

OFFSHORE WIND TECHNOLOGY OVERVIEW

NYSERDA PON 995, Task Order No. 2,
Agreement No. 9998

For the
Long Island - New York City
Offshore Wind Collaborative

Submitted By:
AWS Truewind, LLC
463 New Karner Road
Albany, NY 12205

Date:
September 17, 2009

Contents

Introduction	1
Design Requirements.....	1
Standards and Certifications.....	2
Winds	2
Waves.....	2
Currents	3
Onsite Data Collection	3
Seabed Characteristics and Water Depth.....	4
Overview of Wind Plant Components.....	5
Wind Turbines.....	5
Towers and Foundations.....	8
Electrical System and Balance of Plant	11
Meteorology-Ocean (Met-Ocean) Monitoring System.....	13
O&M Facility and Equipment.....	14
Layout Considerations	15
Logistics for Installation & Maintenance	15
Construction Vessels.....	16
Port Availability.....	17
Conclusions	18
Appendix - Table of Offshore Wind Farms.....	19

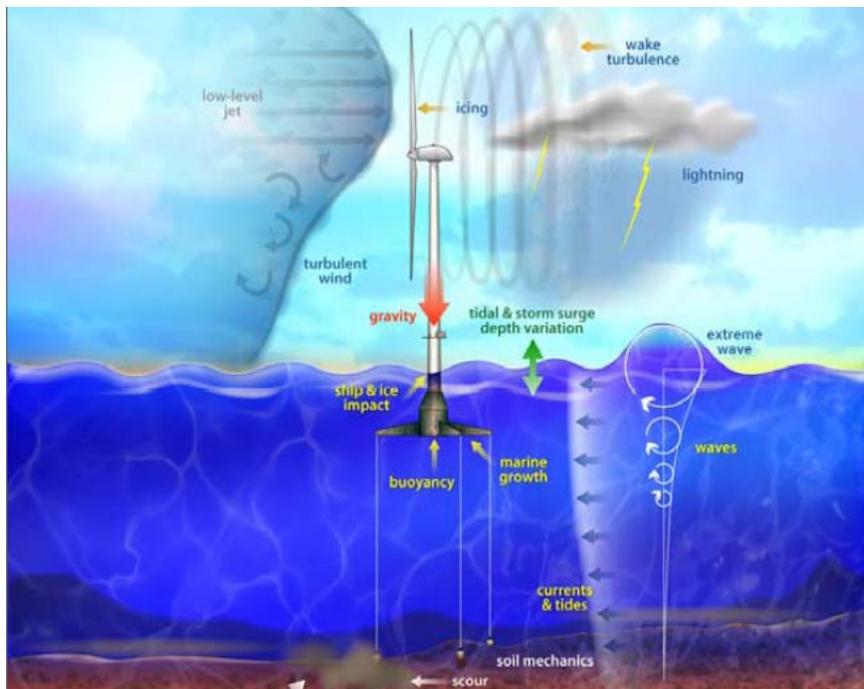
INTRODUCTION

Offshore wind energy development has been an almost exclusively European phenomenon since the early 1990s. More than 35 wind projects totaling over 1500 MW of capacity are now operating off the shores of five countries, most within northwest Europe in the Baltic and North Seas. Another 2,500 MW of capacity are under construction in 16 projects. Overall, the European Union predicts there will be at least 40,000 MW of offshore wind energy in Europe by the year 2020. China has also begun construction on the Sea Bridge Wind Farm in the Bohai Sea, its first offshore wind project scheduled for completion in 2010. Although no offshore wind projects are under construction or in operation yet in North America, proposed projects or ones in the active development phase exist in several states and provinces. These include British Columbia, Delaware, Massachusetts, New York, Ohio, Ontario, Rhode Island, and Texas.

This large body of offshore experience provides an excellent basis to understand the wind turbine technologies and foundation designs likely to be applicable to the Long Island-New York City Offshore Wind Collaborative's project area for a wind facility built in the 2014-2016 timeframe. The objective of this short report is to summarize applicable turbine technologies and foundation designs and to identify the primary design parameters for turbines and foundations.

DESIGN REQUIREMENTS

The design of an offshore wind project is based on the environmental conditions to be expected at a proposed site over the project's lifetime (typically 20 or more years). These environmental conditions are primarily defined by the wind, wave, current, water depth and soil and seabed characteristics. Figure 1 illustrates the various dynamic factors impacting a wind turbine's external environment. Different project components are more sensitive to some of these characteristics than others. For



example, a wind turbine's rotor and nacelle assembly are most sensitive to wind and other atmospheric conditions while the support structure (tower and foundation) design is more dependent on hydrodynamic and seabed conditions. Wind turbine models tend to be designed for applicability for a specified range of wind conditions whereas turbine support structures are usually engineered for on-site conditions. This section provides additional insight into the design parameters relevant to the entire project.

Figure 1: Site Conditions Affecting an Offshore Wind Farm¹

¹ Source: Robinson & Musial, National Renewable Energy Laboratory. (2006, October). Offshore Wind Energy Overview. Webinar. Used with permission.

Standards and Certifications

Several design guidelines and standards have been developed nationally and internationally that apply to wind turbines, wind turbine foundations and offshore structures. While the United States does not currently have any specific standards for offshore wind turbine design and construction, several European institutions do. Germanischer Lloyd (GL), Det Norske Veritas (DNV), and TUV Nord are among the bodies that offer type certification and guidelines for offshore wind turbines and related components and processes. Additionally, the IEC 61400-3 International Standard *Design Requirements For Offshore Wind Turbines* (2008) provides criteria for offshore site conditions assessment, and establishes five critical design requirements for offshore wind turbine structures.² These guidelines were developed to ensure that type-certified wind turbines, support structures and related processes meet the requirements dictated by the site conditions. In the U.S. there are ongoing efforts to establish guidelines that integrate the American Petroleum Institute's (API) recommended practices (API RP-2A) for offshore platforms into the offshore wind industry's practices.³

Winds

Wind conditions are important in defining not only the loads imposed on all of a turbine's structural components, but also in predicting the amount of future energy production at different time scales. The measured on-site wind resource strongly influences the layout of turbines within a defined area as a function of the prevailing wind direction(s). Desired wind data parameters include the following:

- Wind speed – annual, monthly, hourly, and sub-hourly; preferably at hub height
- Speed frequency distribution – number of hours per year within each speed interval
- Wind shear – rate of change of wind speed with height
- Wind veer – change of wind direction with height, especially across the rotor plane
- Turbulence intensity – the standard deviation of wind speeds sampled over a 10-min period as a function of the mean speed
- Wind direction distribution
- Extreme wind gusts and return periods (50 and 100-year).

Air temperature, sea surface temperature and other meteorological statistics (icing, lightning, humidity, etc.) are also desired when evaluating a proposed site.

Waves

In addition to the loading forces imposed on a turbine's support structure, waves also determine the accessibility of offshore projects by vessels during construction and operations. Desired wave data parameters include the following:

- Significant wave height – average height of the third highest waves
- Extreme wave height – average height of the highest 1% of all waves
- Maximum observed wave height
- Wave frequency and direction spectra
- Correlation with wind speeds and direction

² IEC web site: http://www.iec.ch/online_news/etech/arch_2007/etech_0907/prodserv_2.htm

³ Comparative Study of OWTG Standards, MMI Engineering, June 29, 2009

Waves tend to be irregular in shape and height and may approach a wind turbine from more than one direction simultaneously. The probability and characteristics of breaking waves are also important. The correlation of wind and waves is a critical design criterion for an offshore wind turbine. This correlation is normally expressed as a joint probability of wind speeds and wave heights, and may include wave frequency as well. In addition to defining extreme aerodynamic and hydrodynamic loads, it is important to assess the dynamic vibrations induced upon the entire turbine structure. The effects of resonant motion from certain wind and wave loads may be a primary design driver.

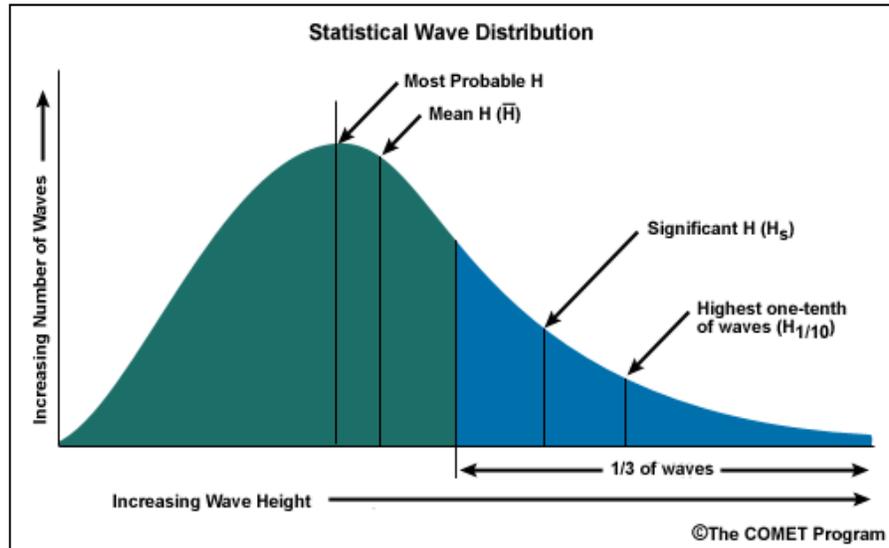


Figure 2: Statistical Wave Distribution and Data Parameters⁴

Currents

Currents are generally characterized either as sub-surface currents produced by tides, storm surges, and atmospheric pressure variations, or as near-surface currents generated by the wind. Currents can drive sediment transport (e.g. sand waves) and foundation scouring. They can also affect sea bottom characteristics and vessel motion during construction or service visits.

Onsite Data Collection

As accurate estimations of energy production potential are requirements by the financial community for offshore wind projects, precise definition of all of these atmospheric and aquatic parameters is critical. These parameters can be derived from various sources depending on the stage of project development. Early stage conceptual planning relies mostly on existing climatological data and model results (such as wind maps). Advanced stages rely on on-site measurement campaigns lasting 1 – 3 years.

Meteorological, wave and current data are monitored using a variety of instrumentation. Atmospheric data is measured by tall meteorological masts installed on offshore platforms to assess the site's wind resource for both energy assessment and maximum loading purposes. These measurements can be complemented by remote sensing devices (such as lidar and sodar), weather buoys, and regional weather observations to assess atmospheric conditions throughout and surrounding the project area. Wave and current data are collected by instrumented buoys and acoustic Doppler current profilers (ADCPs). Additional information acquired from specialized radar and satellite data, as well as regional and historic surface data sources, can further characterize the offshore environment.

⁴ Source: Cooperative Program for Operational Meteorology, Education and Training (COMET). Used with permission.

Seabed Characteristics and Water Depth

The geologic and bathymetric characteristics of a project site are significant design parameters for offshore wind turbines. While the entire system – turbine, tower, substructure, and foundation – is affected by these parameters, the foundation is particularly sensitive to the site conditions. The site bathymetry (water depth) will primarily drive the size of the underwater structure and its exposure to hydrodynamic forces. The seabed soil properties and profiles will influence the suitable foundation types. From a system perspective, the geologic and bathymetric characteristics help determine the axial and lateral pile responses, load-carrying capabilities, resonant frequencies, ultimate strength, fatigue strength, and acceptable deformation of the offshore support structure.

A geologic survey of the site often begins with a desktop review of available data to understand conditions likely found on-site. Detailed design and engineering work involves a multi-step on-site investigation process, including seismic reflection methods combined with soil sampling and penetration tests. These techniques obtain information about sediment characteristics and stratification to depths of at least 60 meters (200 feet) below the sea floor. Sediment and subsurface descriptors include the following:

- Soil classifications
- Vertical and horizontal strength parameters
- Deformation properties
- Permeability
- Stiffness and damping parameters – for prediction of the dynamic behavior of the wind turbine structure.

The first phase of on-site investigation, commonly referred to as the geophysical survey, employs remote sensing technology, often multi-beam sonar and/or high-resolution seismic reflection. This phase, known as hydrographic surveying, generally provides a detailed bathymetric map of the sea bottom as well as general soil characteristics. Both techniques rely on a vessel-mounted array of energy emitters and receivers that can carry out the initial site investigation in a relatively short period of time (see Figure 3). Advanced design work usually requires direct sampling of bottom soils, typically at each foundation location. This phase of investigation involves vibracore sampling to depths of up to 10 m (33 ft) or conventional borings to much greater depths. Retrieved soils are analyzed to determine their textural and engineering properties.



Figure 3: Statistical Wave Distribution and Data Parameters⁵

⁵ Source: Cooperative Program for Operational Meteorology, Education and Training (COMET). Used with permission.

OVERVIEW OF WIND PLANT COMPONENTS

An offshore wind plant's principal components are the turbines, towers, foundations, electric collection and transmission system (including substations), and other balance of plant items. These components are described in detail in this section.

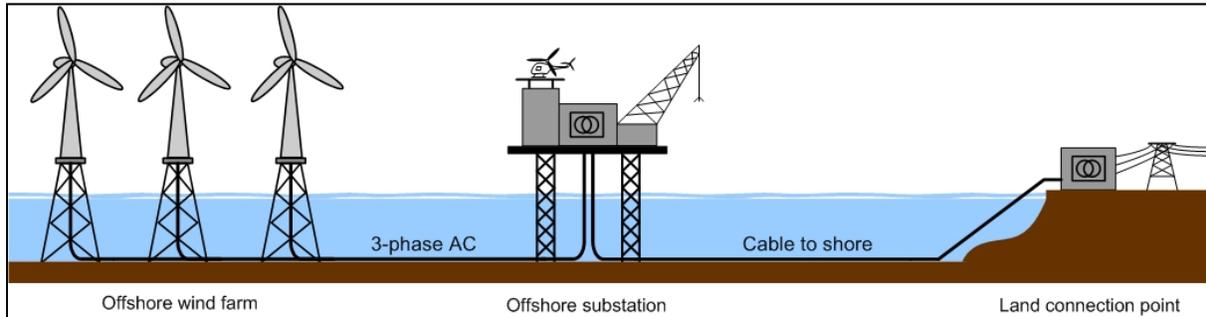


Figure 4: System View of an Offshore Wind Farm⁶

Wind Turbines

Wind turbines are the electricity generating component of an offshore wind plant. As shown in Figure 5, the turbine sits atop the support structure, which is comprised of the tower and foundation. The standard turbine design consists of a nacelle housing the main mechanical components (i.e. gearbox, drive shaft, and generator), the hub, and the blade-rotor assembly (see Figure 6).

Offshore wind turbines have historically been adaptations of onshore designs, although some manufacturers are now developing new models designed specifically for the offshore environment. International standards for wind turbine classes have been defined to qualify turbines for their suitability in different wind speed and turbulence regimes.

Early offshore installations deployed small (less than 1 MW) wind turbines, which was the typical land-based turbine size at the time. To date, Vestas and Siemens have been the most prominent offshore wind turbine suppliers. These two suppliers were among the first to offer offshore technology, entering the market in 2000 and 2003, respectively. Consequently, Vestas' V80 2 MW and V90 3 MW models have been installed predominantly throughout Europe, as have Siemens' 2.3 MW and 3.6 MW models. These turbines have rotor diameters of between 80 and 107 m, and hub heights between 60 and 105 m, which are significantly larger than the turbines deployed in the earliest projects.

In recent years, larger offshore turbines have been developed by BARD Engineering, Multibrid, and REpower. These 5 MW machines stand at a 90 meter or greater hub height, with rotor diameters of 116 to 122 m. These "next generation" turbines are the first batch of machines designed more specifically for offshore applications, as exhibited by their greater rated capacity and offshore-specific design features. Nordex has also entered the offshore market, adapting the 2.5 MW N90 (HS) onshore model for offshore applications.

⁶ Source: Troll Wind Power (www.trollwindpower.no). Used with permission.

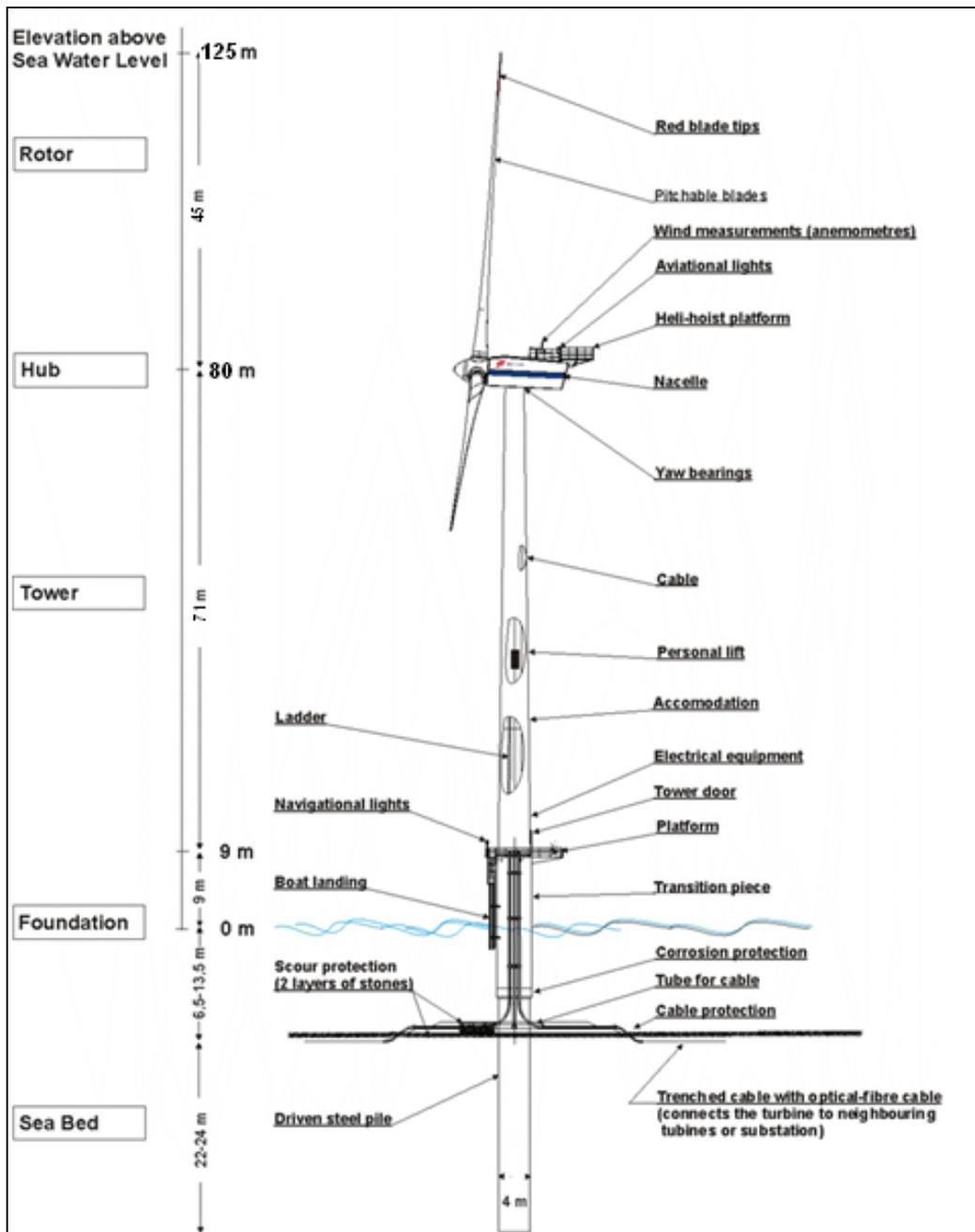


Figure 5: Principal Components and Dimensions of an Offshore Wind Structure⁷

Other manufacturers are also in the process of developing offshore turbine models, including Clipper and Enercon, but these designs have not reached the same level of commercial development as the turbines offered by Vestas, Siemens, BARD, Multibrid, and REpower. General Electric formerly offered a 3.6 MW offshore turbine, but has since exited the offshore market in order to focus on its onshore product line.

⁷ Source: Modified from the Horns Rev wind project, Vattenfall AB. Used with permission.

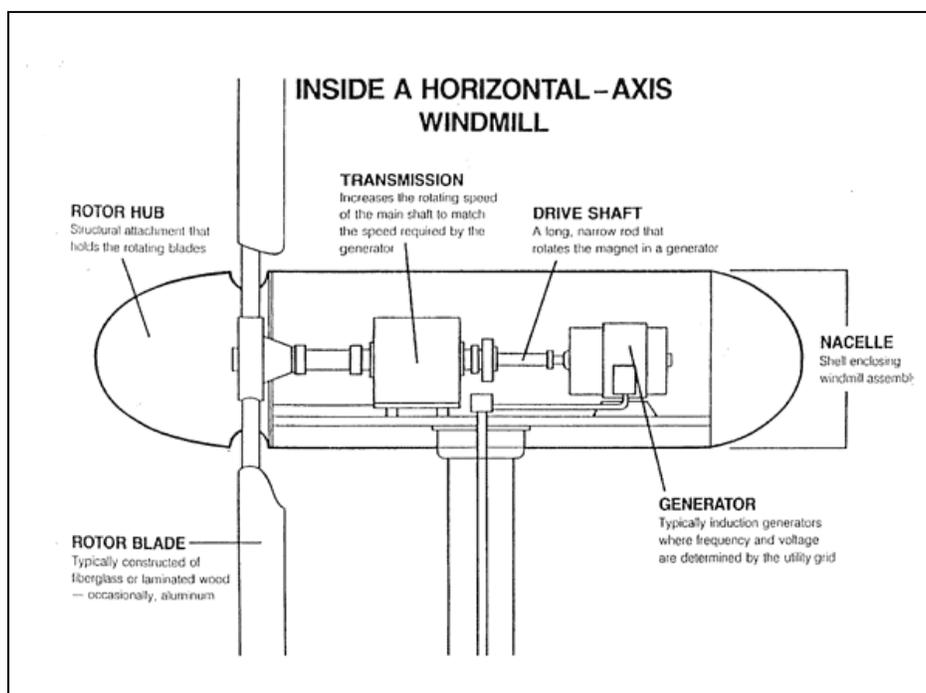


Figure 6: Main Components of a Horizontal Axis Wind Turbine⁸

Table 1 summarizes today's commercially available offshore wind turbine technologies. The availability of some models is limited, however, either due to supply constraints or due to the lack of a 60 Hz version required for installations in North America (European versions are 50 Hz). These limitations narrow the list of turbine models available today for installation in the United States to four: the Vestas V80 and V90; the Siemens SWT-2.3; and the Nordex N90. Manufacturers without 60 Hz versions of their product today are likely to build U.S.-compatible units in the future once they become confident that a sustainable offshore market is established. Siemens, for example, has tentative plans to release a 60 Hz version of their 3.6 MW machine at the end of 2010.

Table 1: Commercially Available Offshore Wind Turbines

Manufacturer	Model	Date of Availability	Rated Power (MW)	Grid Frequency (Hz)	Rotor Diameter (m)	Hub Height (m)	No. Turbines Installed ⁹
BARD	5.0	2008-2009	5	50	122	90	0
Multibrud	M5000	2005	5	50	116	90	0
Nordex	N90 (HS)	2006	2.5	50, 60	90	80	1
REpower	5M	2005	5	50	126	90	8
Siemens	3.6	2005	3.6	50	107	80, 83.5	79
Siemens	2.3	2003	2.3	50, 60	82, 93	60-80	130
Vestas	V80	2000	2	50, 60	80	67, 80	208
Vestas	V90	2004	3	50, 60	90	80, 105	96

⁸ Source: City of Hendricks, MN. Used with permission.

⁹ Not including prototypes. Based on data table in Appendix; only included data from farms already commissioned at the time of this report.

Turbines specially designed and/or type-certified for offshore operation have components and characteristics suited for long-term operation in their environments. Among the systems unique to offshore-specific turbines are special climate control systems for the nacelle and other sensitive components and enhanced corrosion protection.

Towers and Foundations

Offshore wind turbines are typically mounted on tubular towers that range from 60 to 105 meters above the sea surface. Lattice-type towers can also be used. The towers are fixed to the foundation, often employing a transition piece as an interface between the tower and foundation. These towers allow for the turbine to capture winds at heights far above the water's surface, where the wind resource is generally more energetic and less turbulent.

Foundation technology is designed according to site conditions. Maximum wind speed, water depth, wave heights, currents, and soil properties are parameters that affect the foundation type and design. While the industry has historically relied primarily on monopile and gravity-based foundations, the increasing number of planned projects in deeper water has motivated research and pilot installations for more complex multimember designs with broader bases and larger footprints, such as jackets, tripods, and tripiles, to accommodate water depths exceeding 20 to 30 meters. These designs, some of which were adapted from the offshore oil and gas industry, are expected to accommodate projects installed in deep water. These basic designs, along with their pros and cons, are highlighted below. Based on the water depths (18-37 m) and wave conditions of the proposed offshore Long Island project area, it is likely that one of these multi-member larger footprint designs will be selected.

Monopile Foundation

The monopile has historically been the most commonly selected foundation type due to its lower cost, simplicity, and appropriateness for shallow water (less than 20 m). The design is a long hollow steel pole that extends from below the seabed to the base of the turbine. The monopile generally does not require any preparation of the seabed and is installed by drilling or driving the structure into the ocean floor to depths of up to 40 meters. The monopile is relatively simple to manufacture, keeping its cost down despite reaching weights of over 500 tons and diameters of up to 5.1 m, which can be heavier than some more complex foundation designs.

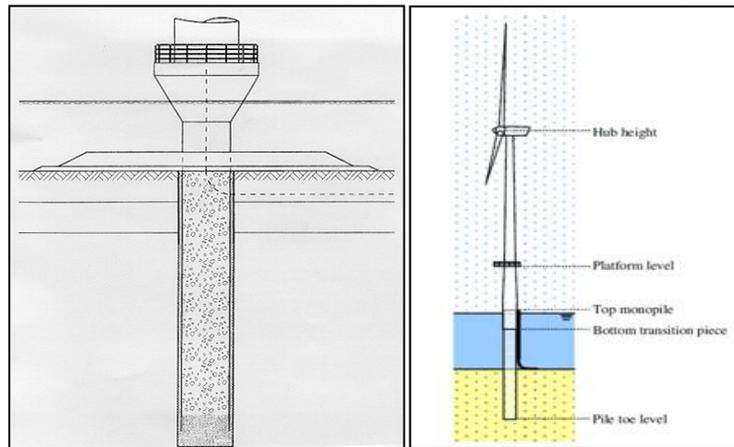


Figure 7: Monopile Foundation¹⁰⁻¹¹

While the monopile is an appropriate foundation choice for many projects, it can be unsuitable in some applications. These foundations are not well suited for soil strata with large boulders. Additionally the required size of an acceptable monopile increases disproportionately as turbine size increases and site

¹⁰ Source: Grontmij-Carlbro. Web site: http://www.middelgrunden.dk/MG_UK/project_info/mg_40mw_offshore.htm. Used with permission.

¹¹ Source: de Vries, W.E. (2007). Effects of Deep Water on Monopile Support Structures For Offshore Wind Turbines. In Conference Proceedings European Offshore Wind 2007. Berlin. Used with permission.

conditions become more challenging. Therefore, sites with deeper water, harsh waves and currents, and larger turbines may require the implementation of more complex and sturdier designs, such as the jacket, the tripod, or the tripile.

Gravity Base Foundation



Figure 8: Gravity Base Foundation¹²

An alternative to the monopile foundation is the gravity base foundation. Historically deployed in shallow waters (usually less than 15 meters), the gravity foundation is now installed at depths of up to 29 meters. This technology relies on a wide footprint and massive weight to counter the forces exerted on the turbine from the wind and waves. The gravity foundation differs from the monopile in that it is not driven into the seabed, but rather rests on top of the ocean floor. Depending upon site geologic conditions, this foundation may require significant site preparation including dredging, filling, leveling, and scour protection.

These structures are constructed almost entirely on shore of welded steel and concrete. It is a relatively economical construction process, but necessitates very robust transports to deploy on-site. Once complete, the structures are floated out to the site, sunk, and filled with ballast to increase their resistance to the environmental loads. While these structures can weigh over to 7,000 tons, they can be removed completely during decommissioning phase of the project.

Jacket Foundation

The jacket foundation is an application of designs commonly employed by the oil and gas industry for offshore structures. The examples currently deployed are four-sided, A-shaped truss-like lattice structures that support large (5 MW) offshore wind turbines installed in deep water (40+ meters). The legs of the jacket are set on the seabed and a pile is driven in at each of the four feet to secure the structure. This foundation has a wider cross-section than the monopile, strengthening it against momentary loads from the wind and waves. Because of its geometry, the jacket foundation is able to be relatively lightweight for the strength that it offers, weighing approximately 600 tons.



Figure 9: Jacket Foundation¹³⁻¹⁴

¹² Source: COWI A/S for Thornton Bank Wind Project. Used with permission.

¹³ Source: Seidel, M. (2007). Jacket Substructures for the REpower 5M Wind Turbine. In Conference Proceedings European Offshore Wind 2007. Berlin. Used with permission.

¹⁴ Source: Scaldis Salvage & Marine Contractors. Photo from Beatrice Wind Project. Used with permission.

Although its design is more complex than that of a monopile, the manufacturing process is generally well understood from the offshore oil and gas industry. The necessary materials (i.e. pipes) are already available due to their prevalent use in this same industry. Once manufacturing and deployment practices can be scaled up to economically meet the needs of large projects, these foundations will likely become the predominant deeper water foundation type.

Tripod Foundation

For deep water installations, the tripod foundation adapts the monopile design by expanding its footprint. The three legs of the structure are seated on the seabed, and support a central cylindrical section that connects to the wind turbine's base. Piles are driven through each of the three feet to secure the structure to the bed. The three supportive legs resist momentary loads exerted on the turbine. Tripod foundations are relatively complex and time consuming to manufacture, and also are more massive than jackets. In cases when using a traditional monopile becomes unwieldy for size reasons, a tripod design can reduce the amount of material needed by broadening the foundation's base.



Figure 10: Tripod Foundation^{15,16}

Tripile Foundation



The tripile foundation is also a relatively new adaption of the traditional monopile foundation. Instead of a single beam, three piles are driven into the seabed, and are connected just above the water's surface to a transition piece using grouted joints. This transition piece is connected to the turbine tower's base. The increased



strength and wider footprint created by the three piles is expected to allow for turbine installation in water up to 50 meters in depth. The tripile design is easily adaptable to a variety of bottom-type conditions, as each or all of the piles can be manufactured appropriately to match site-specific conditions while still being connected to the standard transition piece.

Figure 11: Tripile Foundation^{17,18}

¹⁵ Source: AREVA Multibrid/Jan Oelker 2009. Used with permission.

¹⁶ Source: AREVA Multibrid 2009. Used with permission.

¹⁷ Source: de Vries, E. (November 18, 2008). 5-MW BARD Near-shore Wind Turbine Erected in Germany.

Renewable Energy World. Retrieved July 2009 from www.renewableenergyworld.com. Used with permission.

¹⁸ Source: Copyright BARD-Group (www.bard-offshore.de). Used with permission.

Suction Bucket Alternative to Piles

Suction bucket foundations can conceivably be applied to any of the foundation types previously described as an alternative to driving piles deep into the seabed. Although research continues, the development of bucket foundations was set back substantially by a significant failure in 2007 during a demonstration phase. Instead of a slender beam being driven deep below the surface, bucket foundations employ a wider based cylinder, which does not extend as far below the floor, but still adequately resists loading due to its greater diameter and reactive soil forces. Because of their greater width, the cylinders are not driven under the surface, but rather are vacuum-suctioned into position under the seabed. Depending on soil conditions encountered at a site, the suction bucket alternative may be preferable to deep, slender piles for economic reasons and for ease of installation.

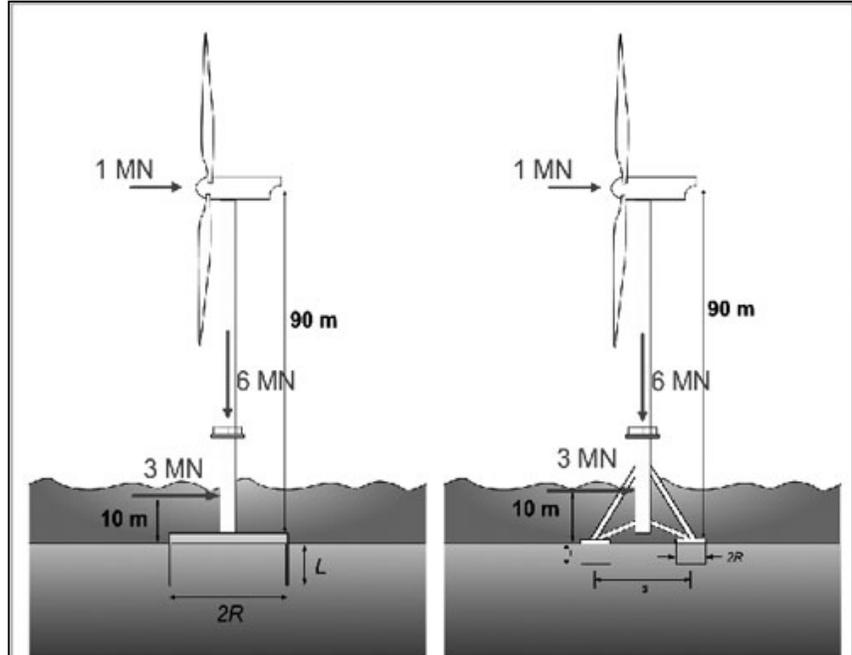


Figure 12: Suction Bucket Alternatives for the Monopile and Tripod Foundations¹⁹

Electrical System and Balance of Plant

Additional components of an offshore wind project include the electrical cabling, the substations, and the meteorological mast. The electrical cabling serves two functions: collection within the project, and transmission to shore. Both types of cable may have trenching requirements and specifications for armoring. Each substation typically includes one or more step-up transformers, switchgear, and remote control and communications equipment for the project. Procurement and coordination of equipment, crews, and materials for the balance-of-plant installation is a nontrivial task, due to the specialized nature of the installation and the limited number of experienced companies in the arena. Therefore, the balance-of-plant portion of development has the potential to drive project scheduling and can be a significant portion of the overall project price.

The typical offshore wind farm's electrical system consists of the individual turbine transformers, the collection system, the offshore substation, the transmission line to the mainland, and the onshore transmission components. Each of these components can impose an electrical loss on the gross energy production collected by the plant, so electrical system design is an important aspect of the overall system.

¹⁹ Source: Villalobos, A. (2009). Foundations For Offshore Wind Turbines. Revista Ingeniería de Construcción, v.24 n.1. Retrieved July 2009 from <http://www.scielo.cl>. Used with permission.

Pad Mount/34.5 Kilovolt Transformers

Individual turbine transformers for offshore turbines differ from those for onshore turbines. Rather than being mounted on the ground, the individual turbine transformer is either located up tower in the nacelle, or at the base of the turbine (down tower) where it is enclosed to protect it from the harsh marine elements. Each transformer takes the energy generated by the turbine and converts it to approximately 34.5 kilovolts for connection with the collection system.

Collection System

The collection system is a series of submarine conductors that are laid using trenching technology, such as utilizing high pressure water jets. As shown in Figure 13, the collection system is designed to connect multiple turbines in each string before delivering power to the project's offshore substation. This design minimizes cost while maintaining the electrical reliability of the lines.

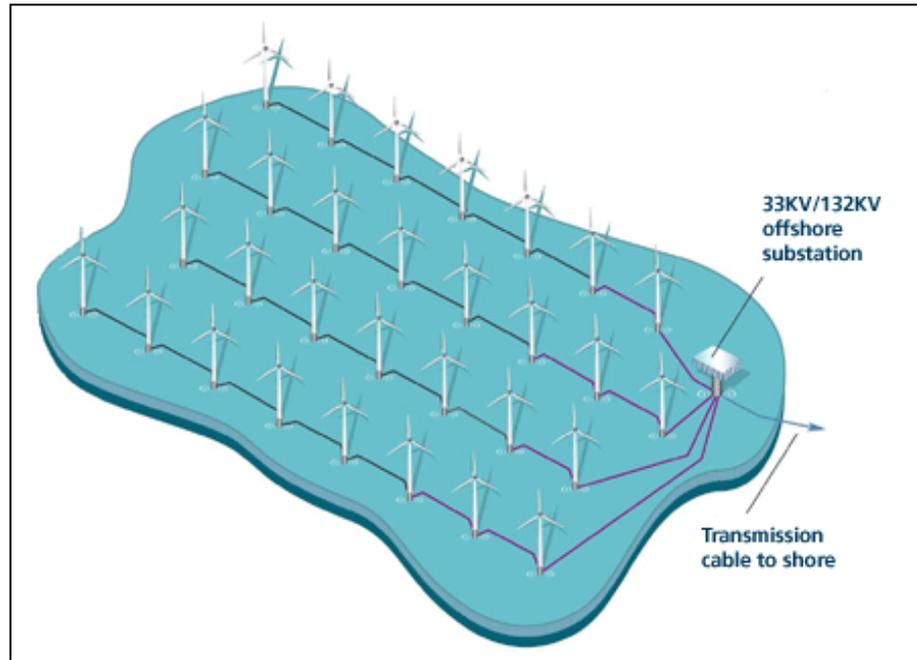


Figure 13: Optimal Collection System Design²⁰

Offshore Substation

Lines from the collection system typically come together at the on-site offshore substation, where the power is transferred to high voltage submarine lines for transmission back to shore. The offshore substation is sized with the appropriate power rating (MVA) for the project capacity, and steps the line voltage up from the collection system voltage to a higher voltage level, which is usually that of the point of interconnection (POI). This allows for all the power generated by the farm to flow back to the mainland on higher voltage lines, which minimizes the electrical line loss and increases the overall electrical efficiency.



Figure 14: Nysted Offshore Substation and Wind Farm²¹

²⁰ Source: Barrow Offshore Wind. Web site: <http://www.bowind.co.uk/project.shtml>. Used with permission from DONG Energy.

²¹ Source: Nysted Offshore Windfarm. Web site: http://www.dongenergy.com/SiteCollectionDocuments/NEW%20Corporate/Nysted/WEB_NYSTED_UK.pdf. Used with permission from DONG Energy.

Transmission to Shore

Transmission lines back to shore are specified at an appropriate voltage and power rating (MVA). The size of these cables is dependent on the project's capacity and the amount of power that will be transmitted to the shore, as shown in the table below. The transmission connects the offshore system (turbines, collection system, and offshore substation) to the mainland. Like the collection system, trenching and scour protection technologies are employed to install transmission lines.

Table 2: Required Line Voltage for Various Project Sizes

Project Size	Minimum Line Voltage (AC)
35 MW	35 kV
70 MW	69 kV
135 MW	115 kV
160 MW	138 kV
210 MW	161 kV
300 MW	230 kV
1000 MW	345 kV
2000 MW	500 kV

High voltage underwater transmission cabling is an important design and contracting consideration during the offshore wind development process. There are few manufacturers of the appropriate cable, and the fabrication and lead time is significant. The specialized installation vessels are relatively rare, costly and in high demand. These factors contribute to an installed cost for underwater transmission of around two to three times more than an equivalent voltage on land transmission.

Onshore Transmission Components (Point of Interconnection)

Depending on where the underwater cabling makes landfall, traditional buried or overhead transmission lines may need to be constructed on shore. At the onshore substation or switchyard, energy from the offshore wind farm is injected into the electric power grid. If the point-of-interconnection (POI) voltage is different than that of the submarine transmission, a substation using appropriately sized transformers is used to match the POI voltage; otherwise, a switchyard is used to directly interconnect the wind farm. Either the offshore or onshore substation acts as the power off-take point. At this point, power generated is metered and purchased via a Power Purchase Agreement (PPA) with a local utility, or by entering the Independent System Operator's merchant market.

For projects close to shore, it sometimes is not economical to construct both an offshore and an onshore substation. In these cases, the collection system is tied into a single substation (typically onshore), which also functions as the point of interconnection with the local electric grid.

Meteorology-Ocean (Met-Ocean) Monitoring System

While standard practices for offshore wind development are still evolving, the installation of an offshore meteorology monitoring system prior to project construction is becoming more common, and is strongly recommended. If sited properly, the monitoring station will also bring added value through the entire operating life of the project. The purpose of the monitoring platform is to provide continuous, real-time characterization of the weather and wave conditions within the project area. It can also serve as a platform for environmental monitoring (e.g. bird and bat, sea organisms, etc.) and other related programs. An offshore monitoring platform (or platforms) is an important component to the balance of

plant for an offshore wind farm, as it will ultimately provide the data necessary for characterizing the site conditions, performance, and environmental impact of the farm.

The platform typically accommodates an offshore meteorological mast, which has multiple uses during the project's lifetime. In the planning stage of the project, data from the mast is used for wind resource assessment. Oftentimes the platform used to qualify a site during the development phase is retained after installation to extend the climatologic record already initiated. This information is useful for verifying on-site conditions, turbine power performance testing, operational performance assessment, due diligence evaluation, and O&M management. For these purposes, the monitoring platform and meteorological tower should ideally be located just upwind of the project area in the prevailing wind direction: its use for power performance testing, for example, is dependent on its unobstructed placement within two to four rotor diameters of the test turbine(s).

The monitoring station can also provide valuable input data for wind forecasting and generation scheduling in the next-hour and next-day markets. Forecasting is a beneficial tool for market bidding strategy and transmission system reliability. In May 2009, NYISO enacted a Wind Management Plan, which requires all wind farms to supply meteorological data to the NYISO, and in turn to the NYISO's Forecasting Vendor. The offshore meteorological mast can be used to supply the necessary resource and climatologic information to comply with the Wind Management Plan requirements.

O&M Facility and Equipment

The design of the operations and maintenance (O&M) facility and the equipment procured for offshore turbine access is dictated by site-specific and environmental conditions. A well developed O&M service plan based on these parameters is essential to minimize turbine downtime, which results in lost revenue. The O&M facility, usually housed at a nearby port, provides rapid access to the project area for turbine maintenance and repairs; however, in cases where the project area is a greater distance from shore, O&M operations could conceivably be housed out of an expanded substation facility, where spare parts could be stored for immediate installation. This would allow for a quicker response time to turbine failures.

The O&M staff is outfitted with vessels to support repair efforts. Accessibility is a prime driver for availability, so vessels capable of operating safely even in slightly higher seas or more adverse conditions can improve farm performance. In situations where site access may be precluded by rough water conditions, helicopter access may provide a more costly but speedy alternative to get turbines up and running as soon as possible. Helicopter access from an oversized substation may prove to be more effective than from onshore, especially if the project is a great distance from shore, due to the cost and complexity of flying a helicopter a great distance while carrying turbine repair parts.

Layout Considerations

Wind farm layout and spacing are design considerations that can have a significant effect on project performance, size and cost. A number of factors can drive how a wind farm is spatially configured. One factor is the potential constraint of limiting the project's size dimensions due to boundary issues imposed by legal, regulatory, or geophysical reasons.



Figure 15: Horns Rev Project Layout²²

Another factor is facility performance and production efficiency, which influence turbine spacing and arrangement relative to the prevailing wind direction(s). As general practice, spacing between turbines aligned in a row is on the order of 5 to 10 rotor diameters, and spacing between rows is between 7 and 12 rotor diameters. Rows tend to be aligned perpendicular to the prevailing wind direction. The spacing goal is to reduce the impacts of wind flow disturbances (wakes) created by wind turbines in the upwind portions of a project area on the rest of the turbine array. These flow disturbances can reduce the energy output of individual turbines by 50% or more compared to unaffected turbines. They also create added turbulence to the flow field, thereby increasing mechanical loading on impacted turbines and decreasing component fatigue life. As future offshore projects become larger in size, the significance and potential impact of these “deep array” effects becomes greater.

Other layout factors can include sensitivity to environmental and aesthetic impacts and to existing uses (such as vessel traffic, fishing, air space usage, etc.) within the project area. The project layout of the 160 MW Horns Rev wind farm in Denmark (Figure 15) illustrates an offshore wind farm array having a turbine spacing of 7 by 7 rotor diameters.

LOGISTICS FOR INSTALLATION & MAINTENANCE

Logistics for offshore wind farm installation are far more complex than those for onshore projects. This is compounded by the lack of an experience base or installation infrastructure in the United States. This section provides an overview of some logistical factors to consider when developing an offshore wind farm.

Unfavorable weather and sea states are a leading cause of construction delays and installation cost risks. The safety of crews, vessels and equipment takes precedence over construction schedules. It is anticipated that the “weather window” for installing wind turbines in the Atlantic Ocean south of Long Island will be limited to the mid-spring to mid-autumn seasons. Even within these more favorable seasons, there will be periods of unsuitable conditions for work on the water or at hub height.

²² Source: Horns Rev wind project, Vattenfall AB. Used with permission.

Strategies have been employed in Europe to minimize the number of vessel transits from ports to offshore sites, thereby reducing the sensitivity of transportation to foul weather.

Construction Vessels

Heavy construction vessels must be employed to install an offshore wind farm. Special purpose vessels, such as the Jumping Jack Barge shown in Figure 16, now exist in Europe for the purpose of wind farm construction. Access to existing European installation vessels for use in the United States may be barred by the Merchant Marine Act of 1920, which is also known as the Jones Act. According to this act, energy-related projects being constructed in U.S. waters are typically required to employ U.S. vessels, although an allowance may be made if no suitable vessel exists.²³



Figure 16: Jumping Jack Barge for Offshore Wind Farm Installation²⁴



Figure 17: Heavy Construction Vessel Installing Wind Turbine on Jacket Foundation²⁶

This jurisdiction may restrict the use of a foreign offshore liftboat for construction of an offshore wind farm in the coast of Long Island. It is estimated that the construction of a U.S. liftboat could cost \$150 million.²⁵ Since the Jones Act restricts a non-U.S. liftboat from picking up equipment from a U.S. dock, complications with the Jones Act may be avoided by using a U.S.-owned feeder barge to transport installation equipment from the dock to a European liftboat on-site. Additional investigation is recommended to assess the implications of the Jones Act on offshore wind farm construction in the United States.

²³ Eisenhower, Brian. 2007. "Memorandum: U.S. Cabotage Laws and Offshore Energy Projects." June 15. <http://law.rwu.edu/sites/marineaffairs/content/pdf/Eisenhower.pdf>

²⁴ Source: Jumping Jack Goes Down (July 31, 2007). Vertical Press News Archive. Retrieved July 2009 from www.vertikal.net. Web site: <http://www.vertikal.net/en/stories.php?id=4366>. Used with permission.

²⁵ See "How to Keep Up With the Jones Act." *North American WindPower*, Vol. 6, No. 5: June 2009.

²⁶ Source: Scaldis Salvage & Marine Contractors. Web site: <http://www.scaldis-smc.com/renewable.htm>. Used with permission.

Port Availability

Nearby ports for wind farm installation must be able to accommodate deep draft vessels and support large equipment offloading. In addition, they must have an adequate laydown area for turbine components. Typically, the available port laydown space should be roughly three-quarters to one acre of land area per turbine.²⁷ Ideally, if adequate space is available at the installation port, hub and blade assemblies can be constructed onshore, minimizing the number of offshore crane operations per turbine installed. This makes the construction schedule less sensitive to weather delays.



Figure 18: Port of Mostyn Construction Base for Burbo Bank Offshore Wind Farm (UK)²⁸



Figure 19: Helicopter Access to Vestas Turbine²⁹

A nearby port is also essential to accommodate the O&M activity during the operational phase of the project. However, the requirements for port specifications are far less demanding because of the much smaller size of service vessels and the limited requirements for any laydown area. A landing location for a service helicopter may be desirable if this mode of transport is used as an alternative to surface vessels, especially when sea states frequently limit the use of surface vessels.

²⁷ For example, Burbo Bank employed 20 acres of lay down area for 25 turbines; and the Port of Romoe near Butendiek is planning to create 60 acres of lay down space for the 80 turbine project. This metric is also dependent on turbine size. Sources: <http://www.porttechnology.org/article.php?id=2777>, <http://www.greenjobs.com/public/industrynews/inews06092.htm>

²⁸ Source: The Port of Mostyn (2008). Used with permission.

²⁹ Source: Nicky Plok/UNI-FLY A/S. Used with permission.

CONCLUSIONS

This report has provided an overview of offshore wind system technologies and design criteria that are likely to be relevant to the Collaborative's proposed offshore project south of Long Island. Key considerations include the following:

- The ultimate selection of a suitable wind turbine models and foundation designs will depend on a site-specific evaluation of the external environmental conditions of the project area. These conditions encompass the winds, weather, waves, currents, water depths, and seabed characteristics.
- There are a limited number of commercially available offshore-specific turbine models available today for use in the United States. The capacity rating of individual units is between 2 MW and 5 MW.
- The preferred foundation type for the proposed project area is likely to be a multi-member (jacket, tripod, or tripile) design that is suitable for deeper waters (>20 m).
- Construction schedules will be highly weather and sea state dependent. The higher frequency of unfavorable conditions during the cold season will likely restrict the primary construction season to the mid-spring to mid-autumn period.
- Access to existing installation vessels may be restricted for U.S.-based projects due to Jones Act restrictions, thereby necessitating creative construction methods and likely the development of domestic special-purpose vessels.

APPENDIX - TABLE OF OFFSHORE WIND FARMS

Project Name	Country	Capacity (MW)	Operating Year	Status	No. Turbines	Turbine Size (MW)	Turbine Model	Water Depth (m)	Distance from Shore (km)	Foundation Type
Vindeby	Denmark	5	1991	Commissioned	11	0.45	Siemens 450	3 to 5	1.5	Gravity
Lely	Netherlands	2	1994	Commissioned	4	0.5	NEG Micon	5 to 10	1	Monopile
Tuno Knob	Denmark	5	1995	Commissioned	10	0.5	Vestas 500 kW	3 to 5	6	Gravity
Dronten/Irene Vorrink	Netherlands	16.8	1996	Commissioned	28	0.6	Nordtank	5	0	Monopile
Bockstigen	Sweden	2.75	1997	Commissioned	5	0.55	NEG Micon 550 kW	6	3	Monopile
Blyth	United Kingdom	4	2000	Commissioned	2	2	Vestas V66	9	1	Monopile
Middelgrunden	Denmark	40	2001	Commissioned	20	2	Bonus 2 MW	5 to 10	2 to 3	Gravity
Yttre Stengrund	Sweden	10	2001	Commissioned	5	2	NEG Micon 2 MW	8	5	Monopile
Horns Rev	Denmark	160	2002	Commissioned	80	2	Vestas V80	6 to 14	14 to 17	Monopile
Samsøe	Denmark	23	2002	Commissioned	10	2.3	Siemens 2.3	11 to 18	3	Monopile
Utgrunden	Sweden	11.4	2002	Commissioned	8	1.425	Enron 1.425	7 to 10	8 to 12	Monopile
Frederikshavn	Denmark	10.6	2003	Commissioned	2 1 1	3 2.3 2.5	Vestas V90 Bonus 2.3 Nordex N90	1	1	Monopile, Bucket
North Hoyle	United Kingdom	60	2003	Commissioned	30	2	Vestas V80	5 to 12	8	Monopile
Sky 2000	Germany	150	2003	Commissioned	50		Repower MM82	20	17	Tripod
Emden Nearshore	Germany	4.5	2004	Commissioned	1	4.5	Enercon	3	0	N/A
Rodsand I/Nysted	Denmark	165.6	2004	Commissioned	72	2.3	Siemens 2.3	6 to 10	6 to 10	Gravity
Ronland	Denmark	17.2	2004	Commissioned	8	2	Vestas V80	1	0	Monopile
Scroby Sands	United Kingdom	60	2004	Commissioned	30	2	Vestas V80	2 to 10	3	Monopile
Setana	Japan	1.32	2004	Commissioned	2	0.66	Vestas V47	13	1	N/A
Arklow Bank	Ireland	25	2005	Commissioned	7	3.6	GE 3.6	2 to 5	10	Monopile
Kentish Flats	United Kingdom	83	2005	Commissioned	30	3	Vestas V90	5	9	Monopile
Barrow	United Kingdom	90	2006	Commissioned	30	3	Vestas V90	15	7	Monopile
Beatrice (Moray Firth)	United Kingdom	10	2006	Commissioned	2	5	REpower 5M	43	25	Jacket
Rostock	Germany	2.5	2006	Commissioned	1	2.5	Nordex 2.5 MW	2	1	N/A
Blue H Puglia (Pilot)	Italy	0.08	2007	Commissioned	1	0.08	WES18 mk1	108	20	Floating
Bohai Bay	China	1.5	2007	Commissioned	1	1.5	Goldwind	N/A	70	Jacket
Burbo Bank	United Kingdom	90	2007	Commissioned	25	3.6	Siemens 3.6	10	5.2	Monopile
Egmond aan Zee (Nordzee Wind)	Netherlands	108	2007	Commissioned	36	3	Vestas V90	17 to 23	8 to 12	Monopile
Inner Dowsing	United Kingdom	97.2	2007	Commissioned	27	3.6	Siemens 3.6	10	5	Monopile
Lynn	United Kingdom	97.2	2007	Commissioned	27	3.6	Siemens 3.6	10	5	Monopile
Hooksiel (Demonstration)	Germany	5	2008	Commissioned	1	5	BARD 5 MW	2 to 8	1	Tripole
Kemi Ajos Phase I	Finland	15	2008	Commissioned	5	3	WindWinD 3 MW	N/A	0 to 1 km	Artificial Island
Lillgrund Oresund	Sweden	110	2008	Commissioned	48	2.3	Siemens 2.3	2.5 to 9	10	Gravity
Princess Amalia (Q7-WP)	Netherlands	120	2008	Commissioned	60	2	Vestas V80	19 to 24	> 23	Monopile
Alpha Ventus/Borkum West	Germany	60	2009	Financed/Under Construction	6 6	5 5	Multibrud M5000 REpower 5M	30	45	Tripod Jacket
Gasslingegrund (Lake Vanern)	Sweden	30	2009	Financed/Under Construction	10	3	(DynaWind AB)	4 to 10	4	N/A
Gunfleet Sands Phase I	United Kingdom	108	2009	Financed/Under Construction	30	3.6	Siemens 3.6	2 to 15	7	Monopile
Gunfleet Sands Phase II	United Kingdom	64	2009	Financed/Under Construction	18	3.6	Siemens 3.6	2 to 15	7	Monopile
Horns Rev Expansion	Denmark	210	2009	Financed/Under Construction	91	2.3	Siemens 2.3	9 to 17	30	Monopile
Hywind/Karmoy (Floating Pilot)	Norway	2.3	2009	Partially Commissioned	1	2.3	Siemens 2.3	120 to 700	10 km initially	Floating
Kemi Ajos Phase II	Finland	15	2009	Financed/Under Construction	5	3	WindWinD 3 MW	N/A	0 to 1 km	N/A
Rhyl Flats/Constable Bank	United Kingdom	90	2009	Partially Commissioned	25	3.6	Siemens 3.6	8	8	Monopile
Robin Rigg (Solway Firth)	United Kingdom	180	2009	Financed/Under Construction	60	3	Vestas V90	>5	10	Monopile
Sprogo	Denmark	21	2009	Financed/Under Construction	7	3	Vestas V90	6 to 15	1	Gravity
Thornton Bank	Belgium	30	2009	Commissioned	6	5	REpower 5M	25	30	Gravity
Avedore/Hvidovre	Denmark	15	2010	Financed/Under Construction	3	5	N/A	N/A	20 to 100	N/A
Baltic I	Germany	48.3	2010	Financed/Under Construction	21	2.3	Siemens 2.3	18	16	N/A
Bard Offshore I	Germany	400	2010	Financed/Under Construction	80	5	BARD 5 MW	39 to 41	100	Tripole
Greater Gabbard Phase I	United Kingdom	150	2010	Financed/Under Construction	140	3.6	Siemens 3.6	24 to 34	25	Monopile
Nordergrunde	Germany	90	2010	Financed/Under Construction	18	5	REpower 5M	4 to 20	30	Monopile or Jacket
Rodsand II	Denmark	207	2010	Financed/Under Construction	90	2.3	Siemens 2.3	5 to 12	6 to 10	Gravity
Sea Bridge	China	102	2010	Financed/Under Construction	34	3	Sinovel 3 MW	8 to 10	8 to 14	N/A
Walney Island Phase I	United Kingdom	183.6	2010	Financed/Under Construction	51	3.6	Siemens 3.6	20	15	N/A
Belwind	Belgium	165	2011	Financed/Under Construction	55	3	Vestas V90	20 to 35	46	Gravity
Borkum West II	Germany	400	2011	Financed/Under Construction	80	5	Multibrud M5000	22 to 33	45	Tripod
Ormonde	United Kingdom	150	2011	Financed/Under Construction	30	5	REpower 5M	17 to 22	10	Jacket
Thanet	United Kingdom	300	2011	Financed/Under Construction	100	3	Vestas V90	20 to 25	7 to 9	Monopile
Borkum Riffgat	Germany	264	2012	Financed/Under Construction	44	5	N/A	16 to 24	15	N/A
London Array Phase I	United Kingdom	630	2012	Financed/Under Construction	175	3.6	Siemens 3.6	23	>20	Monopile
Sheringham Shoal	United Kingdom	316.8	2012	Financed/Under Construction	88	3.6	Siemens 3.6	16 to 22	17 to 23	Monopile
Walney Island Phase II	United Kingdom	183.6	2012	Financed/Under Construction	51	3.6	Siemens 3.6	20	15	N/A