloor disturbance, and potential entanglement. These impact-producing factors are analyzed with respect to air quality and greenhouse gas emissions; benthic resources; commercial and recreational fishing; cultural, historical, and archaeological resources; fish and fish habitat; marine mammals; military use and vessel traffic; recreation and tourism; and sea turtles.

Figure 9 shows that national security concerns are present in and around Call Areas A through D. If the U.S. Coast Guard's planned port access routing measures are superimposed on these areas, relatively little unconflicted shelf space remains within the BOEM Central Atlantic 1 Call Areas.

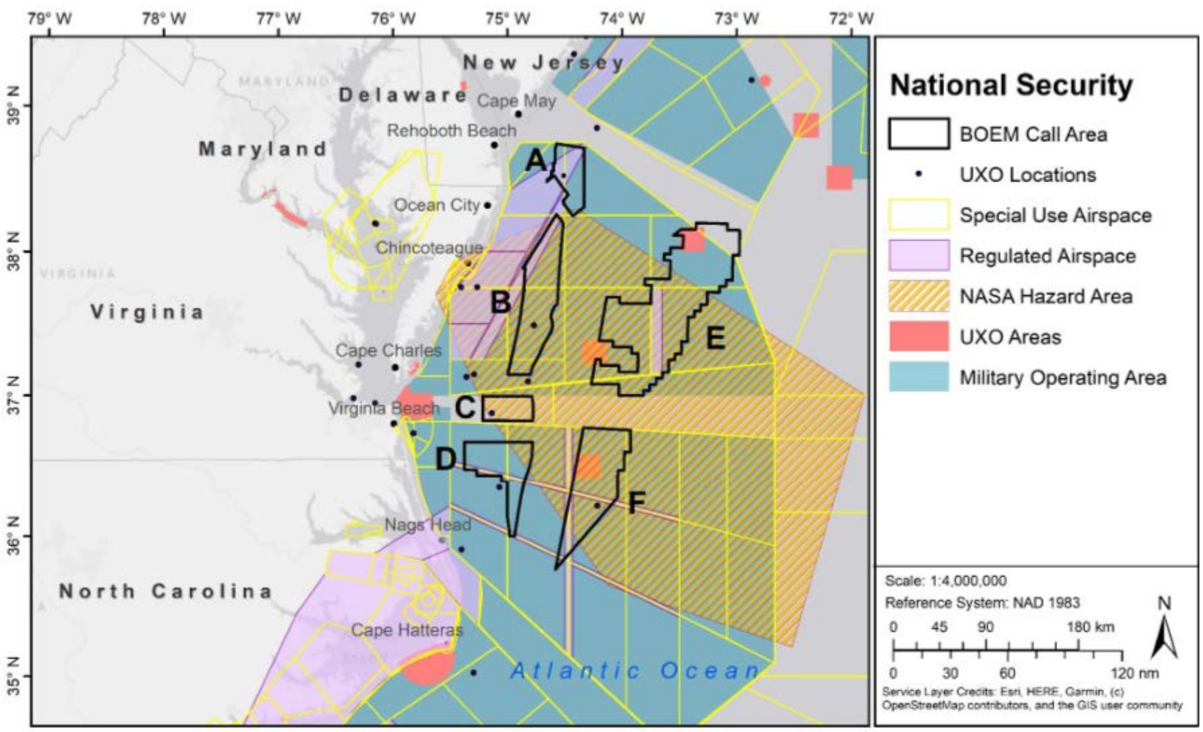


Figure 9. National security considerations for the BOEM Central Atlantic 1 Call Areas. Considerations include special use airspace, military operating areas, regulated airspace, National Aeronautic and Space Administration (NASA) hazard area, and unexploded ordnance (UXO) areas.
Figure from BOEM (2023e)

These concerns in part motivated BOEM to identify ultradeep Call Areas E and F, which are beyond the western boundary of the shipping fairway proposed by the U.S. Coast Guard that runs roughly north-south, just beyond the continental shelf break off North Carolina and Virginia, and then over the geographic shelf off Maryland, Delaware, and New Jersey (BOEM 2023c). However, these ultradeep Call Areas also have conflicts with other ocean users and natural resources, but maybe to a lesser degree than the areas closer to shore. The purpose of this report is to provide BOEM with technical information to inform further leasing in the region.

3.2.2 Stakeholder Issues With Ultradeep Call Areas E and F

The National Oceanic and Atmospheric Administration's (NOAA's) National Centers for Coastal Ocean Science developed a spatial suitability model for BOEM, shown in Figure 10.

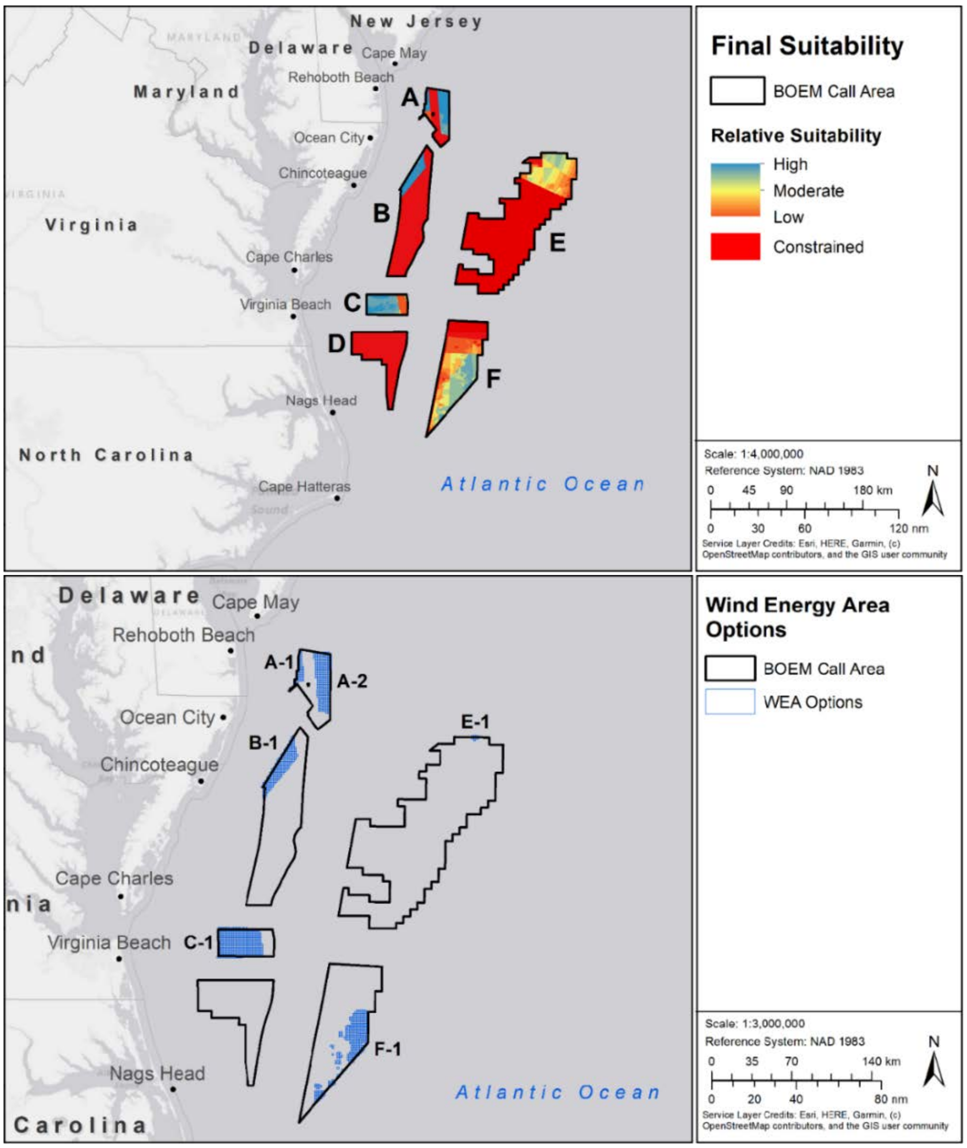


Figure 10. (Top) Final suitability modeling results for Central Atlantic 1 Call Areas A – F. (Bottom) The least conflicted sites were identified by selecting aliquots with the highest suitability.
Figure from BOEM (2023e)

The goal of the Area ID process is to identify conflicts and mitigate impacts with other ocean users and the environment. The spatial suitability model is a tool to help support this process, and as a result, the National Centers for Coastal Ocean Science provided BOEM with six wind energy area options. In the top image of Figure 10, red indicates "constrained" zones generally with multiple conflicts with other ocean stakeholders. Blue zones have fewer conflicts and therefore have the highest suitability with offshore wind energy. Site suitability is based on a wide range of competing assumptions. In addition to the potential national security conflicts mapped in Figure 9, environmental concerns include the Frank Lautenberg Deep Sea Coral Protection Area, which overlaps all of Call Area E and a northern portion (~20%) of Call Area F (www.fisheries.noaa.gov/resource/map/frank-r-lautenberg-deep-sea-coral-protection-areas-map-gis), and a zone of high black-capped petrel abundance in the southernmost part of Call Area F.

Future Round 2 leasing in the Central Atlantic is scheduled in 2026, with BOEM planning to issue a Call for Information and Nominations in late August or early September 2025. NREL recommends a reassessment of potential conflicts and environmental concerns in identifying the Central Atlantic Round 2 Call Area.

4 State Offshore Wind Energy Profiles

This section outlines the regional activities and collaborations between the Central Atlantic 1 states of Delaware, Maryland, Virginia, and North Carolina, and offers an in-depth overview of energy consumption and generation, as well as the policy history related to offshore wind or renewable energy in each state. In addition, this section provides guidance on federal policy support through tax credits for offshore wind federal policy support, specifically addressing offshore wind energy tax credits that apply to all states. We also compare the state policy targets to the present and future lease activity to estimate the future requirements needed to meet individual state goals.

4.1 State and Regional Offshore Wind Summaries

This section summarizes the offshore wind energy activity in the Central Atlantic 1 states to date. Figure 8 shows the current lease areas, proposed lease areas for sale, and Call Areas that are under investigation for the potential delineation of future leases. Here, we provide a more detailed assessment of state activities and plans for offshore wind energy development.

4.1.1 Central Atlantic Regional Activities

In the Central Atlantic 1 region, a collaborative effort to advance offshore wind energy was formalized through a memorandum of understanding signed on October 29, 2020 (Southeast and Mid-Atlantic Regional Transformative Partnership for Offshore Wind Energy Resources [SMART-POWER] 2020b). This agreement, operating under SMART-POWER, outlines a shared commitment among the signatory states (Maryland, Virginia, and North Carolina) to jointly promote, develop, and expand offshore wind energy initiatives, along with fostering growth in the associated supply chain and workforce. As part of the SMART-POWER partnership objectives, these states set a target to procure at least 10 GW of offshore wind energy by 2034, with Maryland committed to 2 GW by 2030, Virginia committed to 5.2 GW by 2034, and North Carolina committed to 2.8 GW by 2030 (SMART-POWER 2020a). This ambitious commitment underscores the dedication to regional collaboration and the substantial expansion of offshore wind energy generation in the Central Atlantic region. Note that the SMART-POWER agreement is independent of the states' own policy targets.

On October 3, 2023, NOWRDC announced the SMART-POWER Workforce and Supply Chain Analysis project. This initiative aims to assess the existing offshore wind energy capabilities within the Central Atlantic region, with a focus on identifying strategic supply chain investments that can effectively leverage those resources. The project is a collaborative effort involving NREL, Maryland, Virginia, and North Carolina. Delaware is also participating in this effort. The project was funded by Maryland and North Carolina through a grant agreement from the Maryland Energy Administration with NOWRDC.

Through these regional activities and partnerships, the Central Atlantic 1 states are actively contributing to the advancement of offshore wind energy, aligning with the broader objectives of the SMART-POWER collaboration and demonstrating a commitment to leveraging regional strengths for the mutual benefit of member states and the offshore wind energy industry as a whole.

4.1.2 Delaware

4.1.2.1 Delaware Energy Use

Delaware, the nation's second-smallest state, relies on various energy sources to meet its consumption demands, with a notable dependance on natural gas. Despite lacking fossil-fuel reserves, the state imports and refines crude oil. In 2021, Delaware's energy consumption was nearly 80 times higher than its production. The industrial sector, particularly chemical manufacturing, and petroleum refining, led energy consumption, accounting for 29% of the state's total (Energy Information Administration [EIA] 2024a).

In terms of electricity generation, natural gas dominates, contributing to 89% of in-state production in 2022. This amount marked a significant increase from 51% in 2010, whereas coal's share dwindled from 46% to 2% over the same period. Notably, Delaware relies on out-of-state power suppliers for a substantial portion of its electricity needs, with only 41% generated within the state in 2021 (EIA 2024a). Figure 11 shows the energy generated in Delaware by primary energy source in 2022.

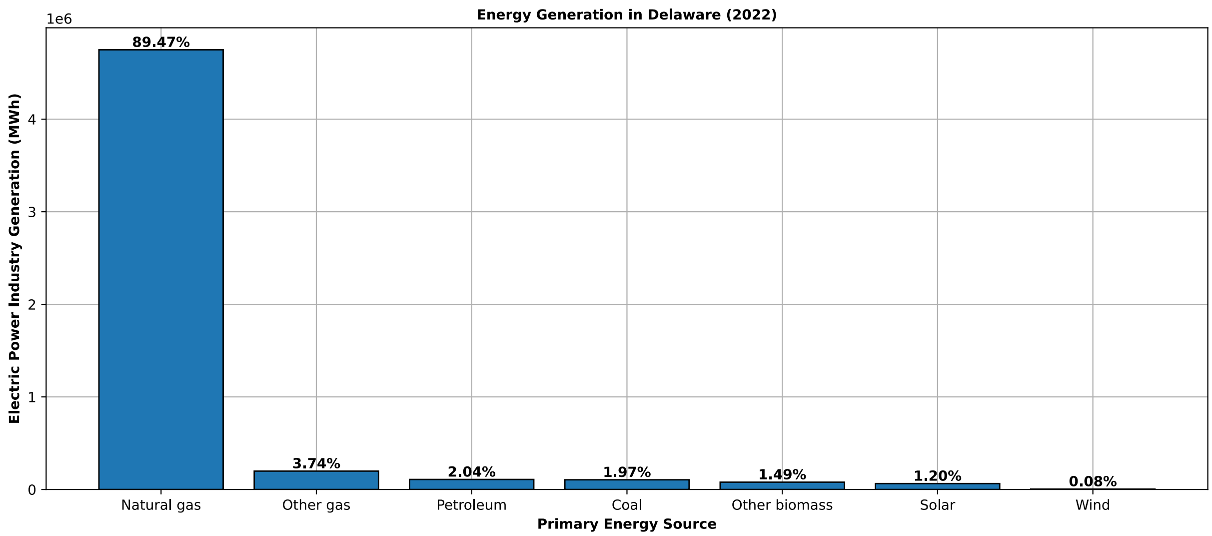


Figure 11. Electric power industry generation by primary energy source in Delaware in 2022. *Image from EIA (2023a)*

Delaware's electricity consumption per capita surpasses that of almost two-fifths of all states, driven by the residential sector, where approximately one in three households relies on electricity for heating. In 2022, residential consumption comprised 45% of the state's electricity sales, followed by the commercial sector at 37% and the industrial sector at 18%. The state also encourages electric vehicle adoption, offering rebates and a growing network of public-access charging stations. Overall, Delaware's energy landscape reflects a balance between its industrial activities, population density, and a shift toward cleaner energy sources, particularly natural gas (EIA 2024a).

4.1.2.2 Offshore Wind Energy Policy in Delaware

Delaware is mandated by state law to have 40% of its energy come from renewable sources like wind and solar by 2035 (Delaware News 2021). While the state was one of the early leaders in support of offshore wind energy,[7] there is no mandate to procure offshore wind yet. In 2017, Governor John Carney established the Offshore Wind Working Group, bringing together government, industry, and the public to study offshore wind development. The group identified options for further study in a report submitted to the governor in 2018 (Department of Natural Resources and Environmental Control [DNREC] and Synapse Energy Economics 2018). In addition, the University of Delaware's Special Initiative on Offshore Wind produced a report, *Offshore Wind Procurement Options for Delaware*, at the request of DNREC's Secretary Shawn Garvin (Special Initiative on Offshore Wind at the University of Delaware 2022). Although insightful, the report does not cover all options proposed by the working group. As a result, DNREC continues to study these options and the technical challenges of connecting offshore wind energy to the grid. Legislation in 2023 directs DNREC to collaborate with PJM Interconnection, LLC to study transmission impacts, work with neighboring states on offshore wind transmission, and report on the procurement process. This report is expected to add momentum that could potentially lead to the state's first offshore wind energy target, a goal supported by many lawmakers and environmental groups (DNREC, Synapse Energy Economics, and Zooid Energy 2023; Energy News Network 2023).

Delaware Senate Bill 265 (Delaware Energy Solutions Act of 2024) was introduced in April 2024 and proposes granting authorization to the State Energy Office, subject to approval by the Public Service Commission, to conduct solicitations for the procurement of offshore wind energy for Delaware, with a capacity ranging from 0.8 to 1.2 GW (Delaware General Assembly 2024). Senate Amendment 1 removed the minimum requirement for deployment but left the 1.2 GW maximum in place. The State Energy Office cannot proceed with negotiating a contract unless a bid comes back with a price at or below 110% of the Delaware benchmark price.[8] The amended bill was approved by the Delaware Senate on May 23, 2024, and the Delaware House on June 30, 2024 (State of Delaware 2024). The bill is on the governor's desk at the time of this report and is expected to pass.

4.1.3 Maryland

4.1.3.1 Maryland Energy Use

Maryland, which is situated around Chesapeake Bay with diverse geographical features, relies on fossil fuels, renewable resources, and a mix of nuclear and natural gas for its energy needs. Despite possessing coal and natural gas reserves, the state consumes about five times more energy than it produces. Nuclear energy and natural gas played key roles in electricity generation in 2022, supplying 77% of Maryland's total net generation. The Calvert Cliffs nuclear power plant contributed about 39% of the state's electricity in 2022. Natural-gas-fired generation, with a 38% share, has tripled since 2015. Coal's contribution decreased to 12% in 2022, with plans to

[7] Note that the Delaware wind energy area was the first to be designated in the United States.
[8] The Delaware benchmark price is the average price that Delmarva Power has paid for power and renewable energy compliance over the prior 3 years.

phase out coal-burning plants by 2025[9] (EIA 2023c). Figure 12 shows the energy generated in Maryland by primary energy source in 2022.

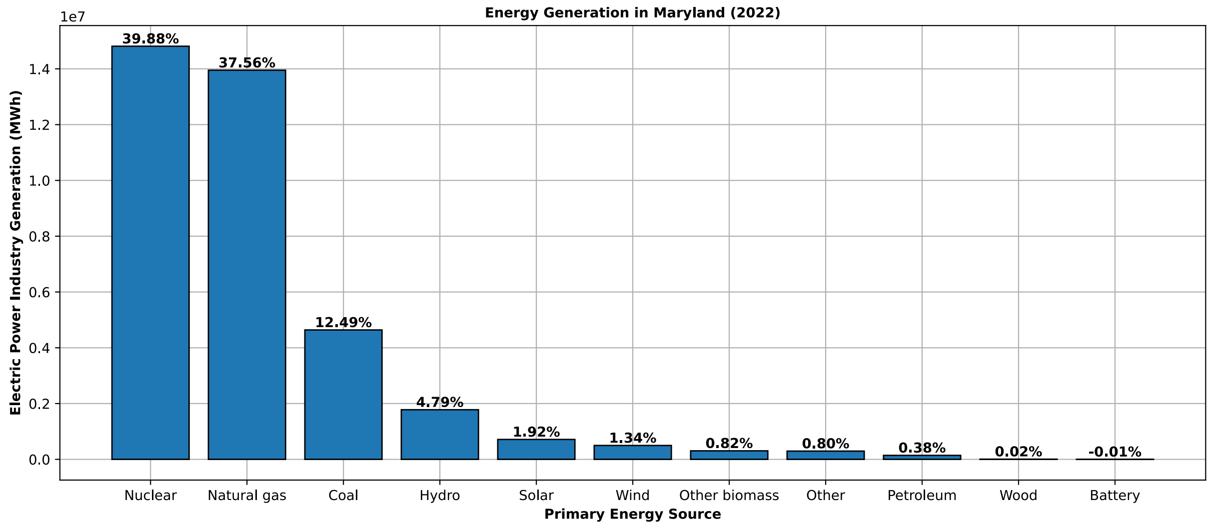


Figure 12. Electric power industry generation by primary energy source in Maryland in 2022. *Image from EIA (2023b)*

In 2021, the transportation sector led energy consumption in Maryland at 33%, followed closely by the residential sector at 31%, and the commercial sector at 29%. The industrial sector accounted for 7% of the state's energy use. Maryland ranks among the states with the lowest per-capita energy consumption and the lowest energy use per dollar (EIA 2023c).

While Maryland uses less electricity per capita than four-fifths of the United States, it relies heavily on imports from the regional PJM grid. The residential sector accounted for 47% of electricity use, closely followed by the commercial sector at 46%. Approximately 40% of Maryland households use electricity as their primary heating source. The industrial sector consumed 6% of electricity, and the transportation sector, including railways and transit systems, comprised about 1% of electricity use (EIA 2023c).

Maryland actively promotes electric vehicle adoption, with about 70,500 registered electric vehicles and 4,600 charging stations by May 2023. Electric vehicle registrations surpassed the 100,000 mark in April 2024 (Maryland Department of Transportation 2024). Financial incentives support both electric vehicle purchases and charging station installations, aligning with the state's commitment to a diversified and sustainable energy future (EIA 2023c).

4.1.3.2 Offshore Wind Energy Policy in Maryland

Maryland's journey toward adopting offshore wind as a primary source of energy has evolved through a series of policies and legislation, starting with the Maryland Offshore Wind Energy Act of 2013. This act revised the renewable portfolio standard goal to achieve 25% of the state's

---

[9] Brandon Shores coal plant's phase out has been postponed as PJM requested the plant outside Baltimore to operate under a reliability-must-run arrangement until the planned transmission upgrades are completed in 2028 (Maryland Energy Administration 2024).

electricity consumption from renewable sources by 2020, including a carve-out specifically for offshore wind not exceeding 2.5% (Maryland Energy Administration n.d.[a]).

In 2019, the Clean Energy Jobs Act further amended the renewable portfolio standard, elevating Maryland's overall renewable energy goal to 50% by 2030. The act eliminated the upper limit on offshore wind energy development and mandated the procurement of at least an additional 1,200 MW through three new rounds of offshore wind energy projects (Maryland Energy Administration n.d. [a]).

In 2020, SMART-POWER was by established the governors of Maryland, North Carolina, and Virginia. This partnership aimed to collaboratively promote, develop, and expand offshore wind energy, with Maryland committing to achieving 2 GW by 2030 (SMART-POWER 2020a).

Recognizing the key role of offshore wind in Maryland's energy landscape, Governor Wes Moore signed the Promoting Offshore Wind Energy Resources Act in April 2023. This legislation set a new ambitious target of 8.5 GW by 2031 and introduced measures to mitigate industry risks through a transmission planning study and a second offshore wind procurement method administered by the Maryland Department of General Services (Maryland Energy Administration n.d. [a]). Following these targets, House Bill 1296 was introduced in February 2024 and enacted later in June by Governor Wes Moore, allowing offshore wind energy projects to revise schedules, sizes, or pricing, subject to Public Service Commission approval (Maryland General Assembly 2024a, 2024b). On June 7, 2024, Governor Moore also signed a memorandum of understanding with BOEM to develop offshore wind leasing areas in Maryland aiming to ensure efficient development, maximize national benefits, and address gaps in available leasing areas (BOEM 2024a).

In addition to these procurement targets, the Maryland Energy Administration established two key funding programs—the Maryland Offshore Wind Supply Chain Investment Program and the Maryland Offshore Wind Workforce and Education Program—and is supporting various research initiatives that facilitate offshore wind energy development and scientific understanding of the offshore wind market, supply chain, workforce, as well as the environment, wildlife, habitat, and ecosystems present on the Mid-Atlantic OCS (Maryland Energy Administration n.d.[b]; n.d.[c]). These programs provide financial support to various entities, including emerging businesses[10] (e.g., minority-owned emerging businesses), nonprofits, academic institutions, labor unions, and government bodies, to help establish a robust offshore wind supply chain and skilled workforce (Maryland Energy Administration n.d.[a]).

4.1.4 Virginia

4.1.4.1 Virginia Energy Use

Virginia's energy landscape is shaped by a diverse array of resources, with nuclear power emerging as one of the primary sources of electricity production. Virginia's geographical

[10] According to the Maryland Energy Administration, an emerging business is a business that is at least 51% owned and controlled by an individual or individuals who are certified to have a personal net worth, as defined in §14-301 of the State Finance and Procurement Article, that does not exceed $6,500,000 as adjusted each year for inflation according to the Consumer Price Index.

diversity ranges from the coastal cities to the inland Appalachian region that serves as a significant fossil-fuel (e.g. coal, natural gas, oil) export center (EIA 2024c).

Figure 13 shows the energy generated in Virginia by primary energy source in 2022. Natural gas and nuclear power are the dominant sources, contributing 54% and 31%, respectively, to Virginia's total in-state electricity net generation. Renewable energy sources, including solar energy, biomass, and hydroelectric power, make up 11% of the state's electricity mix. This energy mix highlights that renewable resources have surpassed coal's contribution, indicating a shift by Virginia toward a cleaner energy future (EIA 2024c).

In terms of use, Virginia relies on a mix of sectors, with the transportation sector leading at three-tenths of the state's energy consumption. The state possesses an extensive transportation infrastructure, including the third-largest state-maintained highway system, major interstates, railroads, commercial airports, and one of the nation's largest seaports. While the commercial sector, residential sector, and industrial sector each play crucial roles, Virginia consumes nearly three times more energy than it produces. However, the per-capita energy use remains below the national average, reflecting relatively efficient energy use patterns (EIA 2024c).

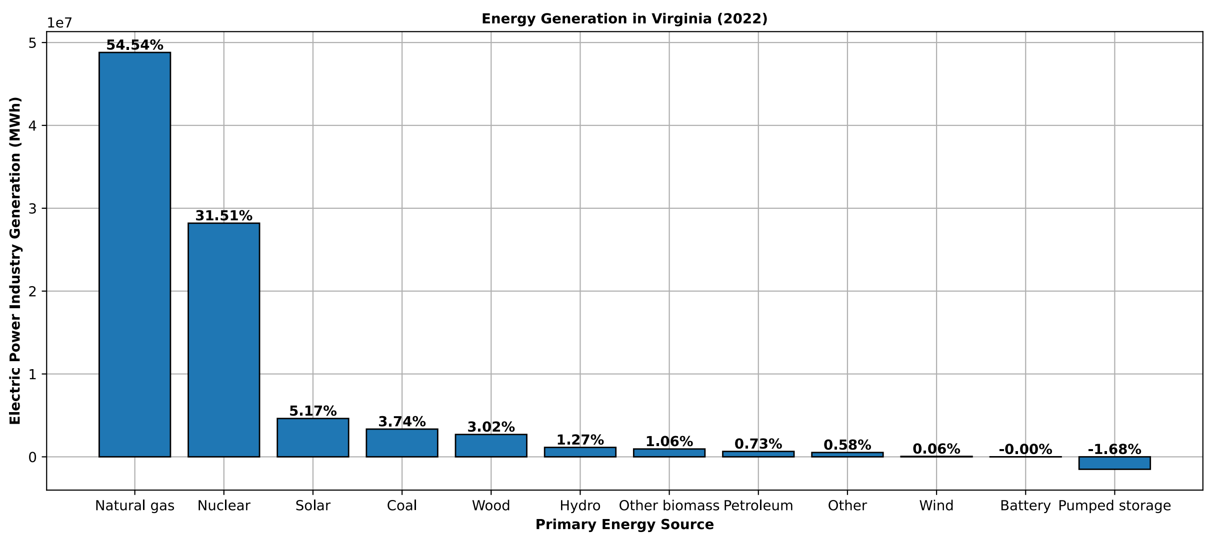


Figure 13. Electric power industry generation by primary energy source in Virginia in 2022. *Figure from EIA (2023e)*

With electricity consumption exceeding in-state generation, the state supplements its needs through two regional grids. Notably, the commercial sector, driven by high electricity use at data centers in Northern Virginia,[11] is the major end-use sector, accounting for half of the state's electricity consumption, followed by the residential and industrial sectors. Virginia's energy landscape is marked by a successful integration of diverse resources, a transition toward cleaner alternatives, and strategic use of regional grids to meet growing demand (EIA 2024c).

[11] According to Dominion Energy, 21% of their 2022 electricity sales in Virginia went to data centers and this percentage is expected to double by 2040 (Piedmont Environmental Council 2024).

4.1.4.2 Offshore Wind Energy Policy in Virginia

Virginia's offshore wind energy procurement target history has progressed through key milestones. In 2018, the Commonwealth of Virginia's Energy Plan recommended establishing a goal to develop 2 GW of offshore wind capacity by 2028 (Office of the Secretary of Commerce and Trade, Department of Mines, Minerals and Energy 2018).

In 2020, SMART-POWER was established by the governors of Maryland, North Carolina, and Virginia. Subsequently, Virginia committed to achieving a more ambitious procurement mandate of 5.2 GW by 2034, showcasing a collaborative effort to promote, develop, and expand offshore wind energy in the region while incentivizing Dominion's 2.6-GW CVOW project that began construction in 2024 (SMART-POWER 2020a). This commitment was reinforced in 2020 with the passage of the Virginia Clean Economy Act, which declared that Virginia's target of up to 5.2 GW of offshore wind capacity by 2034 to be in the public interest of the commonwealth. The act solidified Virginia's commitment to a substantial increase in offshore wind energy development, aligning with the goals set forth in the SMART-POWER initiative (Virginia's Legislative Information System 2020).

4.1.5 North Carolina

4.1.5.1 North Carolina Energy Use

North Carolina has a varied topography, extending from the Atlantic Ocean coastline to the Appalachian Mountains. The state stands out as a solar power leader and possesses substantial woodlands covering three-fifths of its territory. North Carolina owns a significant biomass resource, employing around 72,000 individuals in forestry and forest product industries. Additionally, the state's rivers contribute to hydroelectric power generation. While North Carolina lacks fossil-fuel resources, it has prominent nuclear-power-generating facilities, ranking among the top U.S. states in this regard (EIA 2024b).

In terms of electricity generation, North Carolina relies heavily on natural gas and nuclear power, comprising about three-fourths of the state's total net electric grid generation. The state has witnessed a shift in recent years, with natural-gas-fired generation reaching a record high of 43% in 2022, surpassing coal-fired generation. Nuclear energy remains a significant contributor, providing 32% of the state's net generation. Renewable sources, including solar, hydroelectric, wind, and biomass, collectively contribute to the remaining electricity generation (EIA 2024b). Figure 14 shows the electricity generated by primary energy source in 2022 in North Carolina.

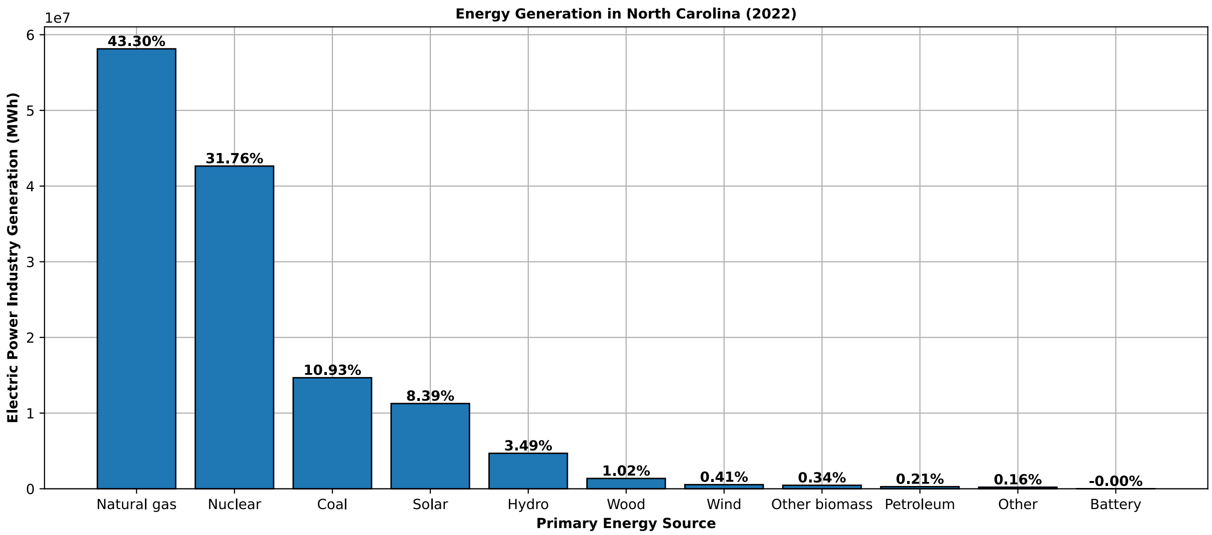


Figure 14. Electric power industry generation by primary energy source in North Carolina in 2022.
Figure from EIA (2023d)

North Carolina uses nearly four times more energy than it produces; however, on a per-capita basis, the state maintains one of the lowest energy consumption rates in the country. The transportation sector takes the lead as the largest end-use energy consumer, comprising three-tenths of the state's total energy consumption. This demand arises from residents, tourists, and truckers using motor gasoline, diesel fuel, and jet fuel. Following closely, the residential sector accounts for slightly over one-fourth of the state's energy use, whereas the commercial and industrial sectors contribute approximately one-fifth each. Despite being among the top electricity-producing states, North Carolina's consumers surpass in-state generation by approximately 10%, relying on electricity from other states through the regional grid. The residential sector dominates electricity use, with nearly half of the total consumption, emphasizing the importance of balancing energy production and consumption in the state (EIA 2024b).

4.1.5.2 Offshore Wind Energy Policy in North Carolina

In June 2021, North Carolina's governor issued Executive Order No. 218, which outlines significant measures, including setting ambitious offshore wind energy development goals of 2.8 GW by 2030 and 8.0 GW by 2040. It establishes the North Carolina Taskforce for Offshore Wind Economic Resource Strategies, which is tasked with providing expert guidance on advancing offshore wind energy projects, fostering economic development, and generating employment opportunities. Additionally, the order mandates relevant state departments to designate leads for offshore wind energy initiatives (State of North Carolina and Governor Roy Cooper 2021; North Carolina Environmental Quality n.d.).

Beyond offshore wind, North Carolina's approach to renewable energy is noticeable in the Carbon Plan Statute (Section 62-110.9), which directs the North Carolina Utilities Commission to pursue a 70% reduction in carbon dioxide emissions from specific electric-generating facilities by 2030. Furthermore, the state aims to achieve carbon neutrality by 2050. This policy framework reflects North Carolina's proactive approach to embracing offshore wind energy and renewable sources as integral components of its transition to a clean energy economy (North Carolina Utilities Commission 2022).

In August 2023, Duke Energy filed an updated carbon plan that builds on the North Carolina Utilities Commission's Carbon Plan. In addition to this updated plan, Duke Energy released a supplemental planning analysis in January 2024. This analysis highlights the additional resource needs identified in the Updated 2023 Fall Load Forecast and includes recommended resource additions by 2035 (Duke Energy 2023, 2024). The North Carolina Utilities Commission is currently conducting its biennial review of Duke Energy's Carbon Plan, which proposes to include 2.4 GW of offshore wind energy but does not yet require a procurement mechanism or other path to market for this offshore wind generation.

4.2 Central Atlantic Offtake and Leasing Needs

Section 3 provides an overview of the existing leases in the Central Atlantic 1 region, whereas Section 4.1 offers the most up-to-date information on regulatory state targets. In this section, we use that information to conduct a practical assessment of the minimum required lease area capacity (in megawatts) to be leased, allowing sufficient opportunity for procurement through power purchase agreements, ORECs, or other forms of offtake agreements to meet current state and regional objectives. Generally, we consider this analysis to be a conservative estimate of the minimum lease requirement because state commitments are likely lower than the clean energy needed to achieve electrification of major use sectors and near-net-zero decarbonization.

This assessment involves estimating the generating capacities (in megawatts) of projects lacking an offtake based on the lease area size and various capacity density assumptions. For more conservative estimates,[12] we adopt the capacity density metric of 4 MW/km^2, which was used by NREL for lease area capacity estimations in DOE's *Offshore Wind Market Report: 2023 Edition*, and later used by BOEM (Mulas Hernando et al. 2023; Musial et al. 2023; U.S. Department of the Interior 2024). For a more aggressive scenario, we assume the U.S.-weighted average capacity density from planned projects, excluding Massachusetts and Rhode Island lease areas, which is 5.64 MW/km^2 (Mulas Hernando et al. 2023).

Table 1 summarizes the capacities, negotiated state offtakes, and potential state offtakes based on geographical location for each project. Additionally, Table 2 outlines the selection of targets used in this assessment—those with the highest megawatt capacities established by individual states. It is important to note that the planning targets shown in Table 2 combine statuary state procurement mandates like those from Maryland and Virginia, with planning goals that are not binding from Delaware and North Carolina.

[12] Note that conservative estimates reflect low-capacity densities and result in a larger amount of required lease area that aligns with NREL's standard metric of 4 MW/km^2.

Table 1. State, Offtake, and Project Capacity Assumptions for Central Atlantic Projects[13]

Projects Names	State	Has Offtake?	Area (acres)	Area (km^2)	Project Capacity (MW)	Capacity Calculation Method
CVOW-P	Virginia (VA)	Yes[a]	2,135	9	12	Utility-owned, two 6-MW turbines
CVOW-C	VA	Yes[a]	112,799	457	2,464–2,587	Utility-owned, 176 14- to 14.7-MW turbines
Kitty Hawk North	VA/North Carolina (NC)	No	38,964	158	631–890	Area-based (4.00–5.64 MW/km^2)
Kitty Hawk South	VA/NC	No	83,443	338	1,352–1,906	Area-based (4.00–5.64 MW/km^2)
US Wind	Maryland (MD)	Yes	79,707	323	1,056[c]	ORECs
US Wind Residual	Delaware (DE)/MD	No			600–800	Area not determined; we use project documentation instead (BOEM 2022)
Skipjack and Garden State Offshore Energy	DE/MD	No	96,430	391	1,562–2,203	Area-based (4.00–5.64 MW/km^2)
Total Energies	NC	No	54,937	222	888–1,253	Area-based (4.00–5.64 MW/km^2)
Duke Energy	NC	No	55,114	223	892–1,258	Area-based (4.00–5.64 MW/km^2)
Final OCS-A 0557	DE/MD	No	101,842[b]	412	1,649–2,324	Area-based (4.00–5.64 MW/km^2)
Final OCS-A 0558	VA/NC	No	176,633[b]	715	2,859–4,032	Area-based (4.00–5.64 MW/km^2)
Total Central Atlantic Existing Capacity (MW)					**13,966–18,321**	-

[a]: Utility-owned projects are assumed to have an offtake for the megawatt count in this assessment.
[b]: According to BOEM, FSN OCS-A 0557 is 101,443 acres and FSN OCS-A 0558 is 176,505, while our QGIS calculations using BOEM's shape files areas result in 101,842 acres and 176,633 acres, respectively. We use our estimates.
[c]: Under House Bill 1296, OREC sizes in Maryland can be subject to increases.

---

[13] In this analysis, southern New Jersey lease areas like OCS-A 0532, 0498, and 0499, were not considered for potential interconnection to Delaware, as New Jersey has a more ambitious mandated target of 11 GW, whereas Delaware's goal of 1.2 GW, pending adoption of Senate Bill 265, is not a mandate.

Table 2. State Targets in the Central Atlantic 1 Region

State	Target	Source
DE	1.2 GW[d]	Delaware General Assembly (2024)
MD	8.5 GW by 2031	Maryland Energy Administration (n.d.)
VA	5.2 GW by 2034	SMART-POWER (2020a)
NC	8.0 GW by 2040	State of North Carolina and Governor Roy Cooper (2021)
Total	**22,900 MW**	

[d]: Pending adoption of Senate Bill 265

State targets serve as a baseline for the potential transmission of offshore wind energy to each respective state. In this analysis, we assess the required megawatt capacity to be secured through offtake agreements and leased to fulfill these baseline targets in the Central Atlantic 1 region. Due to the geographical location of existing active leases, projects from these leases can potentially interconnect with either Delaware or Maryland, or with Virginia or North Carolina. Consequently, we examine the gaps in offtake agreements and leased capacities for the combined regions of Delaware and Maryland (see Figure 15), as well as for Virginia and North Carolina (see Figure 16).[14]

Although our assessment assumes specific capacity densities, developers may select wind plant array configurations with higher or lower capacity densities based on their internal optimization strategies considering relevant economic, technical, and stakeholder considerations. Additionally, we assume that the available area within a given lease area will ultimately be utilized by the leaseholders. This analysis calculates offtake and leasing needs based on targets and goals as of July 2024. It is important to note that offshore wind energy targets and goals may expand over time, increasing the needs outlined in this assessment.

[14] Note that our estimate for required new lease area is based solely on the targets shown in Table 2 and the quantity of area already leased. Offtake agreements are shown for reference, but we assume that all lease areas will eventually be developed and obtain offtake agreements.

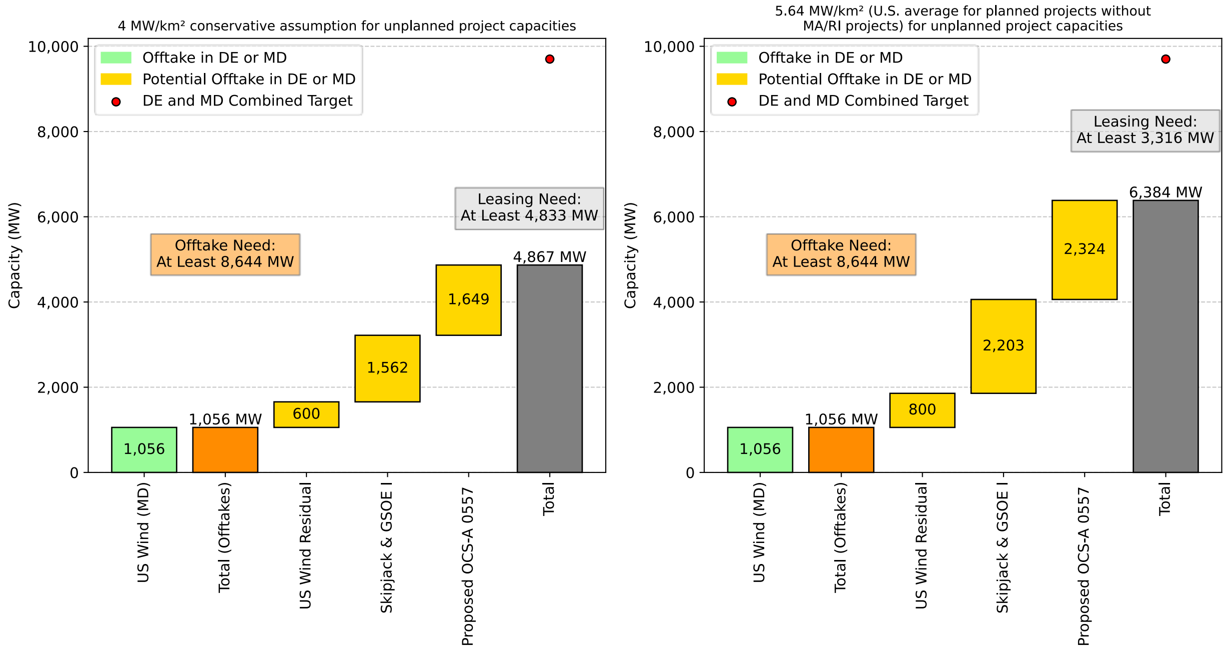


Figure 15. Conservative (left) and advanced (right) assessment of the minimum offtake and leasing needs to meet the combined targets of 1,200 MW (not mandated) in Delaware and 8,500 MW (mandated) in Maryland

As shown in Figure 13, the combined targets of Delaware and Maryland are 9,700 MW. However, because US Wind already holds an offtake agreement for 1,056 MW, an additional 8,644 MW of offtakes are needed between the two states. With Delaware targeting 1,200 MW and Maryland aiming for 8,500 MW, Maryland must procure an additional 7,500 MW to meet its current target, whereas Delaware needs to procure at least 1,200 MW[15] of offshore wind energy to meet the goal.

With regards to leasing planning, our analysis indicates that between 3,316 MW and 4,833 MW of offshore wind capacity will need to be leased to meet Delaware and Maryland's combined targets, assuming sites in southern New Jersey will not be available. Using a conservative 4 MW/km^2 assumption, an estimated area of 1,208 km^2 (298,503 acres) of additional leasing is required in geographical proximity to Delaware and Maryland to achieve minimum state offshore wind energy objectives.

[15] Subject to bid coming back with a price at or below 110% of the Delaware benchmark price.

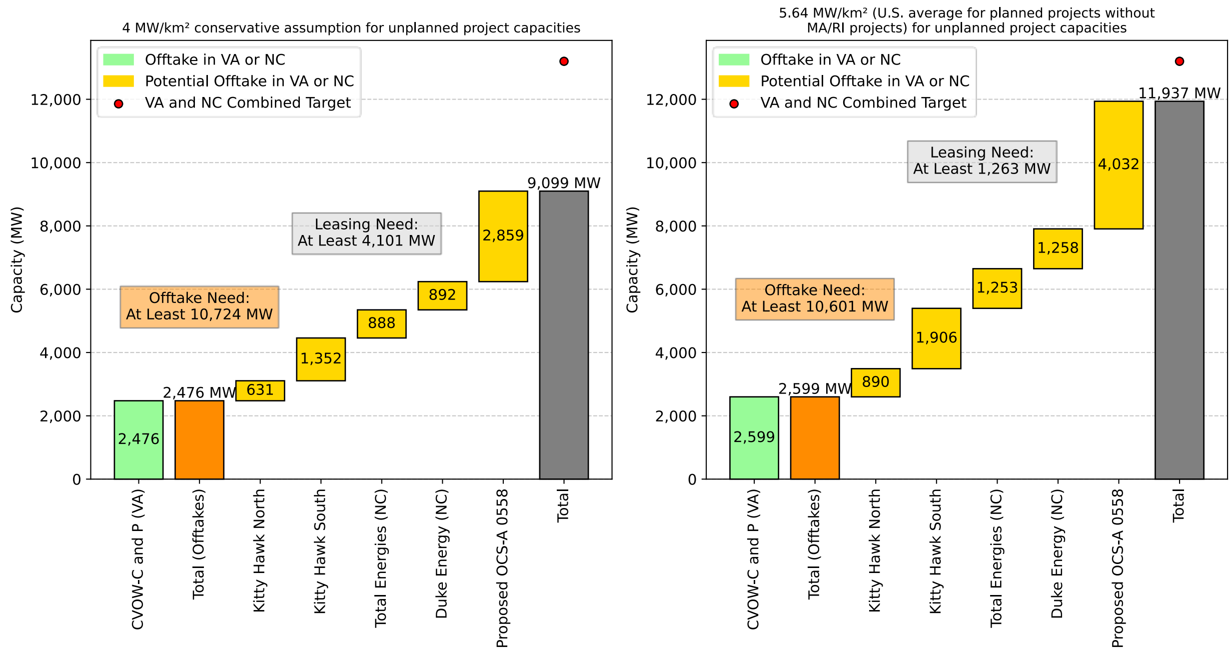


Figure 16. Conservative (left) and advanced (right) assessment of the minimum offtake and leasing needs to meet the combined targets of 5,200 MW (mandated) in Virginia and 8,000 MW (not mandated) in North Carolina

Similarly, the combined targets of Virginia and North Carolina demand 10,600 to 10,700 MW in additional offtakes, as shown in Figure 16. With Virginia aiming for 5,200 MW and NC targeting 8,000 MW and considering the current Dominion offtake of 2,400−2,600 MW from Virginia, Virginia must secure an additional 2,600–2,800 MW in offtakes, whereas North Carolina needs to commence procurement for their entire 8,000 MW in offshore wind energy contracts.

From a leasing planning perspective, 1,263 to 4,101 MW of additional offshore wind lease capacity would be needed to meet Virginia's and North Carolina's combined state targets. Based on the conservative 4 MW/km^2 assumption, an estimated area of 1,025 km^2 (253,283 acres) for leasing is needed in geographical proximity to both states to attain these objectives.

A total of 19.2−19.3 GW would need to be procured from all Central Atlantic states, and using the 4 MW/km^2 metric, about 2,233 km^2 (551,786 acres) of additional lease area would be needed in the Central Atlantic to meet the current state targets. This estimate may be conservative, as state targets have tended to increase over time. Meeting these goals will require BOEM to conduct additional marine spatial planning and site suitability analysis for the Central Atlantic round 2 auctions scheduled for 2026. Round 2 planning may include an expansion of the Central Atlantic region to consider sites off the coast of southern New Jersey as well as options in both the shallower waters on the shelf and ultradeep waters located in Central Atlantic 1 Call Areas E and F. Section 5 assesses the technological feasibility of floating offshore wind in ultradeep water.

4.3 Federal Policy Support

Although state policy is driving offshore wind energy development in the United States, federal policy is an essential component to making the economics of this development viable. During the COVID pandemic from 2020 to 2022, global supply chain disruptions that led to high commodity price inflation and subsequently, high interest rates, caused offshore wind project prices to rise sharply. This inflation resulted in many U.S. offshore wind energy projects to become economically unviable, forcing many to cancel and rebid their power offtake agreements that were negotiated before the pandemic. These economic setbacks affected the entire U.S. and global economies in a similar way. Under the leadership of the Biden administration, the U.S. Congress signed the Inflation Reduction Act into law in August 2022. Among many other things, the act provides incentives for investing in offshore wind energy and the domestic supply chain (U.S. Department of Energy 2023). The Inflation Reduction Act credits include the production tax credits and investment tax credits, as well as stackable bonus credits of 10% points for projects meeting domestic manufacturing thresholds or locating in specified disadvantaged communities. The act also provides opportunities for U.S. businesses under the advanced manufacturing production tax credit, and advanced manufacturing investment tax credit (Office of Energy Justice and Equity 2023; U.S. Department of Energy n.d.).

5 Central Atlantic Offshore Wind Technology

5.1 Overview of Central Atlantic Offshore Technology

The OCS in the U.S. Central Atlantic 1 study area is characterized by four nearshore draft wind energy areas of shallow water less than 60 m deep and two ultradeep Call Areas with average depths over 2,000 m. The shallow sites comprise Call Areas A, B, C, and D. Of these four Call Areas, two smaller lease areas in A-2 (410.5 km^2) and C-1 (714.3 km^2) have been designated in a FSN with a total capacity of about 4.5 GW (Figure 8), where conventional fixed-bottom support structures can be used. This first Central Atlantic offshore wind energy auction is scheduled for August 2024. BOEM has indicated that a second auction is planned in 2026. Based on the assessments shown in Section 4, these two lease areas combined with the existing leases in this region have insufficient capacity to meet the Central Atlantic state planning requirements for offshore wind energy.

The primary purpose of this section is to assess the technical challenges of offshore wind energy development in the ultradeep Call Areas E and F. Table 3 shows the depth range for the six BOEM Call Areas of Central Atlantic 1 planning. In most coastal locations, the continental shelf makes a steep drop after the 60-m isobath (about 35 nautical miles from shore) and levels off around a depth of 2,600 m, where draft wind energy areas E and F are located.

Table 3. Depth Range for Central Atlantic 1 Call Areas

Draft Wind Energy Area ID	Maximum Depth (m)	Minimum Depth (m)	Average Depth (m)	Technology
A	47	27	39	Fixed bottom
B	39	22	30	Fixed bottom
C	129	25	40	Fixed bottom
D	81	17	38	Fixed bottom
E	2,638	780	2,088	Ultradeep floating
F	2,620	1,489	2,208	Ultradeep floating

These areas are not yet part of any auction planning; however, these water depths, referred to in this report as “ultradeep,” represent unexplored design space for offshore engineering. Unfortunately, there are no viable sites in the Central Atlantic 1 study area where water depths for conventional floating wind energy technology can be found (e.g., 60–1,300 m). In this section, we describe the state of the technologies that could be deployed in these areas.

5.2 Global Offshore Wind Technology Overview

The total global pipeline capacity for offshore wind energy was assessed to be over 428 GW at the end of 2023. This amount includes the 68 GW of projects that are currently operating globally but also 38 GW that are under construction, 80 GW awaiting permitting approvals, 28 GW with site control, and over 214 GW in the early planning stage. Most of the 68 GW of installed capacity uses fixed-bottom foundations in water depths less than 60 m with about 211 MW of floating wind installed so far. However, the project pipeline for floating wind has grown exponentially over the past few years, reaching over 100 GW, but most of the projects are still in the early planning stage. Floating costs are significantly higher than fixed-bottom technology, but most of the cost differential can be attributed to the fact that floating wind has not yet reached commercial scale. That scale allows developers to leverage the vast efficiencies provided by commercial volume production, which drives industry learning and lower costs. Based on developer announcements, commercial-scale floating wind energy projects (greater than 500 MW) are expected to begin operations by 2026, as indicated by the sharp rise in deployment shown in Figure 17, with over 14 GW reaching commercial operations by 2029.

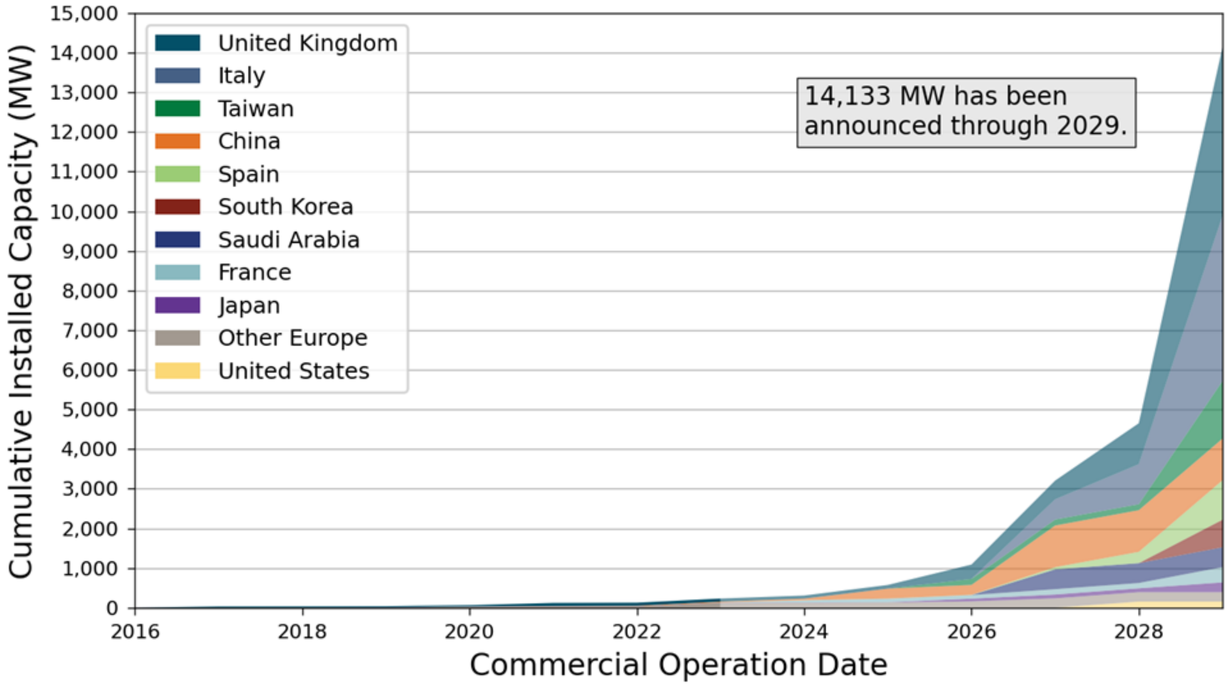


Figure 17. Cumulative floating offshore wind capacity by country based on announced commercial operation dates through 2030. *Image by NREL*

5.3 Fixed-Bottom Technology Overview

Although monopile foundations have been selected for all offshore wind energy projects in the existing shallow lease areas in the Central Atlantic (20- to 40-m depth range), about a third of the seafloor in the two lease areas of the current FSN (A-2 and C-1) are in water depths greater than 40 m, with 60-m depths at the eastern boundary of C-1. As shown in Figure 18, European industry experience has progressed monopile suitability to increasingly larger wind turbine sizes, but beyond 40 m some developers are choosing jackets as the preferred substructure (Gavin 2019).

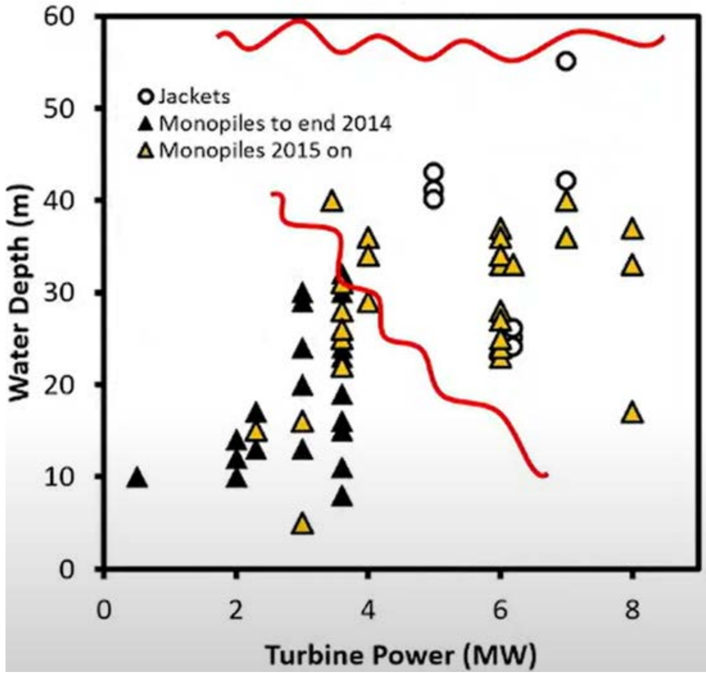


Figure 18. European fixed-bottom offshore wind foundation experience has progressed monopile suitability to ever-larger wind turbine sizes and water depths. *Figure from Gavin (2019)*

This industry experience is consistent with NREL's 2016 study that compares the cost of monopiles with alternative foundation substructures. The study found that pin-piled jackets supporting the NREL 5-MW reference turbine were more economical than monopiles in water depths greater than 40 m (Damiani et al. 2016).

The world's deepest fixed-bottom offshore wind energy project to date is the Seagreen Offshore Wind Farm located off the east coast of Scotland, in the North Sea. Seagreen comprises 114 Vestas 9.5 MW wind turbines and has a total net generating capacity of 1,075 MW. Following its initial delivery of power in August 2022, the site became fully operational in October 2023. Water depths across the project site range from 40 m to 65 m, and the seabed sediments range from silty sand and sand to gravelly sand. The wind turbines are supported by suction-bucket jackets. Each suction-bucket jacket has an average weight of 614 metric tons, which is far lighter than the equivalent monopile needed to support the same turbine in similar water depths.

The feasibility of installing suction buckets improves with deeper water, as the surrounding hydrostatic pressure prevents cavitation during installation. Suction bucket installation designer, SPT Offshore, has had two successful installations for oil-and-gas structures at a water depth of 110 m in the Gulf of Mexico and 140 m in the central North Sea. Both locations had sand/clay interbedded soil profiles similar to those in the Central Atlantic region.

In addition, in May 2024, BOEM approved a plan submitted by Beacon Wind to move forward with ocean testing of a suction bucket concept at their lease area south of Massachusetts. Their environmental analysis found no significant impacts (BOEM 2024b).

In the Central Atlantic 1 study area, there may be areas on the continental shelf that exceed the general depth limit of 60 m used to site most of the current fixed-bottom lease areas.[16] A preliminary assessment of the region suggests that there may be some unexplored ocean space with depths that exceed 60 m before the shelf drop occurs. Industry experience with fixed-bottom shallow water extends only to 60-m depths thus far but there may be lower technical risk to install fixed-bottom foundations at 80-m depth than a floating structure at 2,500 m. A detailed examination of these areas was not in the scope of this report, but we recommend that they be considered in future leasing.

5.4 Floating Technology Overview

In the Central Atlantic 1 study area, Call Areas E and F are both in water depths that will require floating platforms if leased and developed. These depths range from about 700 m to more than 2,600 m, by far the deepest waters ever identified by BOEM for possible offshore wind energy leasing. Figure 19 illustrates three types of wind turbine substructures that most floating wind platforms are based on. Each of these types evolved from floating oil-and-gas platforms.

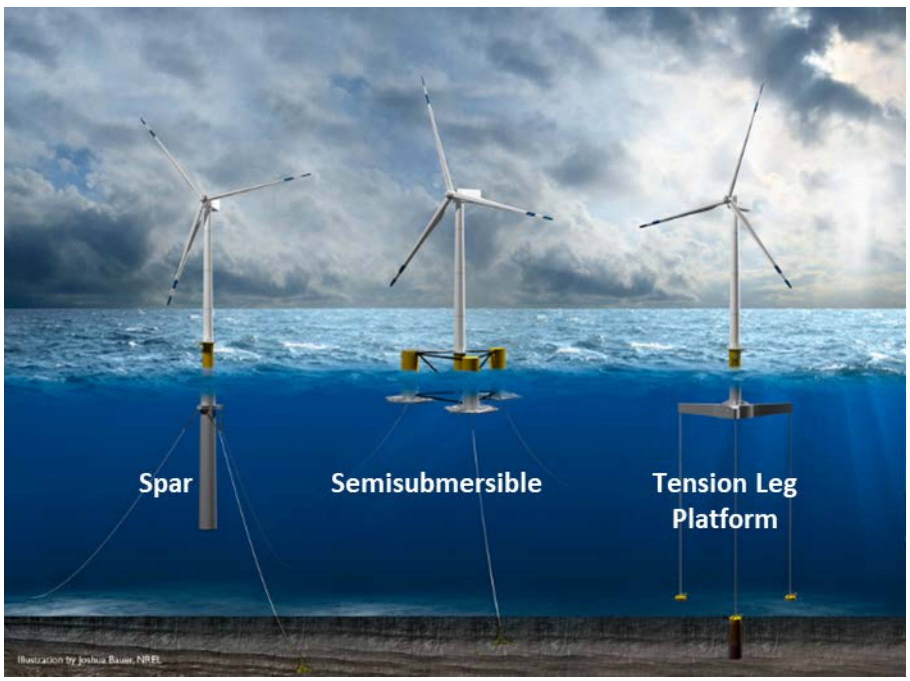


Figure 19. Substructure types for floating offshore wind systems including the spar buoy, semisubmersible, and tension-leg platform. *Illustration by Josh Bauer, NREL*

Each of these concepts has advantages and disadvantages. The semisubmersible depends primarily on buoyancy at the water plane to maintain static stability.[17] Its wide surface footprint provides stability without the mooring lines attached, and buoyancy modules distributed at the water plane provide a shallow draft that allows maneuverability in conventional ports. This

[16] The Massachusetts wind energy areas have some acreage that exceeds a 60-m depth.
[17] Static stability means that it has a general tendency to remain upright and that there are restoring forces that will keep it upright when moderate overturning forces are present.

enables systems to be fully assembled and commissioned at quayside, and towed to an open-ocean station, avoiding most of the expensive labor at sea. Semisubmersibles can generally be disconnected from their moorings at sea and towed to shore for maintenance and repair of major components like blades and generators. Most semisubmersible designs that have been demonstrated use steel, three-column construction (e.g., Principle Power). Some technology developers are designing concrete semisubmersible substructures that may be more easily adapted to the emerging domestic supply chain, both in the availability of raw materials and in suitable fabrication sites. To achieve commercial scale, the industry focus is on design for industrialization to achieve serial production, enabling a maximum number of ports.

The spar buoy, shown on the left side of Figure 19, is stabilized by ballast far below the surface. Its deep draft[18] and slender column at the water line avoid surface wave action but make it difficult to assemble in standard port facilities. Spar buoys have been deployed in multiple projects worldwide including the 30-MW Hywind 2 pilot-scale floating project off the coast of Peterhead, Scotland. Hywind was the world's first commercial floating offshore wind power plant developed by Equinor in October 2017, with a draft of about 100 m. These Hywind wind turbines were developed in Norway and assembled in deep fiords that are not a viable option in the Central Atlantic region. New hybrid spar technology is evolving, however, that uses a deployable ballast weight that is raised up to access shallow-draft ports during assembly. The Stiesdal TetraSpar (steel) and the Esteyco WHEEL (concrete) are examples of this hybrid spar technology and may be suitable for the Central Atlantic 1 Call Areas (Esteyco 2024; Stiesdal 2024).

The tension-leg platform is stabilized by mooring-line tension. It is unstable without the mooring lines unless additional buoyancy is added. These substructures also require high-capacity vertical load anchors that are more expensive and at a higher risk in the event of a tendon failure. Tension-leg platforms are very stable once installed and have the advantage of having the smallest footprint on the seabed. These platforms have not yet been demonstrated by the offshore wind industry but there are projects that are under construction at a pilot scale. One concept, the SBM tension-leg platform, was developed for the Provence Grand Large floating offshore wind farm. When completed it will provide 24 MW of power to the French grid. The wind turbines were installed in October 2023, and it is scheduled to begin commercial operations in 2024. Also, Glosten's Pelestar design has addressed many of the key deployment challenges over the past decade but has not been deployed in the ocean.

In addition to the three substructure types mentioned earlier, barge-type platforms have also been developed and deployed in some global sites using various strategies to resist excess motion from wave loading. Barges can be fabricated locally and at a reasonable cost but are challenged by wave action that can create high-nacelle accelerations and higher fatigue loads if not mitigated.

For the ultradeep Central Atlantic 1 Call Areas, the analysis completed to date would not preclude any of these types but there are significant risks and design challenges in controlling

[18] Draft is the distance the substructure penetrates below the water surface.

dynamic motions, platform stiffness, anchor circle radius, and watch circle radius at these water depths.

5.5 Ultradeep Water Technology Challenges

The technical challenges of deploying offshore wind turbines in ultradeep Call Areas E and F is our primary focus in this section. We do not intend to judge these sites on their potential to alleviate ocean use or environmental conflicts relative to those conflicts encountered closer to shore; we only aim to assess the technical challenges of floating wind energy in deeper water.

5.5.1 Ultradeep Overview

There are currently no floating wind energy projects deployed or in development in water depths beyond 1,300 m. In the United States, there are five BOEM lease areas in California that have a maximum depth of about 1,300 m and are suited for floating wind. BOEM is planning two additional floating wind lease auctions in 2024—one in Oregon and one in the Gulf of Maine where the maximum water depths are about 1,300 m and 300 m, respectively. Globally, of the 211 MW of operating floating wind energy projects, Equinor's 88-MW Hywind Tampen project is the deepest floating offshore wind project to date, with a maximum water depth of 300 m (Frangoul 2023). The deepest oil-and-gas platform installed to date is the Perdido Deepwater platform, which is located in 2,500 m of water (NS Energy 2020), but it is widely understood that the design requirements and costs of oil-and-gas platforms are different than floating offshore wind platforms.

None of the California leaseholders have submitted COPs yet, indicating that floating wind energy project designs are still at a preliminary stage with many remaining technical details to be determined. These design uncertainties include the lack of specifics on mooring and anchor configurations, installation methods, floating substation design, dynamic array and export cables, and wind farm configurations to suspend array cables in the water column. Although there is high confidence among offshore floating wind technology developers that these challenges can be resolved with engineering experience, there is little operating experience in the current fleet of operating floating wind pilot projects to inform the existing depth challenges of the California lease areas and beyond. Venturing into further depths will inevitably introduce additional cost and risk. Although hundreds of gigawatts of floating wind energy deployment is expected by 2050, the industry is still at an early stage of development (DNV 2022).

Initial site identification by BOEM found substantial use conflicts (see Section 3.0) in the shallow waters (0- to 60-m depth) of the Central Atlantic 1 region and a steep drop in water depth at the continental shelf that results in steep slopes that could preclude development at most floating sites at depths less than about 2,000 m. As a result, there are no obvious opportunities for floating wind energy areas in the more moderate depth ranges such as those found in the designated floating lease areas in California, Gulf of Maine, and Oregon.

The depths of Call Areas E and F range from 779 to 2,636 m (Figure 2), and we consider these sites to be predominately "ultradeep" water depths.[19] These ultradeep Call Areas are less attractive from a development standpoint due to the increased technical risk and cost associated

[19] Generally, we define ultradeep water as depths greater than 1,300 m.

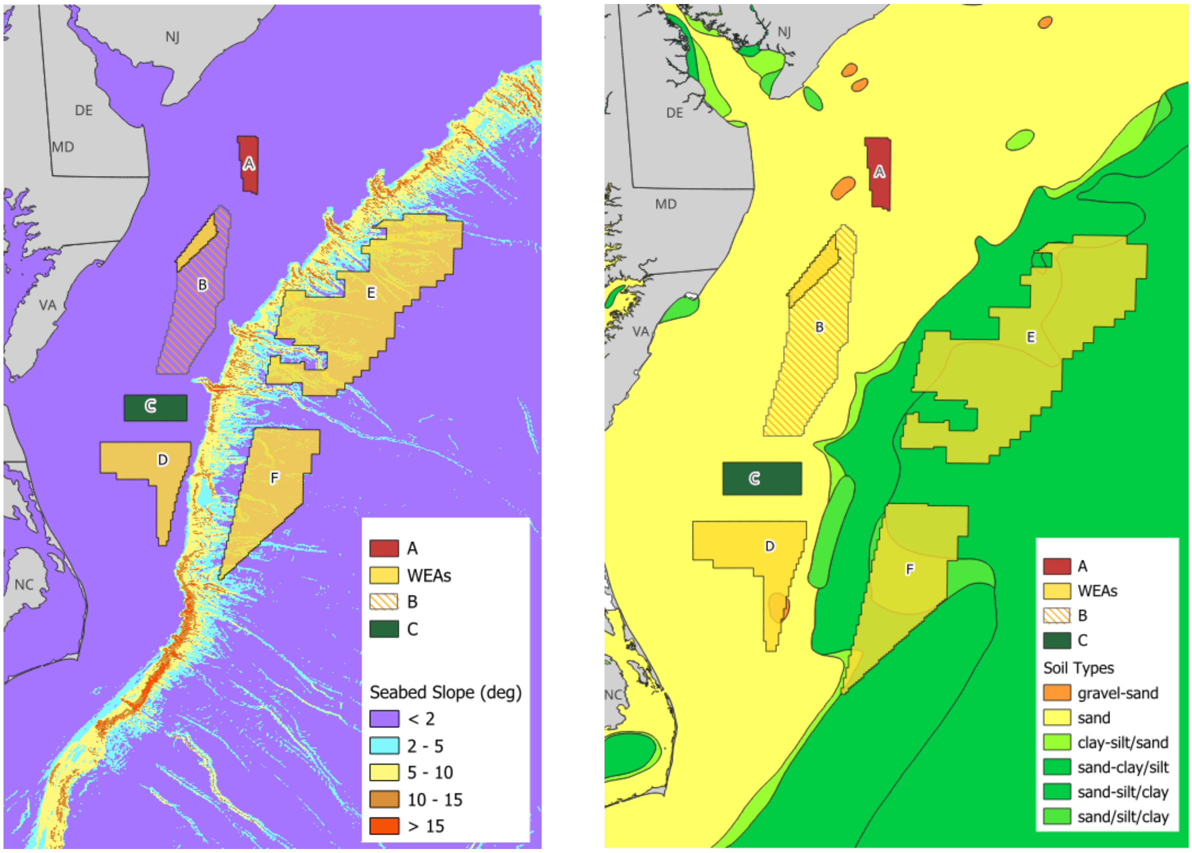
with water depths beyond current industry experience. Floating offshore wind technology evaluations for ultradeep water depths have not been given as much attention as the moderate water depths of the current lease areas. Most ultradeep concepts thus far are typically based on extrapolations from proven moderate-depth water technology solutions. In general, these designs need more rigorous evaluation before we can determine the economic or technical feasibility of offshore wind energy in ultradeep water. Catenary mooring systems, for example, are known to work in relatively shallow water depths, but have already been shown to be economically and technically less suitable in deeper waters because of the enormous mooring line lengths (many miles per wind turbine) and very large anchor circles that would be required (Cooperman et al. 2022).

5.5.2 Physical Characteristics of Ultradeep Areas

Figure 20a shows the seabed slopes over the Central Atlantic study area in degrees. In general, the area is relatively flat; however, along the continental shelf the map shows that water depth drastically decreases over a small distance, resulting in many areas along the ridge where the seabed slopes are higher than 15 degrees (Fisher, Esmailzadeh, and Fillingham 2023). Siting wind turbines over steep slopes increases the risk due to the difficulty of installing anchors, reduced anchor holding capacity, and increased risk of seabed erosion. Subsea cables may also have to be rerouted and extended to avoid areas of high seabed slope. For these reasons, most of the BOEM Call Areas are sited away from steep slopes. The best practice for placing anchors or buried cable on irregular seabed contours or high seabed slopes is to design the mooring systems to avoid those areas as much as possible using geophysical surveys of seabed slope and soil stability. If those areas cannot be avoided, the potential reductions in anchor holding capacity and changes in cable layout must be considered during the design phase.

Figure 20b shows the general seabed soil characteristics in the Central Atlantic Call Areas (Fisher, Esmailzadeh, and Fillingham 2023).

Soils are primarily sand above the continental shelf in the shallower sites. In Call Areas E and F below the continental shelf, the soils shift to a mixture of clay and silt (i.e., mud). The soil consistencies and properties are not expected to be significantly different from muddy and sandy soils in shallower waters and would not impact the suitability of common anchor types for the ultradeep waters of Call Areas E and F.



(a) (b)

Figure 20. Seabed slope (a) and soil types (b) around the Central Atlantic 1 Call Areas. *Image from NREL*

5.5.3 Qualitative Technology Assessment of Ultradeep Call Areas

We performed an initial qualitative assessment on the technical feasibility of current floating wind energy technology in ultradeep water depths. More quantitative information is required to fully understand the level of change needed for the technology to function properly in ultradeep water, but Figure 21 and the following text offer a preliminary evaluation of how the ultradeep water of Call Areas E and F might affect current floating offshore wind energy technology decisions. These assessments are based on NREL's expert opinion, considering the known technology limits of floating wind mooring and cable systems, the increased complexity of installation and maintenance logistics, and the degree of knowledge gaps that were encountered. Technologies classified as needing a "high level of change" are associated with higher risk and uncertainty because the required design modifications are not fully understood.

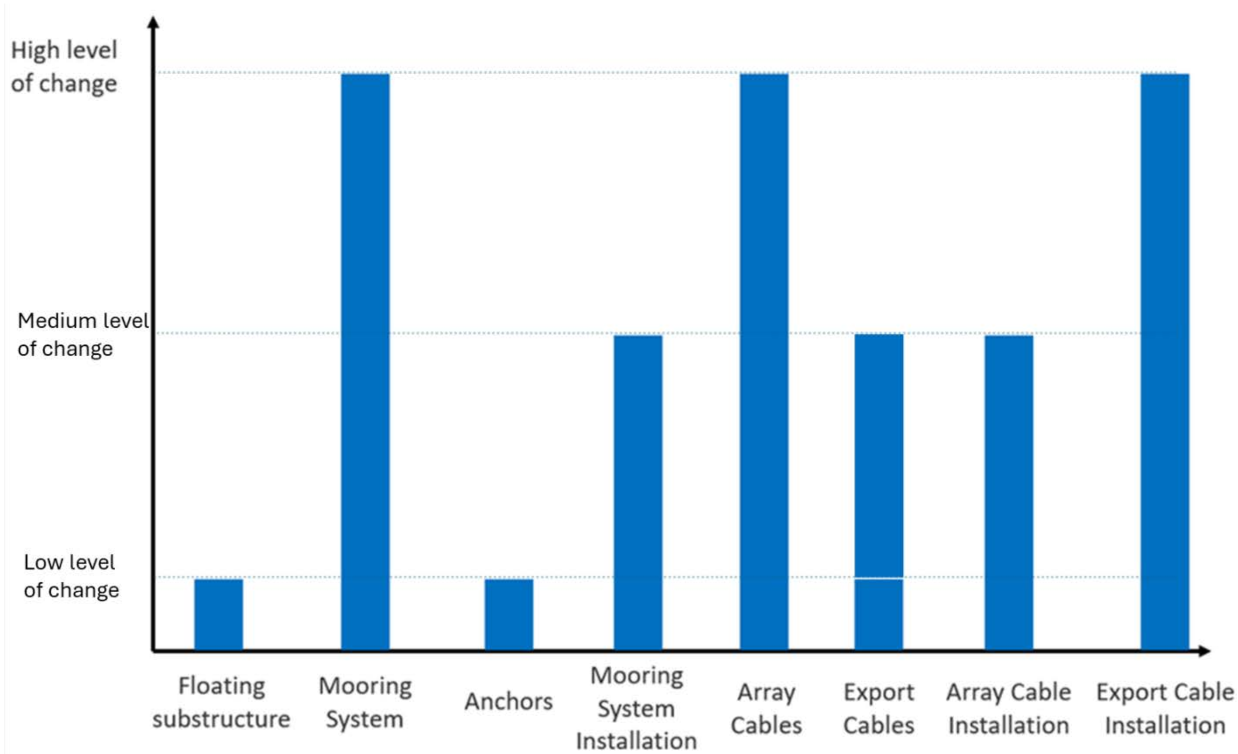


Figure 21. Preliminary qualitative assessment of floating offshore wind technology categories in ultradeep water depths

A qualitative discussion of each of the technology types that make up a floating support structure shown in Figure 21, is provided as follows.

5.5.3.1 Floating substructures

Floating substructure designs in ultradeep water are not expected to require a high level of upgrade or redesign to operate in ultradeep water depths. They may experience higher loads due to incrementally higher extreme environmental conditions (e.g., potentially higher hurricane risk) or higher mooring loads due to softer dynamic response, but those load differences are not expected to significantly impact the size or design of the floating substructure. This general comment would apply to most of the common substructure types shown in Figure 19.

5.5.3.2 Mooring systems

The mooring system design for floating offshore wind in ultradeep water will require some of the biggest design modifications. Most mooring systems will increase in cost, weight, and exhibit larger anchor footprints (anchoring radii) and watch circles[20] as the water depth increases. As mentioned earlier, catenary mooring systems that use mostly heavy chain moorings with horizontally loaded anchors have the largest anchor footprint for a given water depth and will not be a reasonable option in ultradeep waters. Taut mooring systems, which use synthetic fiber rope mooring lines, have lower costs, weights, and seabed footprints, making them more attractive.

[20] A watch circle is the envelop of allowable movement of the floating platform on the surface of the water that can be shaped like a circle depending on the wind direction.

Tension-leg platform mooring systems would also be attractive as their smaller footprint does not increase with water depth. However, the increase in the mooring line lengths for taut or tension-leg-platform mooring systems due to the water depth significantly reduces the mooring system stiffness—a crucial component to the platform's stability—and would require increases in mooring line diameters or the use of new, stiffer synthetic materials to compensate.

Therefore, in addition to the longer mooring line lengths, it is likely that the cost per unit length of mooring line would significantly increase. The mooring system watch circles would also increase with the longer mooring lines, which could present significant challenges affecting the wind turbine position within the floating array, the design of the dynamic array cables, and for vessel navigation near the turbines. Alternative mooring configurations, such as shared mooring systems,[21] may be able to help mitigate some of these design issues by reducing the increase in mooring line length, as shared mooring lines lengths are primarily determined by wind turbine platform spacing (Hall et al. 2022).

5.5.3.3 Anchors

Anchor types are not expected to be affected significantly by water depth. Preliminary assessments indicate soil types in Call Areas E and F are compatible with common anchor types. Mooring loads could increase incrementally due to changes in the mooring system design, but the anchor types can be upsized to properly account for the larger loads. Anchors can also be designed and installed to account for steeper seabed slopes, but if they are too steep, the mooring/anchor system layout can usually be adjusted to avoid those local areas of high slopes. A larger concern is the potential for seabed instability due to higher slopes, which would add significant uncertainty to the anchor loadcarrying capability.

5.5.3.4 Mooring system installation

The installation method of the anchors and mooring system may change in ultradeep water depths, assuming extrapolations from moderate water depths remain valid. The installation time would likely increase with water depth, as the anchor circle and the length of mooring line to be carried by a vessel increase in size, which can increase the total number of trips the installation vessel makes from the port to the site. The precision of anchor placement and mooring line position may decrease in ultradeep water. New technologies like subsea installation equipment, remotely operated vehicles, and torpedo anchors show future promise in potentially offsetting some of these installation challenges.

5.5.3.5 Array cables

In ultradeep water, the distance between wind turbines would typically be smaller than the water depth. It will likely be necessary to design a network of dynamic array cables suspended in the water column, rather than burying array cables in the seabed, to shorten the cable length by many miles. Fully suspended dynamic cables between platforms could potentially introduce new dynamic complexities, reduce cable life due to fatigue, and add new considerations for fishing activities. Fully suspended array cables may also be implemented in shallower sites like the California leases for the same reason, but the motivation for a fully suspended dynamic array

---

[21] Shared mooring systems enable multiple floating platforms to use the same mooring line, which could reduce the number of mooring lines that extend all the way to the seafloor.

cable network increases as the water depth increases. Because a suspended cable network will exhibit complex motions under a wide range of external conditions, array cable designs in ultradeep water will require more careful design modeling and front-end planning to minimize failures and unforeseen risks.

5.5.3.6 Export cables

Design practices are still being developed for export cables in moderate water depths and will require further upgrades to function and survive in ultradeep water depths, but the risks and uncertainty are not well-understood. In addition, dynamic, high-voltage cables and floating substations are still relatively unproven at any depth. The performance of subsea electric cables may have depth design limits due to the greater hydrostatic pressures beyond depths in which the subsea cable industry has experience. These limitations are especially true for cable repairs, and for joints and splices where hydrostatic pressure can cause premature failures. For ultradeep water, cable depth requirements will need to be specified in the design and tested in an accredited facility before the cable can qualify for operation.

Call Areas E and F are slightly under 100 km from shore, whereas the other shallower draft wind energy areas (e.g., A and C) are between 30 and 60 km from shore. The required length of the export cables may increase further due to water depth and longer distance routes to avoid steep seabed slopes, sensitive environmental habitats, and other hazards. Generally, if the distance from the offshore substation to the point of interconnection exceeds 80 km, a high-voltage direct current (HVDC) transmission system is warranted to lower transmission losses and cost (Bredenkamp 2023). The longer distances to Call Areas E and F indicate that HVDC transmission systems may be the best option, but floating HVDC substations have not been demonstrated globally yet and introducing them would increase risk and cost.

5.5.3.7 Array cable installation

The array cable installation method is not expected to change significantly moving from 1,300-m depths to ultradeep waters because it is anticipated that array cables will be suspended in the water column for both 1,300-m depths and ultradeep water. However, longer vessel transit time could add incremental increases in cost to install in deeper waters farther away.

5.5.3.8 Export cable installation

The export cable installation logistics could be significantly altered in ultradeep water. For example, the longer, heavier cable extending to the seabed in ultradeep water may exceed the capacity of conventional cable-laying vessels. Therefore, it may be necessary to develop larger cable-laying vessels or modify existing ones to increase cable weight capacity. Alternative designs for cable configurations and/or new installation methods may also be needed.

5.5.3.9 Supply chain

Other than the specific technology modifications described earlier, the supply chain and infrastructure requirements for floating offshore wind systems in ultradeep waters may also present some significant challenges. The primary challenge is that the length of mooring line needed is proportional to the water depth. If the water depth is approximately double, twice as much mooring line would need to be manufactured and installed for the same size wind farm. In some cases, the size of these mooring lines may also need to be increased to provide higher stiffness to the mooring system. Cable-laying and mooring system installation vessels would need a commensurate increase in deck space to accommodate this greater length or require more vessel trips to the installation site. Similarly, port facilities would need to accommodate the extra volume of mooring lines and cables.

5.5.3.10 Design Tools

We examined the models and design tools used for loads analysis and design simulations of floating offshore wind arrays. The current suite of tools is expected to perform adequately for ultradeep water designs. Most of the modeling features other than the mooring system are independent of water depth. The mooring and cable system modeling tools can be used for any depth but may lose some fidelity in the nonlinear elasticity of synthetic fiber rope mooring lines at greater depths. Otherwise, the modeling tools are not expected to require major upgrades for ultradeep water. The biggest concern is that there is likely to be significantly higher exposure to dynamic loading, such as vortex-induced vibrations, under a wide range of ocean conditions. The life expectancy of the cables depends on properly accounting for dynamic loading at every section.

The technical feasibility of floating offshore wind in ultradeep waters, like Call Areas E and F, is uncertain because are many unanswered questions about extrapolating the existing technology to deeper water and very little experience. Further research should be conducted to investigate and demonstrate technology solutions, and significant industry experience should be obtained from floating wind turbines deployed in California, the Gulf of Maine, and Oregon to help mitigate the technical and economic risks in ultradeep water. Development of Call Areas E and F may be premature based on the status of the technology at this time, but long-term development at these depths could ultimately be technically feasible with the added cost still to be determined.

5.6 Hurricane Risk

5.6.1 Overview

Hurricanes are common along the Eastern Seaboard of the United States, the Gulf of Mexico, Hawaii, Puerto Rico, and the Pacific Islands. The frequency and severity of hurricanes tends to increase from north to south. Most conventional Class 1 offshore wind turbines[22] can withstand the winds from a Category 2 hurricane but Category 3 and above may require additional design upgrades (Mudd and Vickery 2023). The severity of the maximum strength hurricane expected at most lease areas in the North Atlantic are less than the design load limit states[23] based on current practices specified by the International Electrotechnical Commission ([IEC] 2019a, 2019b). As the U.S. offshore wind energy industry moves south into the Central Atlantic, South-Atlantic, and Gulf of Mexico, the hurricane hazard becomes more significant. In addition, the currently accepted design practices for offshore wind turbines in hurricane regions are changing. These changes require wind turbine manufacturers and developers to adapt their turbine and support structure designs as new information about climate change and the complexities of hurricane

[22] The governing standards for offshore wind energy are developed by the International Electrotechnical Commission (IEC) under Technical Committee 88. Under IEC-61400-01, wind turbines design categories are divided into classes based on the severity of the external conditions they are exposed to.
[23] The “limit state” is the maximum load the wind turbine is allowed to experience for a given load case.

turbulence become better understood. This section describes the status of offshore hurricane design in the context of the Central Atlantic study area.

The current best practices for offshore wind turbine hurricane design are covered by American National Standards Institute/American Clean Power OCRP-1-2022, *Offshore Compliance Recommended Practices, Edition 2* (American National Standards Institute 2022). This document is a comprehensive consensus-based roadmap for the design of offshore wind plants in the United States. It refers to more than 200 standards and guidelines and covers the basic details for offshore wind system design. However, as the first commercial projects are being installed in the United States in 2023 and 2024, the best practices for hurricane design are evolving faster than the standards. New turbine system designs are incorporating features such as IEC Tropical Class (T-Class) turbine design ratings, battery back-up systems during loss of grid, and strengthened support structures adjusted per Gulf of Mexico oil-and-gas standards; these features that were once considered optional are now becoming standard for equipment installed in the United States. With these new upgrades, the current practices and standards used in the north Atlantic appear to be sufficient for the Central Atlantic region, but developers should remain vigilant as new information becomes available. There is strong evidence that some regions farther south will need additional upgrades and it is not yet understood exactly where the geographic boundaries (corresponding to more severe external conditions) will be delineated (Fuchs 2023).

5.6.2 Hurricane Technology Design

Offshore wind turbines and their support structures are not required to survive every conceivable hurricane that might occur. That would be impossible because the most destructive hurricanes are very rare and designs to withstand them would be too expensive to be practical. The extreme design load cases for a wind turbine were defined by IEC based on the extreme sustained 10-minute averaged maximum winds measured at hub height, otherwise known as the reference wind speed, V_{ref}. For a Class 1 turbine, V_{ref} is set at 50 m/s (111.0 miles per hour), but for a T-Class turbine, V_{ref} is set at 57 m/s (127.5 miles per hour). The extreme design load cases are derived from V_{ref}. The most important example is the requirement to withstand a 3-s maximum gust, which is calculated by multiplying V_{ref} by a "gust factor" set at 1.4, yielding a 3-s gust requirement of 70 m/s or 80 m/s, respectively. Standard design practices require a statistical estimation of how often these maximum wind speeds are likely to occur at a specific location. This is commonly referred to as the "return period." For wind turbines not impacted by hurricanes, the return period corresponding to the "limit state" reference wind speed is defined to be 50 years. In hurricane-impacted areas like the U.S. East Coast and Gulf of Mexico (including the Central Atlantic region), additional design conditions must be met.

In hurricane-prone regions, there is a much greater probability that the limit state design conditions may occur well before the 50-year return period. As a result, the most recent edition of IEC 61400-3-1 added Annex I, which provides recommendations for wind support structure design augmentations in tropical cyclone regions. These additions are based on American Petroleum Institute (API RP 2A) standards from the proven industry practices founded in the Gulf of Mexico. Annex I is an adaptation of a "robustness check," which requires assessing not only the 50-year storm but also the 500-year storm on the support structure. The unfactored characteristic loads from the 500-year storm relate to the hazard curves (Figure 22). The steepness of the slope of the region-specific lines extending from the design return period of 50 years to the 500-year robustness checkpoint, is sometimes referred to as the coefficient of variation, which is an indicator of how much more severe storms are likely to be after reaching the 50-year limit-state design return period. Offshore wind lease areas along the Atlantic Seaboard and in the Gulf of Mexico tend to experience higher coefficient of variations than the North Sea, for example, as shown in Figure 22. As a result, the normal safety factors prescribed by the standards may not be sufficient.

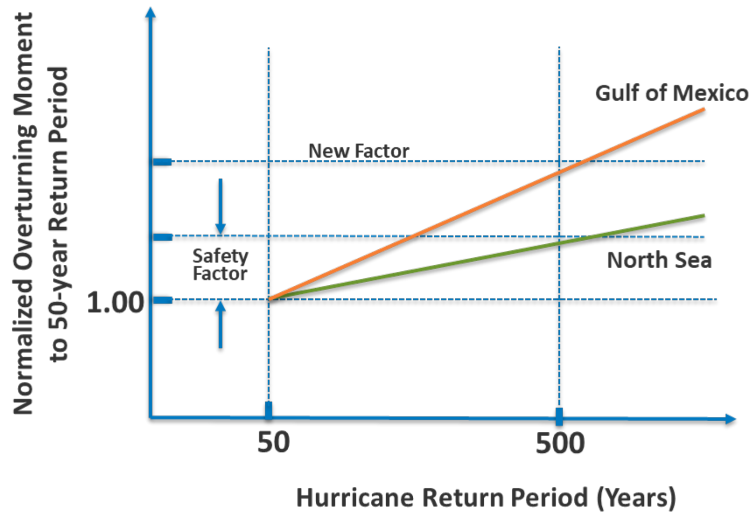


Figure 22. Conceptual hazard curves based on the 50- and 500-year return periods. Image adapted from API RP-2A

Figure 22 shows that (conceptually) in the Gulf, a steeper hazard curve exceeds the design safety factor for the 500-year event, which would indicate that increased strength would be needed in some components. It has been shown that other regions such as in the Central Atlantic may have even higher coefficient of variations than the Gulf of Mexico, making the 500-year event more significant even though the 50-year storms may be less intense by comparison (Hall 2015). Consequently, although Annex I is optional in the IEC 61400-3-1 standard, we recommend that it be mandatory for leases areas on the eastern Atlantic in the United States, including the Central Atlantic.

5.6.3 Hurricane Probability and Intensity

Knowledge of the extreme external characteristics at a particular site is just as important as the design methods used to withstand them. Hurricane probability and intensity cannot be extrapolated from extra-tropic storm records. Instead, they require unique statistical models to predict their occurrence and intensity at a particular site. The state-of-the-art models use synthetic hurricanes derived from historic hurricane data collected over many years, as shown in Figure 23. These hazard models use thousands of synthetic hurricanes to estimate the return periods in terms of the Saffir-Simpson hurricane categories, which are more familiar to the public than the IEC standards (National Hurricane Center 2024).

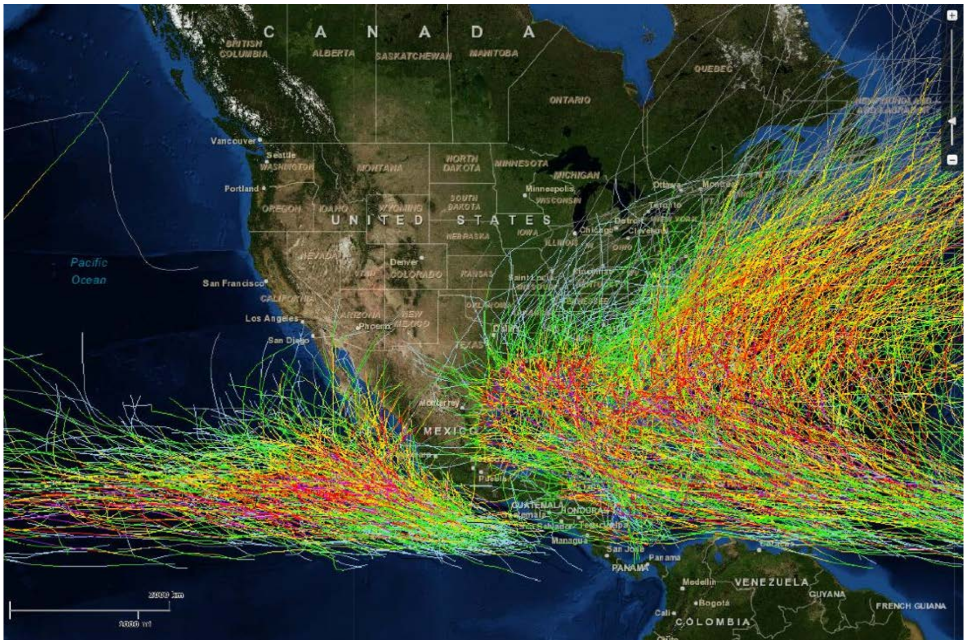
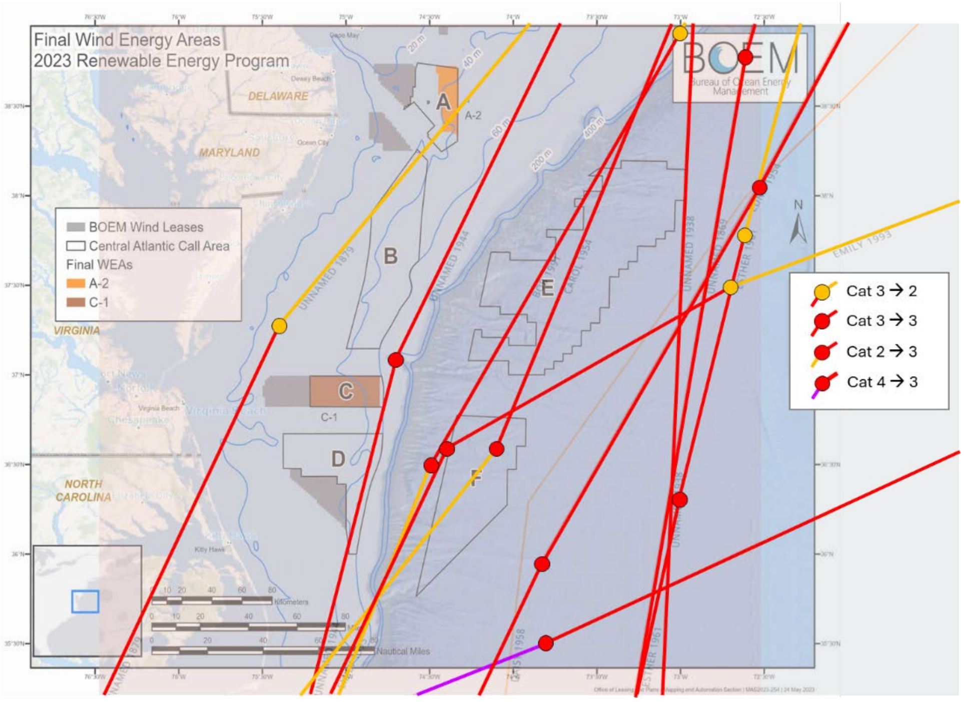


Figure 23. Synthetic hurricane track models like this one are used to determine the 50-year and 500-year return periods used for hurricane design. *Figure from NOAA (2012)*

Outside the Gulf of Mexico, the estimation of hurricane hazards has focused on coastal regions for assessing risk to land-based structures and buildings when storms make landfall. In the Central Atlantic region, there is no validated database of hurricane hazards that is publicly available; however, offshore wind energy developers are currently assessing these conditions using available tools, such as CLIMADA and ARA HurLoss (Mudd and Vickery 2023). An accurate depiction of the extreme conditions will likely be a focus for BOEM and the Bureau of Safety and Environmental Enforcement (BSEE) in future site assessments of offshore wind lease planning where hurricanes are prevalent.

Climate change has added more uncertainty to these hurricane hazard model predictions because offshore wind turbines must be designed to withstand the extreme conditions, they will experience thirty years or more from when they are installed rather than what the models predict today. With warming sea-surface temperatures, tropical storms are expected to increase in intensity and frequency, and travel farther northward. As a result, hazard models must be upgraded to consider these changing statistics.

Another concern for the Central Atlantic region is how hurricane intensity and frequency will change with distance from shore. Normally, we think of north-south variations but geographic features such as Cape Hatteras shelter coastal regions from storms traveling northward. Although this effect has not yet been quantified, it is a subject of current investigation between BSEE and NREL. Figure 24 shows the tracks from historic hurricanes of Category 3 or greater as reported by NOAA (NOAA 2023). As expected, these storms are rare but could be damaging to wind turbines in these regions if the designs are not upgraded to withstand them. Although this NOAA dataset is not statistically valid, it does indicate that the risk could potentially be greater in Call Areas E and F that are farther from shore.



Source: https://coast.noaa.gov/hurricanes

Figure 24. Historic track records for hurricanes of a Category 3 or greater passing through Central-Atlantic 1 Call Areas during the 173-year period from 1851 through 2023.
Figure adapted from NOAA Office for Coastal Management (2024)

5.6.4 Hurricane Load Mitigation and Future Research

Current design practices for hurricane design of offshore wind turbines are evolving faster than the design standards. For the Central Atlantic region, we recommend that offshore wind energy projects adopt the optional features described in the IEC standards that include T-Class wind turbine design ratings, battery back-up systems during loss of grid, and support structures built to the specification of Annex I in IEC 61400-3-1. Many wind turbine manufacturers and developers are already incorporating these features into their facility designs. Questions remain about the reliability of the battery back-up systems and the additional loading the turbine might experience if the backup system fails. On-going research indicates that the loading caused by extreme cross winds resulting from an incapacitated yaw drive could be significantly higher and should be avoided (Fuchs 2023).

New research programs are now underway to improve the knowledge base and physical understanding of hurricane turbulence. Generally, the assumption that extreme loading can be characterized by a 3-s gust is not well-founded and there is evidence that other characteristics such as wind shear variations and wind veer may help define extreme external conditions but are not yet represented in the current design practices. To address this, multiple research initiatives are underway to develop high-fidelity models that characterize the complex turbulence within typical limit state hurricanes. Argonne National Laboratory, Pacific Northwest National Laboratory, and the NREL are engaged in a DOE-sponsored program in hurricane research investigating methods of high-fidelity mesoscale modeling of hurricanes and coupling to microscale. In addition, NOWRDC is sponsoring research funded by Massachusetts, New Jersey, and Maryland to address these concerns as they affect the design of projects adjacent to their state borders. BSEE is also sponsoring research at NREL to investigate the requirements for battery backup systems on offshore wind turbines. NREL is coordinating these efforts and focusing them on developing engineering tools that better characterize the design conditions and modifying the design practices if necessary.

6 Central Atlantic Supply Chain

6.1 Port Development

6.1.1 Current Ports Supporting Fixed-Bottom Offshore Wind Energy Projects

The Central Atlantic region currently has two operational marshalling ports specifically designed to support the staging and deployment of fixed-bottom offshore wind energy, namely Portsmouth Marine Terminal in Virginia, near the entrance to the Chesapeake Bay, and the New Jersey Wind Port, where the Delaware River meets the Delaware Bay. There is also an offshore wind fabrication port at Sparrows Point in Baltimore, Maryland. These ports are mapped in Figure 25.

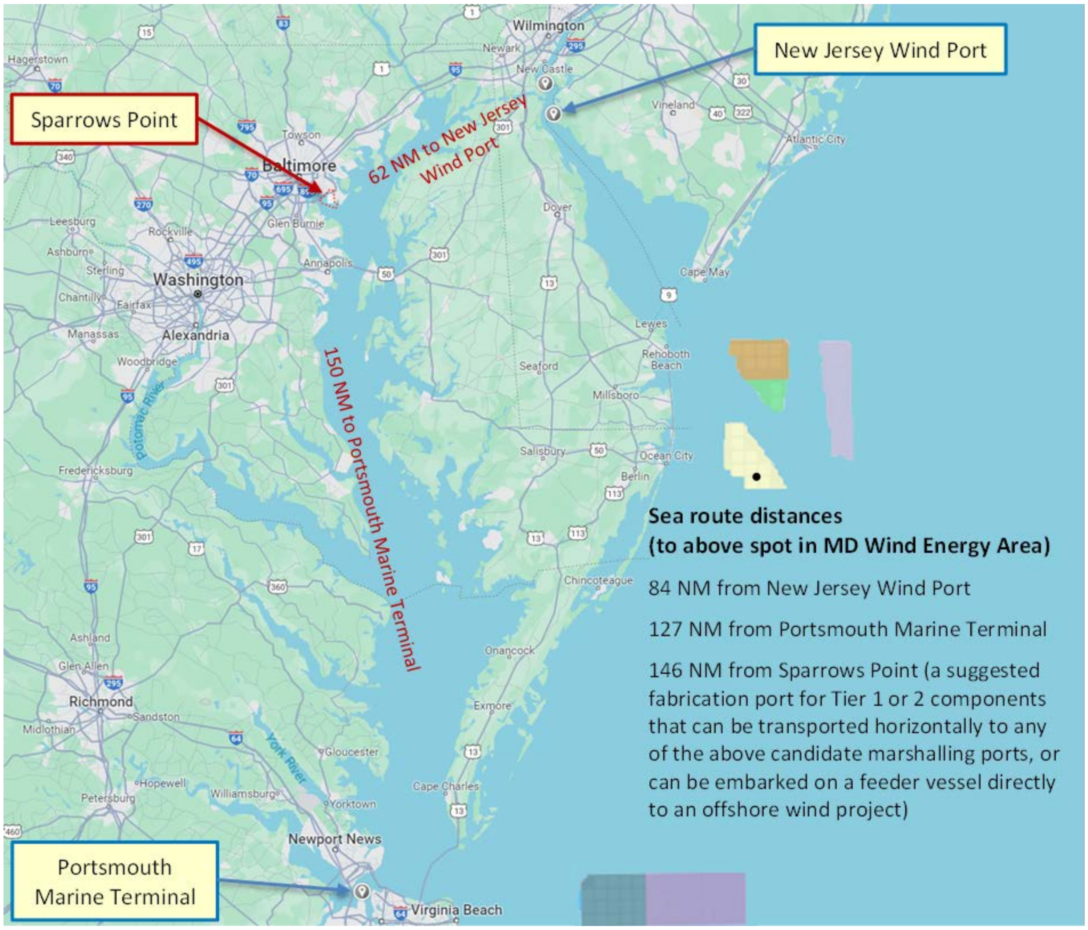


Figure 25. Central Atlantic map of two marshalling ports and one fabrication port supporting four existing fixed-bottom offshore wind energy projects and two proposed lease areas. *Figure from George Hagerman, NREL*

Table 4 indicates the sea route distances from the two Central Atlantic marshalling ports to existing Mid-Atlantic wind energy lease areas, which are all fixed-bottom projects.

Table 4. Key Features of Central Atlantic Marshalling Ports.
Sources are Shields, et al (2022) and the NOAA Office of Coast Survey (2019)

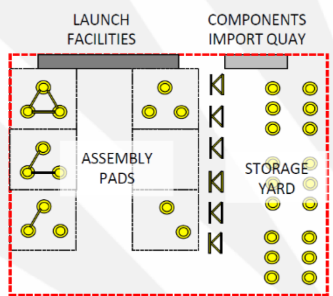
Port Name	State	Laydown Area (acres)	Quayside Length (m)	Alongside Depth (m)	Sea Route Distance (nautical miles) to: NJ Wind Energy Area	Maryland Wind Energy Area	Kitty Hawk
New Jersey (NJ) Wind Port	NJ	70	854	11.5	104	84	218
Portsmouth Marine Terminal	VA	287	1,079	13.1	197	127	69

6.1.2 Port Requirements for Floating Offshore Wind Energy Projects

Both floating and fixed-bottom marshalling ports have the same requirements for storage and staging of Tier 1 components, namely blades, nacelles, and tower sections. The biggest difference is the floating project requirement for short- and long-term wet storage of floating substructures and fully integrated turbine-substructure units, as compared with land storage of foundation substructure components for fixed-bottom projects (e.g., monopiles and transition pieces). Two types of ports are needed for floating offshore wind energy project deployment shown in Figures 26 and 27.

Steel manufacturing/assembly port

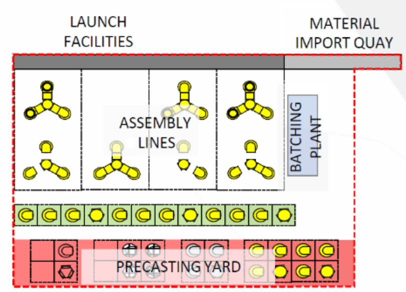
A steel substructure assembly port, which can be further away from project sites, is an intermediate facility used to construct steel substructures before being transported to an integration site.



KEY REQUIREMENT[1]	17MW	20MW
Entrance Width (m)	120	130
Air Draft (m)	50	50
Access Channel Width (m)[1]	230	260
Access Channel Water Depth (m below MLWS)	13.0	14.5
Landside Area (ha)	30	40
Launch Quay Length (m)[2]	275	275
Launch Berth Water Depth (m below CD)	8.5	8.5
Assembly Duration for Substructure (wks)	6	6
Number of Assembly Pads Required (No.)[3]	6	6

Concrete manufacturing/assembly port

A concrete manufacturing port, which can be further away from project sites, is a facility where concrete substructures are manufactured and assembled.



KEY REQUIREMENT[1]	17MW	20MW
Entrance Width (m)	120	130
Air Draft (m)	50	50
Access Channel Width (m)[1]	230	260
Access Channel Water Depth (m below MLWS)	13.0	14.5
Landside Area (ha)	30	40
Launch Quay Length (m)[2]	520	560
Launch Berth Water Depth (m below CD)	8.5	8.5
Manufacturing Duration for Substructure (wks)	13	13
Number of Assembly Lines (No.)[3]	4	4

Figure 26. Manufacturing/assembly port layout alternatives for steel and concrete floating substructures, with key requirements given for two different wind turbine sizes (17 MW and 20 MW). *Figure from RenewableUK (2023)*

- **Manufacturing/assembly ports** are located on navigable waterways, receiving raw materials via road, rail, or vessels, producing larger components in the offshore wind supply chain, and loading these components onto vessels for waterborne transport to a staging and integration port as shown in Figure 26. Manufacturing/assembly ports for wind turbine components (e.g., blades, nacelles, and tower sections) are identical for both fixed-bottom and floating offshore wind projects and require sufficient land area to temporarily store finished components until they can be moved by vessel to the staging and integration port. Manufacturing/assembly ports for floating substructures may be designed for either steel or concrete fabrication and assembly.

- **Staging and integration ports** receive and store wind turbine components on shore, in preparation for assembling them on floating steel or concrete substructures. Fully assembled units are precommissioned at quayside and then moved to wet storage, ready for towing to the offshore project lease area. The staging and integration port can also allow for heavy maintenance, such as replacing a nacelle or blade, which cannot be performed in the offshore project lease area. The typical layout and key requirements for a staging and integration port are shown in Figure 27, which also shows how four different types of wet storage are distributed between the manufacturing/assembly port and the staging and integration port.

- **Wet storage** is a critical element of the floating offshore wind supply chain, and is needed to de-risk deployment in the following process steps:

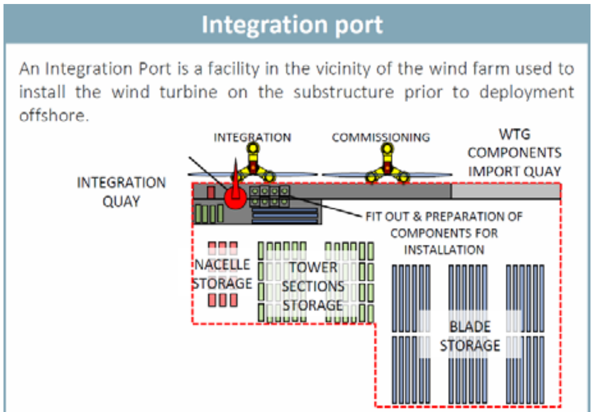
    - **Buffer storage of substructures at the manufacturing/assembly port**. After launching the completed floating substructures, short-term storage may be required until suitable weather, tidal, or navigational channel access is available.

    - **Long-term (seasonal) wet storage of substructures**. To compensate for differences between year-round substructure production at the manufacturing/assembly port and 5−7 months of quayside wind turbine assembly at the integration and staging port during milder weather.

    - **Buffer storage of substructures at the integration and staging port**. To offset short-term interruption of floating substructure delivery during the summer assembly season.

    - **Buffer storage of fully assembled units at the integration and staging port**. Short-term storage of a few completed units may be required until suitable weather windows are available for safe tow-out and installation at the offshore wind energy project site.

Wet storage of substructures requires protected water areas of suitable depth for temporary moorings. Fully assembled units will require more room to enable safe spacing between rotors.



KEY REQUIREMENT[1]	17MW	20MW
Distance from Wind Farm (km)	265	265
Entrance Width (m)	120	130
Air Draft (m)	Unrestricted	Unrestricted
Access Channel Width (m) [1]	230	260
Access Channel Water Depth (m below MLWS)	15.0	16.5
Landside Area (ha)	20	25
Integration Quay Length (m)	400	440
Integration Berth Water Depth (m below CD)	15.0	16.5

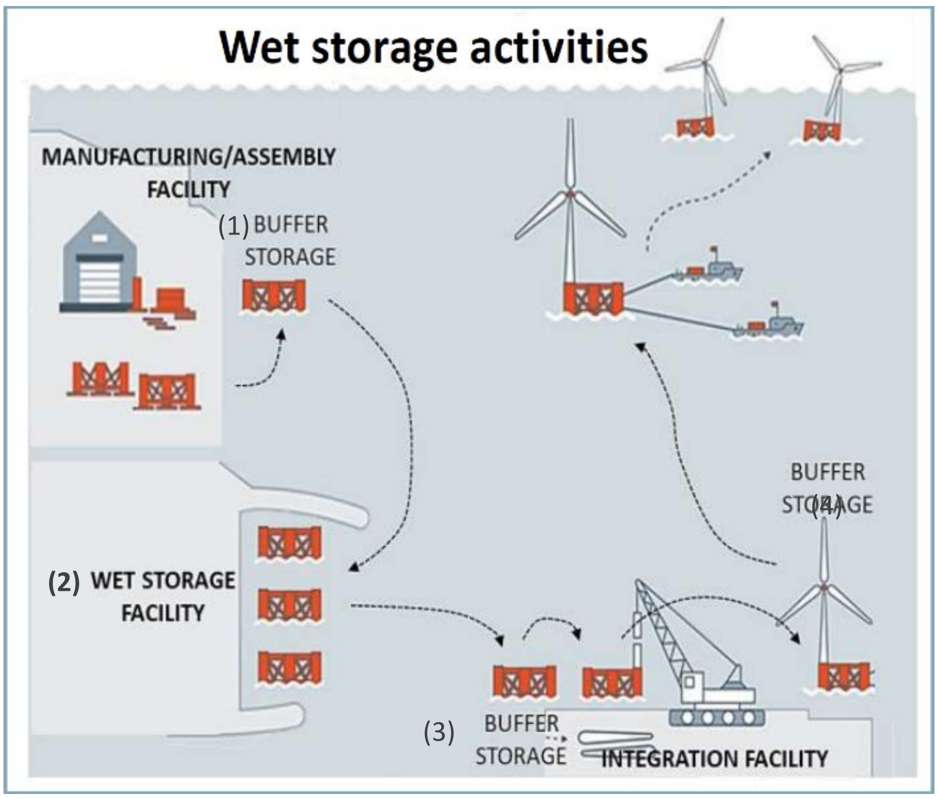


Figure 27. (Top) Integration and staging port layout, with key requirements given for two different wind turbine sizes (17 MW and 20 MW). (Bottom) Four different types of wet storage. *Figure from RenewableUK (2023)*

The Sparrows Point manufacturing port in Maryland has wide channel connections to many neighboring water bodies and marine terminals in the Baltimore area, most of which could provide Type (1) wet storage of completed floating substructures produced at Sparrows Point. Likewise, New Jersey Wind Port and Portsmouth Marine Terminal have wide channel connections to many neighboring water bodies that could provide the other three types of wet storage listed earlier. State and federal environmental reviews would be required before those could be developed as wet storage areas.

6.2 Vessels

6.2.1 Vessel Demand

The offshore wind vessel requirements in the Central Atlantic region will be influenced by varying installation methods that change with the depth-dependent technology requirement. Designated lease areas and leases proposed for sale in this region are currently suitable for fixed-bottom foundations, requiring a tailored fleet of vessels. On the other hand, Central Atlantic 1 ultradeep Call Areas E and F would require floating offshore wind turbines, demanding a fleet specifically configured for deeper water depths. American Clean Power estimates the 2- to 3-year installation phase for a typical fixed-bottom offshore wind project necessitates a minimum of 25 vessels (American Clean Power 2021). An average estimate derived from four fixed-bottom projects shown in Table 5 provides insights into varying vessel requirements, guiding the planning of future fixed-bottom offshore wind energy projects.

Table 5. Average Vessel Needs per Installation Phase Across Four Fixed-Bottom Offshore Wind Projects (Vineyard Wind 1, New England, Atlantic Shores South, and Kitty Hawk North)

Installation Phase	Vessel Category	Average Range of Vessel Needs per Phase – Fixed-Bottom Projects
Array Cable	Anchor handling tug supply (AHTS)	1
	Cable support vessel	2
	Cable lay vessel (CLV)	1
	Crew transfer vessel (CTV)	1
	Rock dumping or scour protection vessel	1
	Safety vessel	1
	Survey vessel	1
Export Cable	AHTS	1
	Cable support vessel	2
	CLV	2
	CTV	1
	Dredging vessel	1
	Rock dumping or scour protection vessel	1
	Safety vessel	1
	Survey vessel	1
Foundation	AHTS	1
	Feeder (barge or heavy transport carrier)	3–6
	CTV	2–4
	Heavy-lift foundation vessel	1–2
	Rock dumping or scour protection vessel	1

Installation Phase	Vessel Category	Average Range of Vessel Needs per Phase – Fixed-Bottom Projects
	Safety vessel	1
	Support vessel	1
	Tugboat	4–5
Offshore Substation	Feeder (barge or heavy transport carrier)	2
	CTV	2
	Heavy-lift foundation installation vessel	2
	Tugboat	3–4
Scour Protection	Dredging vessel	1
	Rock dumping or scour protection vessel	1
Wind Turbines	Barge	1–2
	CTV	2
	Feeder barge or vessel	2–5
	Tugboat	2–6
	Wind turbine installation vessel	1–2
Commissioning	CTV	1–3
	Service operation vessel	1

While U.S. fixed-bottom projects have documented vessel needs through COPs, there is less documentation for floating projects off California, which are much earlier in the environmental review process and therefore lack published COPs. Next, we list the primary differences in vessel needs between fixed-bottom and floating projects to help inform the planning and execution of future floating offshore wind energy projects.

A key advantage of floating offshore wind energy is that the installation of floating wind turbines requires smaller vessels that generally cost significantly less to build, and with correspondingly lower day rates. The installation of fixed-bottom wind turbines requires much larger, costly vessels such as wind turbine installation vessels (WTIVs) and heavy-lift foundation vessels that perform foundation pile driving, lift the tower, install it on the foundation, and attach the nacelle and blades to the tower. However, in floating wind, the wind turbine and floating substructure are assembled at port and towed out to the site, where anchor-handling tug supply (AHTS) vessels connect the mooring lines to the floating foundation. In comparison with a fixed-bottom offshore wind project, a floating wind project would not need the most expensive vessels, which include:

- Heavy-lift foundation vessels
- WTIVs
- Rock dumping/scour protection vessels
- Feeder barges.

Floating offshore wind projects would generally need:

- A larger fleet of small vessels including tugboats and AHTS vessels, all of which are available within the United States
- Service operation vessels and crew transfer vessels for maintenance

- A vessel spread that is prepared to operate at deeper waters and more challenging meteorological ocean conditions.

A critical constraint on vessel requirements for the U.S. offshore wind industry is the Jones Act, also known as the Merchant Marine Act of 1920. The act requires that goods transported between two U.S. points must be carried on vessels that are built, owned, and crewed by U.S. citizens or permanent residents (also known as "U.S.-flagged vessels") (Papavizas 2022). To comply with the Jones Act, the U.S. offshore wind energy industry is working to develop domestic vessel manufacturing facilities. Some companies have already begun to invest in building vessels in the United States while others are partnering with U.S. shipyards to retrofit existing vessels or construct new ones. In the short term, the U.S. vessel market will have shortages of U.S.-flagged WTIVs, and developers will solve this shortage by combining U.S.-flagged feeder barges with foreign-flagged WTIVs.

6.2.2 Vessel Supply

To comply with the Jones Act, floating offshore wind projects must use U.S.-flagged AHTS vessels. An indication of the potential supply is given in Figure 28, which shows that offshore oil-and-gas activities in the North Sea and in North America have similarly sized AHTS fleets.

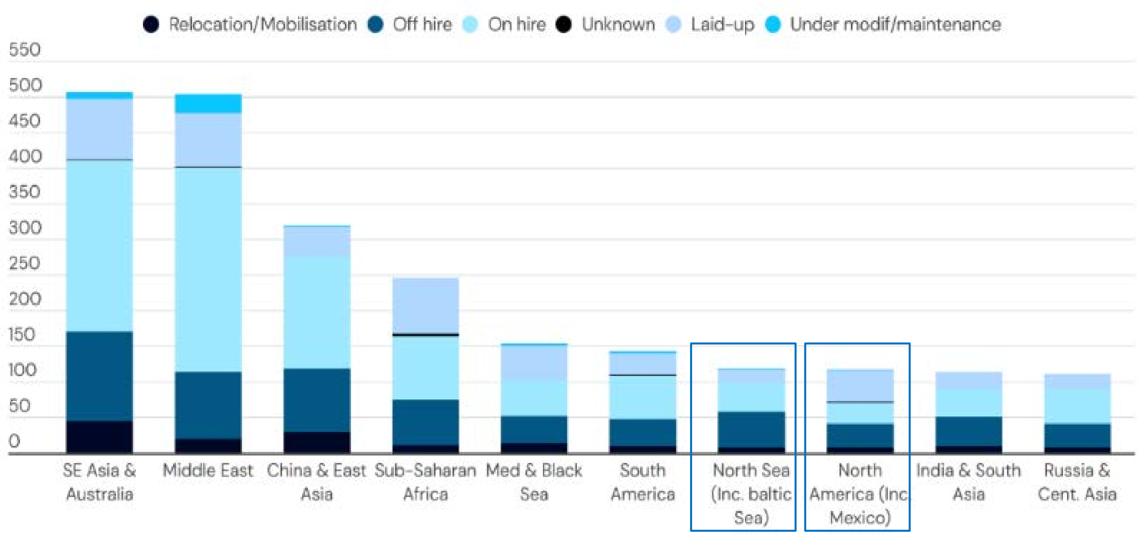


Figure 28. Global AHTS status by region. *Figure from Spinergie (2023)*

An important difference between these two regions, however, is that the North Sea offshore wind energy industry and the North Sea oil-and-gas industry operate in the same waters and share the same port infrastructure where AHTS vessels are based, with the same crew used for offshore wind as well as oil-and-gas activities. In the United States, AHTS vessels based in the Gulf of Mexico earn higher day rates (which is customary in the highly profitable and mature U.S. oil-and-gas industry) than they could command in the Gulf of Maine or off the U.S. West Coast, where the profitability of offshore wind energy is uncertain, and where fuel costs and crew wages are also likely to be much higher.

In the absence of government subsidy, or a significant downturn in the price of oil and gas, it will be difficult to attract the required Jones-Act-compliant AHTS vessels to install floating wind turbines, unless innovative technologies can reduce the nonvessel capital expenditures of floating wind projects to the point that they can afford to pay competitive day rates that would enable AHTS vessel owner-operators to profitably relocate vessels from the Gulf of Mexico to the Gulf of Maine or the U.S. West Coast.

This challenge will be made greater by the ultradeep waters of the Central Atlantic region, as compared with the Gulf of Maine and U.S. West Coast. In Central Atlantic 1 Call Areas E and F, vessels will need to handle much longer and heavier mooring lines, and in lease areas that are much farther from ports and shore-based search-and-rescue assets. As a result, these areas incur a greater risk of disruption by tropical storm and hurricane activity, as compared to the Gulf of Maine and U.S. West Coast.

7 Future Leasing Considerations

This report takes a long-term look at the Central Atlantic regional needs for offshore wind energy with a focus on the ultradeep Call Areas E and F. Our investigation provides mostly a qualitative assessment of the technical trade-offs relative to shallower sites and a quantitative assessment of the need for further leasing. The following are our key findings for BOEM to consider in developing a future leasing plan for this region:

- State procurement mandates and policy targets are driving the market for offshore wind energy in the United States. We used these targets to establish a baseline estimate for the additional lease area that will be required, but it is likely that the actual long-term leasing need will be greater than the policy targets.
- The combined policy targets announced by Delaware, Maryland, Virginia, and North Carolina thus far indicate at least 22.9 GW of offshore wind will need to be procured, with about 3.6 GW already secured by offtakes in the region.[24]
- Accounting for the lease area capacity in the current Final Sale Notice (FSN OCS-A 0557 and FSN OCS-A 0558) plus the existing leases, there remains a need to secure up to 2,233 km^2 or 551,786 acres of additional lease area to meet the combined targets of Delaware, Maryland, Virginia, and North Carolina. This lease area requirement includes about 4.8 GW (1,208 km^2 or 298,503 acres) of offshore wind energy development in proximity to Delaware and Maryland, and about 4.1 GW (1,025 km^2 or 253,283 acres) in proximity to Virginia and North Carolina. Long-term lease requirements in the Central Atlantic region are likely to be much greater to meet national net-zero decarbonization targets.
- Most of the Central Atlantic 1 Call Areas are conflicted with competing use and natural resource issues by various stakeholders, and in particular the military and U.S. Coast Guard. This report does not conduct marine spatial planning or site-suitability analysis. The primary challenge in identifying future lease areas is generally overcoming siting constraints and not the availability of the offshore wind resource. The entire region has adequate wind resources from an energy production standpoint, but technology readiness in ultradeep waters should be a major concern in establishing future site suitability for round 2 leasing. Additional ocean space with access to Delaware and Maryland points of interconnect may also be available on the OCS off southern New Jersey.
- Section 5 describes the state of the technology and technical challenges that developers would face, especially in the ultradeep Call Areas E and F. The technical challenges for these ultradeep waters are extensive compared to the shallow water sites in the planned 2024 lease auction. Moreover, when compared to the other floating wind sites (60 m to 1,300 m) that have been leased in California and identified in the Gulf of Maine and

[24] The additional offtakes needed to fill current state procurement targets include 1.2 GW for Delaware, 7.5 GW for Maryland, 2.6–2.7 GW for Virginia, and 8 GW for North Carolina.

Oregon the additional depth challenges are significant. Offshore wind energy development in ultradeep areas would carry significant additional technical risk due to design uncertainties regarding moorings, cables, and vessels, and would increase the challenge for the supply chain to meet demand, especially for mooring lines.

- The difficulty in developing Call Areas E and F may be exacerbated by increased hurricane risk, although these studies have not been quantified yet. Siting offshore wind farther from shore adds additional uncertainty and may increase the exposure of wind turbines to major hurricanes that tend to track north from Cape Hatteras, which provides some shelter for the more nearshore regions.
- A preliminary assessment of the region suggests that there may be some unexplored ocean space with depths that exceed 60 m before the shelf drop occurs. Industry experience with fixed-bottom shallow water extends only to 60-m depths so far but there may be lower technical risk to install fixed-bottom foundations at, for example, an 80-m depth than a floating structure at 2,500 m.
- BOEM should consider that the current state targets and mandates are a lower boundary for offshore wind lease requirements and that net-zero decarbonization scenarios in this region may call for additional leasing beyond the 2,233 km^2 identified in this report. Long-term electrification and decarbonization scenarios developed and analyzed by federal and state energy planners should include realistic energy supply curves for land-based wind, solar photovoltaics, hydroelectric, offshore wind, and nuclear capacity to inform BOEM's future leasing requirements.
- To help mitigate the technical and economic risks of floating wind technologies in ultradeep water, we recommend conducting extensive deep-water technology research and obtaining industry experience from floating wind projects in California, the Gulf of Mexico, and Oregon.

References

American Clean Power. 2021. "Offshore Wind Vessel Needs." https://cleanpower.org/wp-content/uploads/2021/09/OffshoreWind_Vessel_Needs_240214.pdf.

American National Standards Institute. 2022. Standard: ANSI/ACP OCRP-1-2022 "Offshore Compliance Recommended Practices, Edition 2." https://webstore.ansi.org/standards/ansi/ansiacpocrp2022

Andres. 2021. "Spatial and Temporal Variability of the Gulf Stream Near Cape Hatteras."17 August 2021. https://doi.org/10.1029/2021JC017579

Bane et al. 1988. "Gulf Stream bimodality and variability downstream of the Charleston bump." Journal of Geophysical Research: Oceans Volume 93, Issue C6 p. 6695-6710. 15 June 1988. https://doi.org/10.1029/JC093iC06p06695

Bodini, N, M. Optis, S. Redfern, D. Rosencrans, A. Rybchuk, J. K. Lundquist, V. Pronk, S. Castagneri, A. Purkayastha, C. Draxl, R. Krishnamurthy, E. Young, B. Roberts, E. Rosenlieb, W. Musial. 2023. *NOW-23: The 2023 National Offshore Wind Data Set*. https://nationaloffshorewind.org/wp-content/uploads/147502_Final-Report.pdf.

Bureau of Ocean Energy Management. 2022. "Maryland Offshore Wind Project BOEM Scoping Meetings June 21, 23, and 27, 2022." https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/Maryland%20Offshore%20Wind%20Project_US%20Wind%20Presentation.pdf.

BOEM. 2023a. "Biden Harris Administration Advances Offshore Wind in the Central Atlantic." December 11, 2023. https://www.boem.gov/newsroom/press-releases/biden-harris-administration-advances-offshore-wind-central-atlantic.

BOEM. 2023b. *Record of Decision: Coastal Virginia Offshore Wind Commercial Project Construction and Operations Plan*. https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/CVOW-C-ROD.pdf.

BOEM. 2023c. Randall, Alyssa L., Jonathan A. Jossart, Brandon M. Jensen, Bridgette H. Duplantis, and James A. Morris, Jr.. *Development of the Central Atlantic Wind Energy Areas*. 175 pp. https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/BOEM_NCCOS_JointReport_DraftWEAs_FINAL.pdf.

BOEM. 2024a. "Memorandum of Understanding Between the Bureau of Ocean Energy Management and the State of Maryland on Offshore Wind Energy." https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/Maryland-BOEM-Offshore-Wind-MOU.pdf.

BOEM.2024b. "BOEM Completes Environmental Review of Beacon Wind's Proposal for Additional Site Testing Offshore Massachusetts." https://www.boem.gov/newsroom/press-releases/boem-completes-environmental-review-beacon-winds-proposal-additional-site.

BOEM. 2024c. “Atlantic Wind Lease Sale 10 for Commercial Leasing for Wind Power Development on the U.S. Central Atlantic Outer Continental Shelf – Final Sale Notice.” Bureau of Ocean Energy Management, Interior. June 28, 2024. https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/CenAt%20Final%20Sale%20Notice.pdf

Carolina Long Bay. n.d. “About TotalEnergies Carolina Long Bay.” Accessed March 5, 2024. https://carolinalongbay.com/about/.

Cooperman, Aubryn, Matt Hall, Stein Housner, Cris Hein, Patrick Duffy, Daniel Mulas Hernando, Lucas Carmo, Walt Musial. Forthcoming. *Investigation of the Challenges of Offshore Wind in Ultradeep Water*. Golden, CO: National Renewable Energy Laboratory (NREL).

Cooperman, Aubryn, Patrick Duffy, Matthew Hall, Ericka Lozon, Matt Shields, and Walt Musial. 2022. *Assessment of Offshore Wind Energy Leasing Areas for Humboldt and Morro Bay Wind Energy Areas, California*. Golden, CO: National Renewable Energy Laboratory (NREL). NREL/TP-5000-82341. https://www.nrel.gov/docs/fy22osti/82341.pdf.

Damiani, R., K. Dykes, and G. Scott. 2016. “A comparison study of offshore wind support structures with monopiles and jackets for U.S. waters.” *Journal of Physics: Conference Series* 753 (September): 092003. https://doi.org/10.1088/1742-6596/753/9/092003

Davidson, Ros. 2024. “Ørsted Scraps More US Offshore Wind Power Deals amid Cost Pressures.” Wind Power Monthly. January 26, 2024. https://www.windpowermonthly.com/article/1858935/orsted-scraps-us-offshore-wind-power-deals-amid-cost-pressures.

Delaware General Assembly. 2024. “Senate Bill 265: An Act to Amend Titles 17, 26, and 29 of the Delaware Code Relating to the Delaware Energy Solutions Act of 2024.” https://legis.delaware.gov/BillDetail/141232.

Delaware Natural Resources Environmental Control (DNREC) and Synapse Energy Economics. 2018. *Offshore Wind Working Group Report to the Governor*. https://documents.dnrec.delaware.gov/energy/offshore-wind/Offshore%20Wind%20Working%20Group%20Report%20June%2029%202018.pdf.

DNREC, Synapse Energy Economics, and Zooid Energy. 2023. *Proposed Offshore Wind Procurement Strategy for Delaware*. https://documents.dnrec.delaware.gov/energy/offshore-wind/Proposed-Offshore-Wind-Procurement-Strategy-20231229.pdf.

Delaware News. 2021. “Governor Carney Signs Legislation Raising Renewable Portfolio Standard (RPS).” February 10, 2021. https://news.delaware.gov/2021/02/10/governor-carney-signs-legislation-raising-renewable-portfolio-standard-rps/.

Disavino, Scott. 2023. “Offshore wind developers likely to cancel some contracts after New York decision.” October 20, 2023. https://www.reuters.com/sustainability/offshore-wind-developers-likely-cancel-some-contracts-after-ny-decision-2023-10-19/.

DNV. 2022. *Energy Transition Outlook 2022*. https://www.dnv.com/energy-transition-outlook/download.html.

Duke Energy. 2022a. "Carolina Long Bay Offshore Wind Fact Sheet." https://www.duke-energy.com/-/media/pdfs/our-company/carolongbay/carolina-long-bay-fact-sheet-duke-energy.pdf?rev=21d5eae31a66442188e5e49a587fb598.

Duke Energy. 2022b. "Duke Energy secures offshore wind lease for Carolina Long Bay." May 11, 2022. https://news.duke-energy.com/releases/duke-energy-secures-offshore-wind-lease-for-carolina-long-bay.

Duke Energy. 2023. "Duke Energy files updated Carbon Plan to serve the growing energy needs of a thriving North Carolina." August 17, 2023. https://investors.duke-energy.com/news/news-details/2023/Duke-Energy-files-updated-Carbon-Plan-to-serve-the-growing-energy-needs-of-a-thriving-North-Carolina/default.aspx.

Duke Energy. 2024. "Supplemental Planning Analysis" January 31, 2024. https://www.duke-energy.com/-/media/pdfs/our-company/carolinas-resource-plan/supplements/supplemental-planning-analysis.pdf?rev=f134d62ba6d645ccb3de2bc227a0d42d.

Energy Information Administration. 2023a. "Delaware Electricity Profile 2022." https://www.eia.gov/electricity/state/delaware/.

Energy Information Administration. 2023b. "Maryland Electricity Profile 2022." November 2, 2023. https://www.eia.gov/electricity/state/maryland/.

Energy Information Administration. 2023c. "Maryland Profile Analysis." December 21, 2023. https://www.eia.gov/state/analysis.php?sid=MD.

Energy Information Administration. 2023d. "North Carolina Electricity Profile 2022." https://www.eia.gov/electricity/state/northcarolina/.

Energy Information Administration. 2023e. "Virginia Electricity Profile 2022." https://www.eia.gov/electricity/state/virginia/.

Energy Information Administration. 2024a. "Delaware Profile Analysis." January 17, 2024. https://www.eia.gov/state/analysis.php?sid=DE.

Energy Information Administration. 2024b. "North Carolina Profile Analysis." February 15, 2024. https://www.eia.gov/state/analysis.php?sid=NC.

Energy Information Administration. 2024c. "Virginia Profile Analysis." January 17, 2024. https://www.eia.gov/state/analysis.php?sid=VA.

Energy News Network. 2023. "Delaware eyes its first offshore wind target, but trouble looms." August 23, 2023. https://energynews.us/2023/08/23/delaware-eyes-its-first-offshore-wind-target-but-trouble-looms/.

Esteyco. 2024. “Wheel Technology Page”. https://esteyco.com/wheel/

Fisher, James E., Saba Esmailzadeh, and Jacob N. Fillingham. 2023. “Geological and Geotechnical Considerations for Floating Offshore Wind Infrastructure within the U.S. Atlantic OCS.” OnePetro. https://doi.org/10.4043/32578-MS.

Forsyth, J., M. Andres, and G. Gawarkiewicz, 2020. Shelfbreak Jet structure and variability off New Jersey using ship of opportunity data from the CMV Oleander. *J. of Geophysical Research: Oceans, Vol. 125*, 19 pp. https://doi.org/10.1029/2020JC016455.

Frangoul, Anmar. 2023. “The world’s largest floating wind farm is now officially open — and helping to power North Sea oil operations.” CNBC. August 23, 2023. https://www.cnbc.com/2023/08/23/the-worlds-largest-floating-wind-farm-is-officially-open.html.

Fuchs, Rebecca, Musial, Walt, Zuckerman, Gabriel R., Chetan, Mayank, Marquis, Melinda, Rese, Leonardo, Cooperman, Aubryn, Duffy, Patrick, Green, Rebecca, Beiter, Philipp, Mulas Hernando, Daniel, Morris Jr., James A., Randall, Alyssa, Jossart, Jonathan A., Mudd, Lauren, and Vickery, Peter. 2023. “Assessment of Offshore Wind Energy Opportunities and Challenges in the U.S. Gulf of Mexico.” United States: N. p., 2023. https://doi.org/10.2172/2274828

Gavin, Ken, 2019. “Foundations for Offshore Wind Turbines Key Geotechnical and Geological Uncertainties.” *EuroWorkshop: Geology and the Energy Transition*. Delft, The Netherlands. European Federation of Geologists. https://eurogeologists.eu/wp-content/uploads/2019/06/11_EuroGeol-Workshop-Gavin-2019.pdf.

Hall. 2015. Hurricane Design in the Standards -IEC Hurricane Classes and API Hazard Curves, Keystone Engineering. Accessed March 2020. http://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&ved=2ahUKEwj4_P-Oi6foAhUygnIEHWkxAtMQFjACegQIBxAB&url=http%3A%2F%2Fusmodcore.com%2Fcontent%2Ffile%2FHallRudy_IECHurricaneClassesAndAPIHazardCurves.pdf&usg=AOvVaw0gB8y5QeLeOCjO3l4fBeVL

Hall, Matthew, Ericka Lozon, Stein Housner, and Senu Sirnivas. 2022. “Design and Analysis of a Ten-Turbine Floating Wind Farm with Shared Mooring Lines.” Journal of Physics: Conference Series 2362 (1): 012016. https://doi.org/10.1088/1742-6596/2362/1/012016

[IEC] International Electrotechnical Commission. 2019a. Standard: IEC 61400-1:2019 Edition 4, “Wind turbines—Part 1: Design requirements.” Available at: https://www.iec.ch/dyn/www/f?p=103:23:27965083281002::::FSP_ORG_ID.

IEC. 2019b. Standard: IEC 61400-3-1:2019, “Wind Energy Generation Systems - Part 3-1: “Design Requirements for Fixed Offshore Wind Turbines.” Available at: https://webstore.iec.ch/publication/29360.

Joyce, T., R. Backus, K. Baker, P. Blackwelder, O. Brown, T. Cowles, R. Evans et al., 1984 "Rapid evolution of a Gulf Stream warm-core ring." *Nature 308*, no. 5962, pp. 837-840.

Maryland Department of Transportation. 2024. "Electric Vehicle Registrations Pass Record-Breaking 100,000 Mark in Maryland." https://mdot.maryland.gov/tso/pages/newsroomdetails.aspx?newsId=779&PageId=38#:~:text=Under%20the%20Moore-Miller%20Administration%2C%20Maryland%27s%20EV%20registration%20numbers,2023%20to%20102%2C530%20as%20of%20April%2030%2C%202024.

Maryland Energy Administration. n.d.(a). "Maryland Offshore Wind." Accessed March 5, 2024. https://energy.maryland.gov/Pages/Info/renewable/offshorewind.aspx.

Maryland Energy Administration. n.d.(b). "Maryland Offshore Wind Supply Chain Investment Program." https://energy.maryland.gov/Pages/Info/renewable/supplychaininvestment.aspx.

Maryland Energy Administration. n.d.(c). "Maryland Offshore Wind Workforce Training & Education Program." https://energy.maryland.gov/Pages/Info/renewable/offshorewindworkforce.aspx.

Maryland Energy Administration. 2024. "Cost-Effective Alternatives to Reliability-Must-Run Agreements." March 19, 2024. https://www.pjm.com/-/media/about-pjm/who-we-are/public-disclosures/2024/20240319-mea-letter-regarding-cost-effective-alternatives-to-reliability-must-run-agreements.ashx.

Maryland General Assembly. 2024a. "House Bill 1296. Electricity – Offshore Wind Projects – Alterations." February 9, 2024. https://mgaleg.maryland.gov/2024RS/bills/hb/hb1296f.pdf.

Maryland General Assembly. 2024b. "House Bill 1296. Electricity – Offshore Wind Projects – Alterations." June 1, 2024. https://mgaleg.maryland.gov/2024RS/chapters_noln/Ch_431_hb1296E.pdf.

Minerals Management Service. 2007. Alternative Energy EIS, October 2007, section 4.1. https://tethys.pnnl.gov/sites/default/files/publications/Alt_Energy_FPEIS_Chapter4_0.pdf

Mudd, Lauren A., and Peter J. Vickery. 2023. Gulf of Mexico Offshore Wind Energy Hurricane Risk Assessment. Golden, CO: National Renewable Energy Laboratory. NREL/SR-5000-88211. https://www.nrel.gov/docs/fy24osti/88211.pdf.

Mulas Hernando, Daniel, Walt Musial, Patrick Duffy, and Matt Shields. 2023. *Capacity Density Considerations for Offshore Wind Plants in the United States*. Golden, CO: National Renewable Energy Laboratory (NREL). NREL/TP-5000-86933. https://www.nrel.gov/docs/fy24osti/86933.pdf.

Musial, Walter, Paul Spitsen, Patrick Duffy, Philipp Beiter, Matt Shields, Daniel Mulas Hernando, Rob Hammond, Melinda Marquis, Jennifer King, and Sathish Sriharan. 2023. *Offshore Wind Market Report: 2023 Edition*. Washington, D.C.: U.S. Department of Energy Office of Energy Efficiency & Renewable Energy. DOE/GO-102023-6059. https://www.energy.gov/sites/default/files/2023-09/doe-offshore-wind-market-report-2023-edition.pdf.

National Hurricane Center. 2024. "Saffir Simpson Wind Scales." https://www.nhc.noaa.gov/aboutsshws.php

National Offshore Wind Research and Development Consortium 2024. The National Offshore Wind Research and Development Consortium Project List. https://nationaloffshorewind.org/wp-content/uploads/NOWRDC-Project-List-4.pdf.

National Oceanic and Atmospheric Administration (NOAA). 2012. "NOAA Provides Easy Access to Historical Hurricane Tracks." https://2010-2014.commerce.gov/blog/2012/08/13/noaa-provides-easy-access-historical-hurricane-tracks.html.

NOAA Office for Coastal Management, 2024. "Historical Hurricane Tracks - GIS Map Viewer" www.climate.gov/maps-data/dataset/historical-hurricane-tracks-gis-map-viewer.

NOAA Office of Coast Survey, National Ocean Service, National Oceanic and Atmospheric Administration. 2019. *Distances Between United States Ports,* 13th Edition. www.nauticalcharts.noaa.gov/publications/docs/distances.pdf.

North Carolina Environmental Quality. n.d. "Offshore Wind Development; Jurisdiction." Accessed March 5, 2024. https://www.deq.nc.gov/energy-climate/offshore-wind-development.

North Carolina Utilities Commission. 2022. Biennial Consolidated Carbon Plan and Integrated Resource Plans of Duke Energy Carolinas, LLC, and Duke Energy Progress, LLC. https://www.ncuc.gov/consumer/carbonplan.html.

NS Energy. 2020. "Perdido Deepwater Oil and Gas Development." Accessed April 9, 2024. https://www.nsenergybusiness.com/projects/perdido-deepwater-oil-and-gas-development/.

Office of Energy Justice and Equity. 2023. "Low-Income Communities Bonus Credit Program." 2023. https://www.energy.gov/justice/low-income-communities-bonus-credit-program.

Office of the Secretary of Commerce and Trade, Department of Mines, Minerals and Energy. 2018. "The Commonwealth of Virginia's 2018 Energy Plan." https://energy.virginia.gov/energy-efficiency/documents/2018VirginiaEnergyPlan.pdf.

Ørsted. 2024. "Skipjack Wind to be repositioned for future offtake opportunities." January 25, 2024. https://orsted.com/en/media/news/2024/01/skipjack-wind-to-be-repositioned-for-future-offtak-815811.

Papavizas, Charlie. 2022. "Jones Act Considerations for the Development of Offshore Wind Farms." Benedict's Maritime Bulletin. https://www.winston.com/a/web/262961/First-Quarter-2022-Benedict-s-Maritime-Bulletin-Papavizas.pdf.

Piedmont Environmental Council 2024. "Data Centers & Energy Demand." https://www.pecva.org/our-work/energy-matters/data-centers-energy-demand/.

Public Service Commission of Maryland. 2021. "ORDER NO. 90011. Order Granting Offshore Wind Renewable Energy Credits." https://www.psc.state.md.us/wp-content/uploads/Order-No.-90011-Case-No.-9666-Order-Granting-Offshore-Wind-Renewable-Energy-Credits.pdf.

Ross, Steve, and S. Brooke. 2012. "Mid-Atlantic Deepwater Canyons." https://oceanexplorer.noaa.gov/explorations/12midatlantic/background/canyons/canyons.html#:~:text=Submarine%20canyons%20are%20dominant%20features,to%20the%20Gulf%20of%20Maine.

Rossol, M., and G. Buster. 2024. NREL/Rex: Resource Extraction Tool (REX). GitHub. https://github.com/NREL/rex.

M. Sanchez Gomez, J. K. Lundquist, G. Deskos, S. R. Arwade, A. T. Myers, J. F. Hajjar. "Wind Fields in Category 1–3 Tropical Cyclones Are Not Fully Represented in Wind Turbine Design Standards." 09 August 2023. https://doi.org/10.1029/2023JD039233

Shields, M., R. Marsh, J. Stefek, F. Oteri, R. Gould, N. Rouxel, K. Diaz, J. Molinero, A. Moser, C. Malvik, and S. Tirone. 2022. *The Demand for a Domestic Offshore Wind Energy Supply Chain.* Golden, CO: National Renewable Energy Laboratory. NREL/TP-5000-81602. https://www.nrel.gov/docs/fy22osti/81602.pdf

Siemens Gamesa. 2020. "Unmatched in the U.S.: Siemens Gamesa SG 14-222 DD offshore wind turbines to power 2.6-GW Dominion Energy project." May 26, 2020. https://www.siemensgamesa.com/en-int/newsroom/2020/05/200526-siemens-gamesa-dominion-energy-usa-project.

SMART-POWER. 2020a. "Maryland Virginia and North Carolina Regional SMART-POWER Partnership." https://energy.maryland.gov/SiteAssets/Pages/Info/renewable/offshorewind/SmartPower%20Factsheet%20%284%29.pdf.

SMART-POWER. 2020b. "Memorandum of Understanding Among Maryland, North Carolina, and Virginia To Create the Southeast and Mid-Atlantic Regional Transformative Partnership for Offshore Wind Energy Resources (SMART-POWER)." chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.advancedenergy.org/wp-content/uploads/imported-files/SMART-POWER-MOU_FINAL.pdf.

Special Initiative on Offshore Wind at the University of Delaware. 2022. "Offshore Wind Procurement Options for Delaware." https://documents.dnrec.delaware.gov/energy/offshore-wind/SIOW-report.pdf.

Spinergie. 2023. **"**Hywind Tampen installation illustrates the impact of floating wind on the AHTS market." www.spinergie.com/resources/hywind-tampen-installation-illustrates-the-impact-of-floating-wind-on-the-ahts-market.

State of Delaware. 2024. "An Act to Amend Titles 17, 26, And 29 Of the Delaware Code Relating to The Delaware Energy Solutions Act Of 2024." https://legis.delaware.gov/BillDetail/141232.

State of North Carolina. 2024. *Chapter NC: 2023–2024 CPIRP Update*. https://starw1.ncuc.gov/NCUC/ViewFile.aspx?Id=e6477bcc-6b50-4284-8365-1521bba249c4.

State of North Carolina and Governor Roy Cooper. 2021. Executive Order No. 218. Advancing North Carolina's Economic and Clean Energy Future with Offshore Wind. https://governor.nc.gov/documents/files/executive-order-no-218/open.

Stiesdal. 2024. "The Tetraspar Full-scale Demonstration Project." https://www.stiesdal.com/offshore/the-tetraspar-full-scale-demonstration-project/

TotalEnergies. n.d. "Carolina Long Bay, USA. 1 GW." Accessed March 5, 2024. https://renewables.totalenergies.com/en/our-projects-worldwide/wind/carolina-long-bay.

TotalEnergies. 2024. "The Opportunity for Offshore Wind, Including TotalEnergies' Carolina Long Bay Project, to Be Developed off the Coast of Wilmington, NC."https://dms.psc.sc.gov/Attachments/Matter/26fc279e-d419-467e-857e-a01dacf50247.

U.S. Department of Energy. n.d. "Section 48C Tax Credits - Designated Energy Communities." Accessed March 5, 2024. https://arcgis.netl.doe.gov/portal/apps/experiencebuilder/experience/?id=a44704679a4f44a5aac122324eb00914&page=home.

U.S. Department of Energy. 2023. "Advancing the Growth of the U.S. Wind Industry: Federal Incentives, Funding, and Partnership Opportunities." Fact Sheet. Washington, D.C.: U.S. Department of Energy Office of Energy Efficiency & Renewable Energy. https://www.energy.gov/sites/default/files/2023-06/weto-wind-funding-taxday-factsheet-june-fy23.pdf.

U.S. Department of the Interior. 2010. "Salazar Launches 'Smart from the Start' Initiative to Speed Offshore Wind Energy Development off the Atlantic Coast", https://www.doi.gov/news/pressreleases/Salazar-Launches-Smart-from-the-Start-Initiative-to-Speed-Offshore-Wind-Energy-Development-off-the-Atlantic-Coast

U.S. Department of the Interior. 2024. "Gulf of Maine Area Identification Pursuant to 30 C.F.R.§ 585.211(b)." Washington, D.C. Bureau of Ocean Energy Management. https://www.boem.gov/sites/default/files/documents/renewable-energy/Gulf%20of%20Maine%20Area%20ID%20Memo_03142024.pdf.

United Nations. 1982. "Part V - Exclusive Economic Zone, Article 56." Accessed May 8, 2024. https://www.un.org/depts/los/convention_agreements/texts/unclos/part5.htm.

Esteyco. 2024. "Wheel Technology Page". https://esteyco.com/wheel/

Virginia's Legislative Information System. 2020. Virginia Clean Economy Act. https://lis.virginia.gov/cgi-bin/legp604.exe?201+sum+HB1526.