National Offshore Wind Energy Grid Interconnection Study

Executive Summary

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DISCLAIMER

TABLE OF CONTENTS

LIST OF ACRONYMS

AAM - alternative arm modular

AC - alternating current

AWC - Atlantic Wind Connection

BA - balancing areas

BOEM - Bureau of Ocean Energy Management

CF - capacity factor

COE - cost of energy

COWICS - Carolina Offshore Wind Integration Case Study

CREZ - competitive renewable energy zone

CSP - concentrating solar power

CTL - cascaded two-level

DC - direct current

DFIG - doubly-fed induction generator

DOE - U.S. Department of Energy

DOI - U.S. Department of the Interior

DOWNVInD - Distant Offshore Wind farms with No Visual Impact in Deepwaters

EA - environmental assessment

EENS - expected energy not supplied

EIA - U.S. Energy Information Administration

EIS - environmental impact statement

EMM - U.S. Energy Information Agency Electricity Market Modules

ENTSO-E - European Network of Transmission System Operators for Electricity

EPR - ethylene propylene rubber

ERCOT - Electric Reliability Council of Texas

ERGIS - Eastern Renewable Generation Integration Study

EWITS - Eastern Wind Integration and Transmission Study

FERC - Federal Energy Regulatory Commission

GIP - generator interconnection process

GW - gigawatts

HV - high voltage

HVAC/HVDC - high-voltage alternating/direct current

IEC - International Electrotechnical Commission

IEEE - Institute of Electrical and Electronic Engineers

IGBT - insulated-gate bipolar transistor

ISO - independent system operator

ISO-NE - Independent System Operator New England

kV - kilovolts

kW - kilowatts

LCC - line-commutated converter

LCOE - levelized cost of energy

LMP - locational marginal prices

MASS - Mesoscale Atmospheric Simulation System

MISO - Midcontinent Independent System Operator

MMC - modular multi-level

MMS - Minerals Management Service

MOU - memorandum of understanding

MTDC - multi-terminal direct current

MVDC - medium-voltage direct current

MW - megawatts

MWh - megawatt-hours

NAMTGM - North American transmission grid model

NCF - net capacity factor

NEPA - National Environmental Policy Act

NREL - National Renewable Energy Laboratory

NERC - North American Reliability Corporation

NOWEGIS - National Offshore Wind Energy Grid Interconnection Study

NOAA - National Oceanic and Atmospheric Administration

nmi - nautical mile

NPC - neutral-point-clamped

NWPP - Northwest Power Pool

OCS - Outer Continental Shelf

ODIS - National Grid’s Offshore Development Information Statement

OREC - offshore wind renewable energy certificate

PCC - point of common coupling

PJM - the regional transmission organization covering all or parts of 13 states and the District of Columbia

PPA - power purchase agreement

PUC - public utilities commission

REC - renewable energy certificate

ReEDS - Regional Energy Deployment System

RPS - renewable portfolio standards

RTO - regional transmission organization

TRC - technical review committee

TWh - terawatt-hours

USGS - U.S. Geological Survey

var - volt-ampere reactive

VOWTAP - Virginia Offshore Wind Technology Advancement Program

VSC - voltage source converter

WEA - wind energy area

WTG - wind turbine generator

XLPE - cross-linked polyethylene

LIST OF FIGURES

LIST OF TABLES

SYNOPSIS

This executive summary is a companion to the full National Offshore Wind Energy Grid Interconnection Study (NOWEGIS) report and primarily discusses the conclusions and recommendations of the study, with limited descriptions of the work conducted to arrive at those conclusions. For a more complete treatment of the assumptions, methods, and results of the study tasks, please refer to the main report.

NOWEGIS is one piece of a body of work funded by the U.S. Department of Energy (DOE) under funding opportunity announcement DE-FOA-0000414, which was designed to identify and help address the market barriers to the large-scale introduction of offshore wind energy into the U.S. energy portfolio. NOWEGIS was a national-level study (of the lower 48 states) that considered the resources, technologies, and regulatory environment that may advance or hinder this goal. The key results are expected to be of primary interest to executives and decision makers. These are discussed immediately below, with additional supporting descriptions of the work in the balance of the executive summary and in the main report.

Key Results and Observations

1. **The United States has sufficient offshore wind energy resources to consider having at least 54 GW of offshore wind.** NOWEGIS focused on the ability to integrate up to 54 gigawatts (GW) of offshore wind into the U.S. grid by 2030 based on the levels proposed in the DOE report *20% Wind Energy by 2030* [1]. However, the resource assessment—which considered exclusion zones as a result of military use, commercial shipping lanes, environmental concerns, and sites that were not ultimately selected—indicates that a significantly larger amount of offshore wind could, in theory, be utilized.
2. **The methods used for evaluating the integration of land-based wind energy are also appropriate for studying offshore wind energy.** The methods currently used for onshore wind power plants to evaluate system impacts, determine generation reserve requirements, and estimate system-wide operational costs apply directly to studying offshore wind. The same types of data—including wind production profiles in the hourly and intra-hourly time frames, system topology, and rating information—are required.
3. **Appropriate technologies exist for interconnecting large amounts of wind energy to the U.S. grid.** Multiple technologies exist that can be used to collect wind-generated electricity and deliver it to the onshore grid. Technologies that are designed for alternating current (AC) have distance limitations that require them to be near shore or require additional offshore equipment to allow for farther distances. Technologies that are designed for direct current (DC) are generally more expensive, because they require larger converter systems; however, when they are configured in an offshore backbone or grid, they show the potential to bring important benefits onshore that may help justify their higher costs.
4. **At a regional or national level, offshore wind energy may provide significant value.** Although offshore wind projects are likely to have high capital costs, some benefits will accrue from a system-wide perspective that can help to justify the high initial investment. For example, NOWEGIS estimated that the 54 GW of offshore wind would provide a national reduction of annual production costs of $7.68 billion, resulting in an approximate value of offshore wind at $41/MWh.
5. **State policies that recognize the energy, environmental, and economic benefits of offshore wind are critical to encouraging investment in offshore wind.** Because of the higher capital

costs, potential grid reinforcement requirements, and, to some degree, the uncertainties associated with first deployments of commercial-scale offshore wind projects, state policies requiring the purchase of power from offshore wind projects will be necessary. State policies can encourage offshore wind deployment by creating demand for this resource through renewable portfolio standards (RPS) that establish policy mechanisms based on the needs of the state—such as carve-outs, minimum requirements, or even aspirational goals. Some states have altered the regulatory paradigm to allow for the inclusion of a broader range of benefits—including economic development, environmental benefits (carbon-free power), and energy benefits of offshore wind. State policies are needed to recognize offshore wind's energy, environmental, and economic benefits and to create demand for offshore wind.

6. **Reductions in the federal permitting and siting process are critical to achieving gigawatt-scale offshore wind deployment in the next decade.** Although great strides have been made to reduce the permitting schedule from the 12 yr it took for Cape Wind to between 2 yr and 4 yr today, further enhancements by the multitude of federal permitting and regulatory agencies are needed. Further, if offshore delivery networks interconnect multiple entities (utilities; independent system operators, or ISOs; and regional transmission organizations, or RTOs), significant cooperation will be required to ensure the equitable distribution of cost burdens and benefits. This may require oversight at the federal level, but it is currently unclear what form of oversight might work best.
7. **Current organizational structures in the United States may make it more difficult to attain the offshore wind value found in the study.** This is because the value levels indicated above rely on a regional (or broader) perspective. Areas such as the southeast United States that do not have RTOs may find it difficult to sufficiently socialize and justify the costs compared to the benefits. Even large utilities such as Duke Energy may have difficulty doing so. On the other hand, working from such a perspective may be more straightforward in areas that have an ISO or RTO (e.g., ISO-New England, or ISO-NE; or PJM), but even here each state and utility involved must be willing to consider and share in the broader perspective, costs, and benefits.
8. **Research and development promise to help reduce initial capital investment.** One of the major market barriers to offshore wind is and will continue to be the high capital costs compared to other forms of energy production. However, several areas of research and development are available that can help reduce these initial costs. These include cable developments, offshore platform innovations, and platform size and weight reductions accomplished through the companion development of wind turbine configurations and collector system designs as well as the development of compact high-voltage direct-current (HVDC) converters. Many of these developments may be pursued by the industry, but governmental and academic cooperative agreements with industrial manufacturers will help to more rapidly commercialize any developments and in a manner consistent with actual market demands.

SUMMARY

Background

The United States has multiple objectives in developing a national energy strategy. Among these are increasing economic growth, improving environmental quality, and enhancing national energy security. Electric power generated by wind resources has become an increasingly important part of the nation's energy production portfolio. All current U.S. wind production is land based, despite significant accessible offshore wind resources. Many factors contribute to the lower use of offshore wind resources, but among them are accessibility to data for determining resource levels and optimal locations as well as the difficulty and cost of transmitting the wind-generated electricity to the onshore power grid.

In February 2011, the DOE published *A National Offshore Wind Strategy: Creating an Offshore Wind Energy Industry in the United States* [2], which identified numerous market barriers to the adoption of responsible commercial offshore wind development. As part of its national strategy, the Offshore Wind Innovation and Demonstration (OSWInD) initiative, DOE issued funding opportunity announcement DE-FOA-0000414 to help address these barriers. One of these efforts is the National Offshore Wind Energy Grid Interconnection Study (NOWEGIS), a study that will help provide the data necessary to produce a roadmap to achieving offshore wind energy goals such as those proposed in *20% Wind Energy by 2030* [1]. That report indicated the potential to achieve 54 GW of deployed offshore wind-generating capacity by 2030 (at a production cost of $0.07/kWh) and 10 GW of capacity deployed by 2020 (at a production cost of $.10/kWh). The guidance received through the entirety of the funding opportunity announcement efforts will also assist in bringing the United States levels of renewable resources that are more comparable to those achieved in other areas of the world, such as Europe.

The intent of the NOWEGIS effort described here was to help address DOE's two critical objectives in overcoming offshore wind barriers: (1) to reduce the cost of energy (COE) and (2) to reduce deployment timelines. The study built upon the significant body of work previously performed under DOE's direction and by the wind industry to identify various opportunities for and roadblocks to the integration of offshore wind energy into the various interconnections throughout the United States. The study team, led by ABB, Inc., included AWS Truepower, Duke Energy, the National Renewable Energy Laboratory (NREL), and the University of Pittsburgh. Each of the team members' strengths and areas of expertise were leveraged to address four primary tasks that assessed offshore wind development near the U.S. coastal regions, including the Atlantic Ocean, the Gulf of Mexico, the Great Lakes, and the Pacific Ocean. These areas and the flow of the study are illustrated in Figure ES-1, with a more detailed description of each given below.

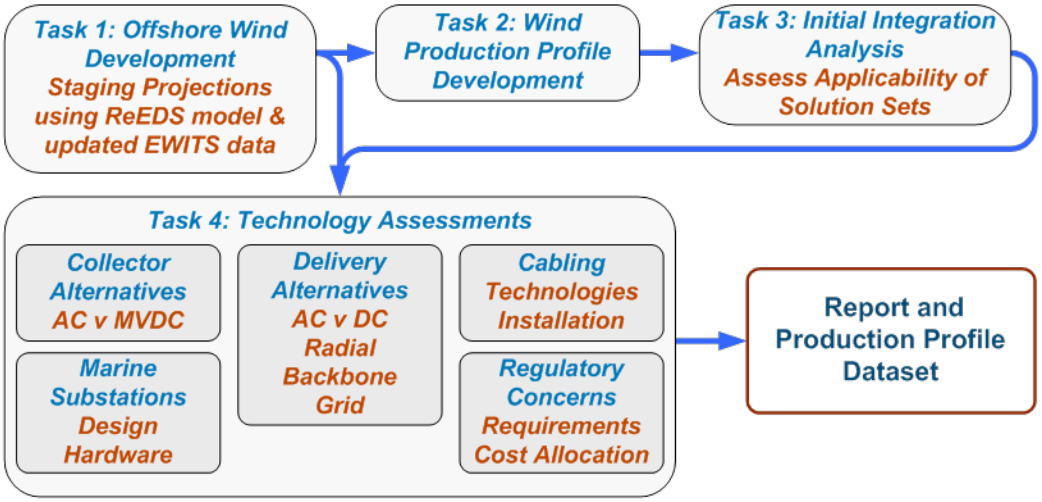


Figure ES-1. NOWEGIS tasks and study flow

The tasks identified in Figure ES-1 are as follows:

1. **Offshore wind development staging projections**—This task determined the expected offshore wind development staging. The work built upon the Eastern Wind Integration and Transmission Study (EWITS) [3], with updated data to reflect current trends in offshore development and expanded to include areas not previously considered. Site screening based on a geographic information system was used to select likely locations for offshore wind development, including the areas not considered in EWITS.
2. **Wind production profile development**—This task determined the wind production profiles based on the site-screening results. Mesoscale atmospheric simulations were performed to determine the anticipated wind power production profiles appropriate for integration studies.
3. **Initial integration analysis**—This task assessed the integration impacts of offshore wind, such as wind variability, and the applicability of current wind integration study methods to offshore wind deployment scenarios.
4. **Technology assessments**—This task assessed offshore wind energy collection and delivery technologies. This included a qualitative overview of the technologies currently used or those with a strong potential for consideration at some future period, as well as quantitative assessments of cost, reliability, potential operational impacts, and potential production cost impacts of several technology alternatives. Five focus areas were considered: the offshore collection system, the delivery system from platform to onshore substation, undersea cabling and installation, marine substation design and hardware, and regulatory issues.

As shown, Tasks 1 through 3 were directly related and performed in order. Much of the review of the technologies could be performed in parallel with these efforts, but other aspects of the review, such as the assessments of production cost impacts, could be performed only upon completion of Task 3.

The ultimate goal of these study efforts was to provide useful information for the wind energy industry to help establish a roadmap to achieve greater levels of offshore wind power production in the United States.

To ensure that the study efforts were appropriately focused and of interest to the industry, a technical review committee (TRC) was established that included members from regional system operators, industry groups, and governmental entities. The study team met with the TRC regularly throughout the study effort and kept them informed of progress and results.

Offshore Wind Development—Staging Projections

The first task in the study was to determine the location and timing for the development of the 54 GW of offshore wind capacity as outlined in [1]. The deployment was determined using NREL's Regional Energy Deployment System (ReEDS) model [4], which is a long-term generation and transmission capacity expansion model. It accommodates the diversity of the various renewable energy technologies and applications, the location-dependent quality of many of these resources, and the inherent variability and uncertainty of wind and solar generation. ReEDS is the analytical backbone of many NREL studies that involve capacity expansion, such as the aforementioned DOE study [1], *Renewable Electricity Futures* [5], and the *Sunshot Vision Study* [6].

The *20% Wind Energy by 2030* report [1] determined that the capacity build-out for onshore and offshore wind with sufficient resource quality (capacity factor) could reach the 20% target based on the assumed technology costs and performance data (Figure ES-2). This resulting schedule was used as an input to ReEDS in this study to reproduce the timing of the deployment of the 54 GW of offshore wind. Updated assumptions—such as capital and operational costs, transmission costs, fuel and demand projections, and RPSs—were used in this study.

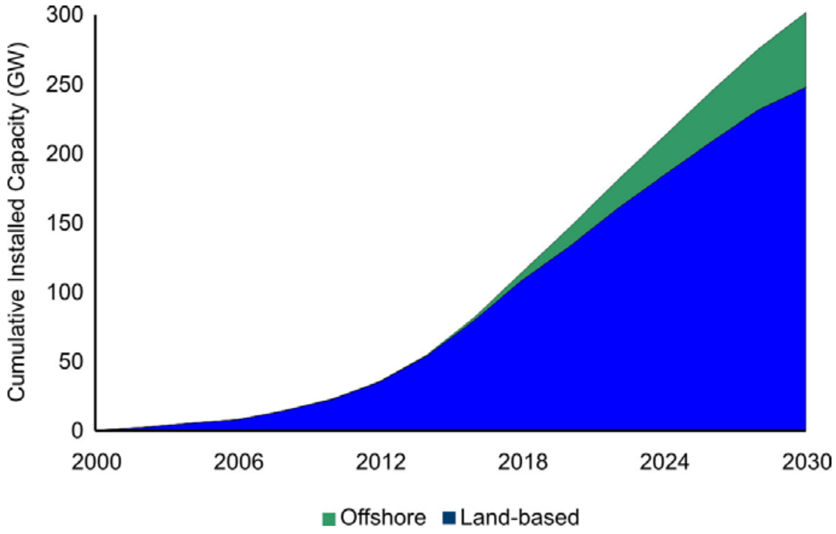


***Figure ES-2. Installed onshore and offshore wind as outlined in* 20% Wind Energy by 2030**

Figure ES-3 shows where the 304 GW of onshore and offshore wind were deployed. Onshore wind was heavily installed in the resource-rich Midwest (especially in northern and southeastern Texas, eastern Colorado, and Iowa), the Great Lakes (Michigan), and to a lesser extent throughout the Western Interconnection, the Northeast, and Appalachia. Offshore wind deployment was concentrated in the North and Mid-Atlantic, and marginally in the Gulf Coast, Great Lakes, and northern California/southern Oregon area.

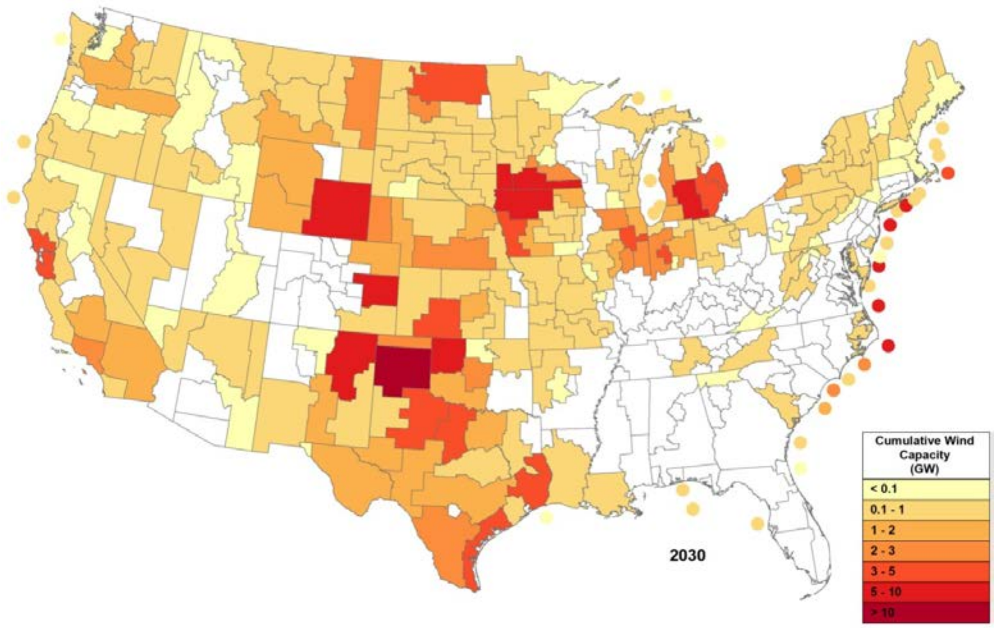


Figure ES-3. Onshore and offshore wind deployed in 2030

The geographical resolution in ReEDS allowed for a detailed analysis of offshore deployment. The maps in Figure ES-4 show the two-year increments for the East Coast, where an offshore grid would be most likely to benefit from offshore wind deployment and integration. The first steps of the deployment would occur in the northern portion of the coast, between New Jersey and Massachusetts. It is in that area where the first phase of the grid could be laid out, possibly in the 2018 time frame. In the next few years, deployment would then begin to be more present in Virginia, which could represent a second phase. Finally, Phase 3 would extend to North and South Carolina. Based on the level of deployment, the grid would not continue beyond this point, unless other economic or operational factors were taken into account.

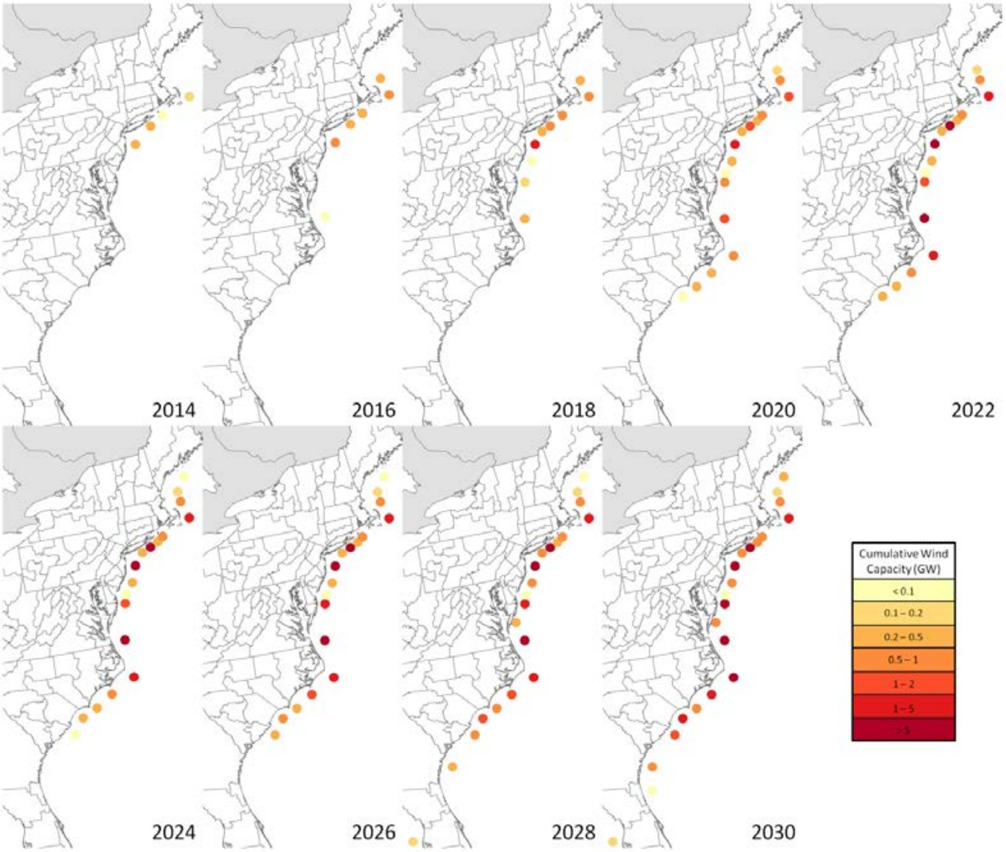


Figure ES-4. Offshore wind build-out for the East Coast

Wind Production Profile Development

The updated set of runs from NREL's ReEDS model provided a likely build-out scenario over time across various zones in the Atlantic, Gulf, Pacific, and Great Lakes based on wind resource, cost, and wind variability. For Task 2 of the study, the site-selection process built upon these scenarios by identifying likely locations of individual wind farms (roughly 300 MW to 1,000 MW each), meeting and/or exceeding the expected 2030 capacity in each ReEDS zone. The screening first incorporated areas identified in previous studies as being favorable for offshore development and areas of all projects currently in planning stages.

Next, areas to be excluded from development because of environmental, governmental, or technical constraints were compiled from a variety of sources. Exclusions were relaxed in cases where they overlapped Bureau of Ocean Energy Management (BOEM) wind energy areas (WEA). The remaining wind resource was then considered. A net capacity factor map was constructed from 200-m offshore wind speed maps and historical wind speed distributions, environmental loss factors, and a composite turbine power curve derived from characteristics of current and future turbine technologies. (A 7.5-MW International Electrotechnical Commission, or IEC, Class I machine with a hub height of 100 m and a rotor diameter of 165 m was assumed.)

A geographic information system (GIS) based analysis was employed to consider the WEAs, exclusion areas, and net capacity factor to select the likely locations for offshore wind farms. The screening algorithm sought to identify near-contiguous locations with enough area to support a project of at least

300 MW while avoiding excluded areas. It allowed each site to expand as long as the capacity factor did not decrease by more than 5%. Given the large size of the composite turbine and the preliminary nature of the screening, a 10 x 10 rotor-diameter spacing was used, which resulted in a site density of 2.75 MW/km^2. A 20-km buffer between sites was applied (without regard to prevailing wind direction) to reduce the impact of neighboring wind farms. The maximum site size was initially set at 1,000 MW; however, size and separation constraints were relaxed when necessary to meet the ReEDS zone target capacities. Water depth was not a limiting factor in the site selection, but depth was considered in the Great Lakes and Pacific Ocean to increase variety in site depth and distance to shore.

The sites were then ranked using simplified COE assumptions from the ReEDS model, with a cost multiplier applied to sites in water depths greater than 30 m. The lowest cost sites that fulfilled capacity targets in each ReEDS zone were retained, resulting in 209 potential sites totaling more than 134 GW. Ultimately, the lowest cost sites totaling 54 GW were retained, regardless of ReEDS zone targets.

Wind profiles were then simulated at each of the potential wind sites. Simulations from EWITS were used in the Northern Atlantic and Great Lakes; whereas new simulations using the same model configuration and period were run in the remaining regions to ensure consistency between the data sets. Modeled wind speeds were compared to offshore wind measurements greater than 20 m height taken from 13 National Data Buoy Center locations during the study period. The predicted 100-m wind speed was on average 0.14 m/s, or 1.5% lower than the observed mean speeds sheared to 100 m; whereas the standard deviation of the biases was 0.40 m/s, or 5.2% of the observed mean. The model bias was not regionally based. It was found that the model generally captured annual, monthly, and diurnal wind speed patterns well, slightly underpredicting cool season wind speeds. The modeled speeds were slightly less variable than observed, likely because the model represents a 2-km grid cell (which is more representative of a wind farm) instead of measurements that represent a single point.

The simulations were used to synthesize wind power production profiles at each of the selected sites following the EWITS methodology. The loss assumptions were refined for the larger turbine assumption, and electrical losses were reduced to include only those from the turbines to the offshore substation. Modeled wind speeds were adjusted to match mean diurnal patterns from offshore measurements and scaled to AWS Truepower's 200-m resolution offshore wind maps. Resulting wind speeds were reduced for wake losses based on wind direction. Winds were further adjusted by the simulated turbulence's kinetic energy to reflect the impact of gusts. The composite power curve was adjusted for air density and applied to the wind speeds. Finally, availability and electrical losses were applied, and high wind hysteresis was taken into account to simulate net power.

In previous studies, a correction was developed to reduce spurious patterns in wind speed variability caused by model restarts and ingestion of measured data into the model; however, this method proved insufficient for the large hypothetical wind farms in this study. Instead, a new correction was developed that removed the spurious increase in wind speeds and net power ramps and produced more realistic profiles. A technique developed for the Eastern Renewable Generation Integration Study (ERGIS) [7] to reduce this issue in sites aggregated across a region was also applied to the final data set.

The end result was a 10-minute wind speed and net power data set spanning the study years from 2004 to 2006 at each hypothetical site. Results indicated expected net capacity factors in excess of 50% offshore New England, Northern California, and southern Oregon, decreasing to 40% throughout the Pacific Coast, much of the Great Lakes, the Mid-Atlantic, and southern Texas. The only sites with capacity factors less than 30% were offshore Florida. (See Figure ES-5.) These capacity factors are generally higher than previous studies such as EWITS and the New England Wind Integration Study [8], the PJM renewable integration study [9], and ERGIS, likely as a result of the larger, more productive composite turbine in the present study. For example, the NOWEGIS power curve is 27% to 28% more productive in midrange wind speeds than the composite curve used in EWITS and 21% higher than the composite curve used in the PJM study and ERGIS. Because the power curves were updated over time to reflect advances in turbine technology, the increase in expected net capacity factor is not surprising.

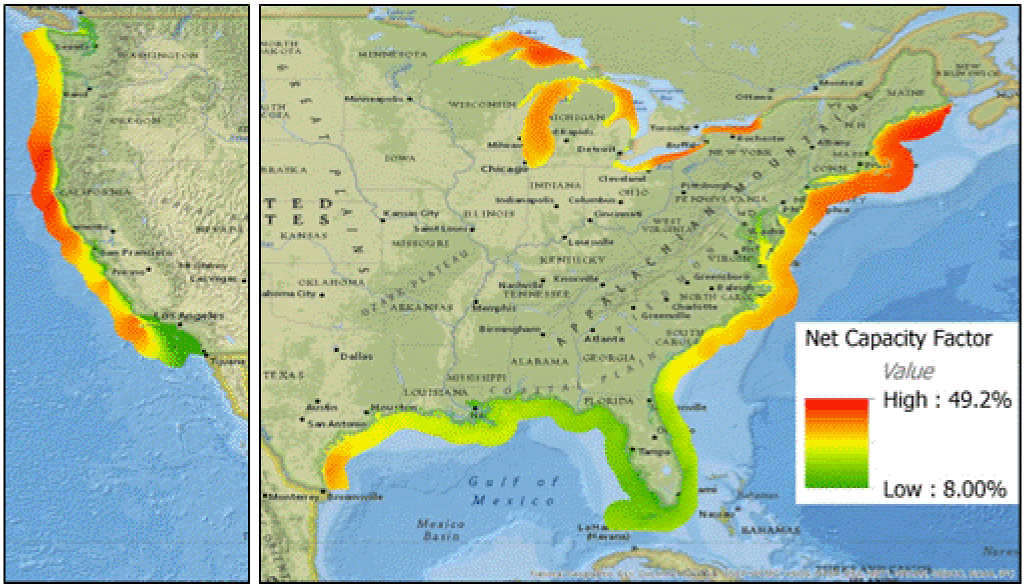


Figure ES-5. Map of national wind net capacity factor

Initial Integration Analysis

The potential operational impact of deploying 54 GW of offshore wind in the United States was examined. The capacity was not evenly distributed; instead, it was concentrated in regions with better wind quality and close to load centers, as shown in Table ES-1. Most of the capacity was located in the East Coast regions, with additional capacity installed in the Great Lakes, the Electric Reliability Council of Texas (ERCOT), and on the West Coast. The location of the offshore wind was determined with ReEDS and later refined using high-resolution data and numerical weather prediction models. These models were used to simulate 10-minute power profiles for the years 2004, 2005, and 2006.

Table ES-1. Installed Offshore Capacity by GridView Region

Interconnection	GridView Region	Offshore Wind Capacity (GW)
Eastern	PJM	18.2
	New England	13.1
	Carolinas	8.3
	MISO	6.0
Western	Northern California	2.9
	NWPP	2.9
Texas	ERCOT	2.8

A statistical analysis of the offshore wind power time series was used to assess the effect on the power system. The behavior of offshore wind resembled that of onshore wind, despite the higher capacity factors, more consistent power output across seasons, and higher variability levels of the former. Thus, methods developed to manage onshore wind variability can be extended and applied to offshore wind.

The western regions (Northern California and the Northwest Power Pool, or NWPP) presented the highest capacity factors (above 55%), although the installed capacity was relatively low (less than 3 GW). The profiles in those regions were also the most unique, with consistent high power generation during the summer months. The capacity factor in New England, where more than 13 GW of wind were installed, was almost 50%. The capacity factors in the remaining regions averaged from 40% to 42%. Wind generation in the eastern regions, ERCOT, and the Great Lakes was higher during nights and spring months. Some regions, such as the Carolinas and PJM, presented singular daily profiles during the summer with consistent positive ramps in the afternoon as a result of sea breezes.

Wind variability was typically small, as shown in Figure ES-6, with most of the hourly ramps below 3% of nameplate capacity. That dropped to 1% for the 10-minute ramps. However, extreme values were much larger, from 10% to 35%, but rare. Overall, Northern California and NWPP had small variability, especially during the summer, when wind output is high and sustained. Other regions presented less relative variability with more installed capacity or more geographic diversity. The variability of offshore wind had a very distinct relationship to power levels, similar to onshore wind. Variability tended to be largest when power output was in the midrange of installed capacity, and it decreased toward the extremes.

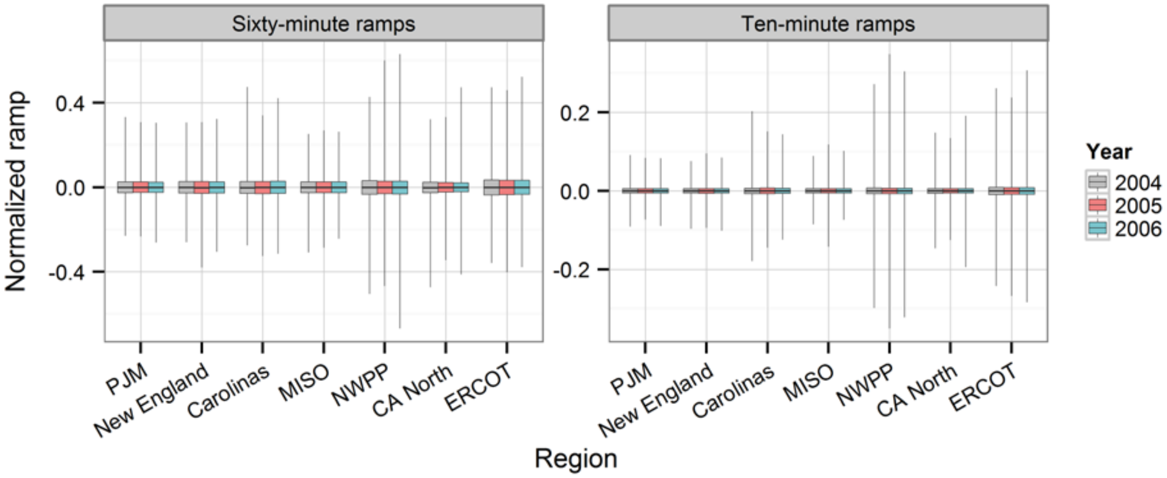


Figure ES-6. Box plots showing hourly and 10-minute ramps by region and year

The impacts on net load are shown in Figure ES-7. They were largest in New England, where almost 40% of the load could be provided by wind. There were a few hours when wind power surpassed load levels. Net load profiles shifted considerably, and the peak-to-valley ratio increased significantly. In other regions, the change was moderate. Northern California is the only region in which high loads and high wind aligned. All other regions experienced higher drops in net load during low-load hours.

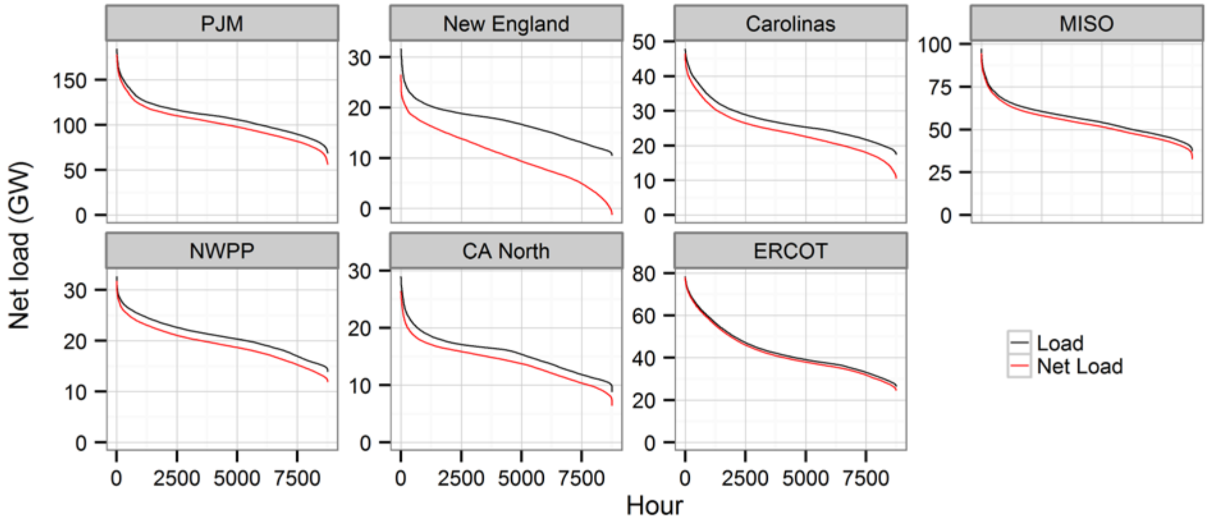


Figure ES-7. Load and net load power duration curves

The effects on net load variability were relatively small for most of the year, even in New England. The most significant changes were typically increases in rare and extreme ramp values. Hourly load and wind variability were found to be independent, although the relative magnitude of both varied across regions. In New England and the Carolinas, both were very similar (see Table ES-2).

Table ES-2. Load and Total Reserve Requirements and Differences

Region	Load Up/Down (GW-h)	Total Up (GW-h)	Total Down (GW-h)	Increase Up	Increase Down
PJM	9,461	10,105	10,117	7%	7%
New England	1,500	3,112	3,161	107%	111%
Carolinas	2,378	3,272	3,332	38%	40%
MISO	4,942	5,086	5,101	3%	3%
NWPP	1,836	2,053	2,075	12%	13%
CA North	1,376	1,541	1,544	12%	12%
ERCOT	3,810	3,973	3,981	4%	4%
TOTAL	25,303	29,142	29,310	15%	16%

The methodology developed for Phase 2 of the Western Wind and Solar Integration Study was used here to determine the increase in reserve requirements as a result of wind variability, because offshore wind behaves like onshore wind for this purpose: there is a clear dependency between power and forecast error, and wind and load ramps are independent. The biggest increase in requirement was found in New England, where it more than doubled, followed by the Carolinas, which experienced a 40% increase. The remaining regions experienced marginal increases. These reserve requirements became an input of the production cost simulations in NOWEGIS.

Technology Overview

To use the offshore resources, it is necessary to bring the energy produced to shore and inject that energy into the onshore transmission grid. To do this, three specific processes can be defined, as illustrated in Figure ES-8: namely, the production or generation, the collection, and the delivery. Each process presents its own set of technology options. It is common within the industry to call the delivery system a “transmission” system, but because of its specific purpose in this context, and to avoid confusion with the onshore transmission network, the term *delivery* is used in this report.

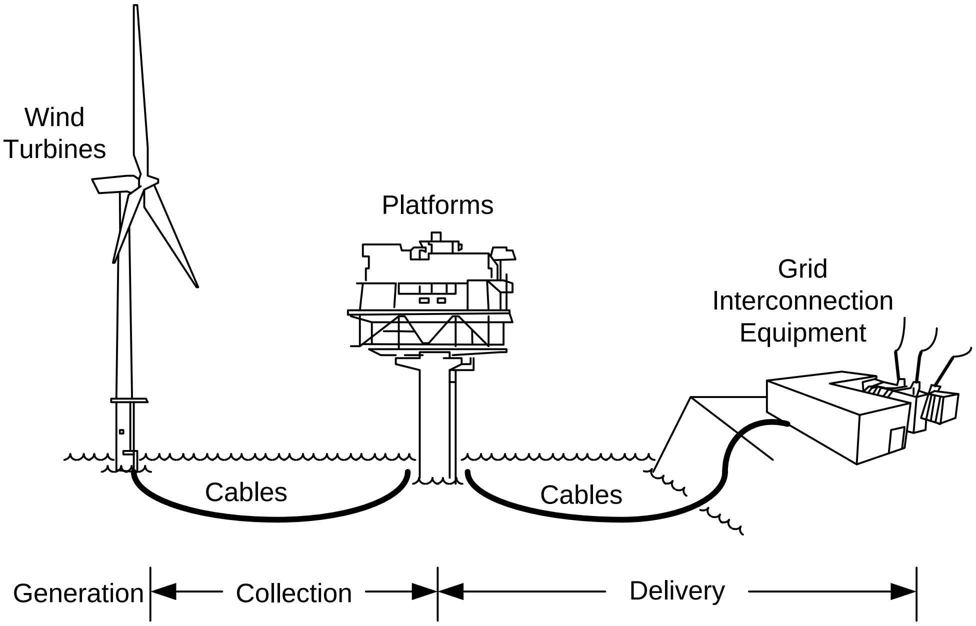


Figure ES-8. Generalized concept for an offshore wind energy system

As shown in Figure ES-8, multiple components must be considered to build the wind energy system. Also, there are generally multiple options for each component.

Standard wind turbines available today normally utilize either a doubly-fed induction generator (DFIG, or Type 3) or an induction generator behind a full AC-DC-AC converter (Type 4). Permanent magnet synchronous generators are also available, but their use is less common than the other types. Significant opportunities exist for alternate designs for wind turbines, but these are not addressed in NOWEGIS.

The fundamental electrical consideration that must be addressed for each section of the offshore system is whether it will operate using AC or DC. To date, all generation and collection systems have been AC, but there are technical options that could be exploited today that would allow for the operation of a DC network for the collection system, some of which are anticipated to reduce the cost of operating an offshore wind farm. Also, alternative topologies of the generation system could move much of the equipment from the individual towers to the collector platforms, where maintenance can be more easily performed and for less cost. Such advanced topologies and considerations have not yet been exploited, but no technical hindrance is apparent.

Another aspect that must be considered for the collector system is the configuration of the wind power plant itself. Multiple wind turbines are generally connected into a “string” that feeds into the collector substation, and wind farms consist of multiple strings. These strings may be arranged in a number of configurations, such as radial connections, single-sided rings with a secondary cable connected between the last turbine in a string and the collector station, double-sided rings that connect the far ends of two strings together, or star patterns, where the cables of multiple turbines come to a central turbine from which the energy of the entire group is shipped to the collector substation. The design selected for a given development will seek to balance costs of the equipment and the desired reliability.

Similar considerations must be given to the delivery system. High-voltage alternating current (HVAC) delivery systems with radial connections to shore comprise the majority of the offshore wind power plants currently in service in the world. The distance from shore has practical limitations because of the cable charging currents. To alleviate the constraints caused by these charging currents, additional cables may be used, or additional platforms with reactive compensation can be used, but these add to the cost of the overall system. HVDC delivery systems do not experience this same limitation of distance, because the cable charging is not a concern, but they do generally require large converter stations at an offshore platform. The distance in cost crossover between HVAC and HVDC systems is generally considered to be approximately 50 mi (80km) between the offshore platform and the onshore connection site.

HVDC technologies have advanced significantly in recent years. Land-based converter stations have generally been of the line commutated converter (LCC) type, meaning that the system is used to help transition the condition (conducting versus non-conducting) of the power electronic switching devices. These types of converters require connections to strong systems, so they are impractical for offshore wind systems. More recently, voltage source converters (VSC) have been developed for high voltages (e.g., 115 kV to 345 kV) by a number of manufacturers. These types of converters do not need strong interconnecting systems and are quite appropriate for offshore wind power plants. Several offshore HVDC systems have been installed in Europe. Originally, these VSC systems required large filters to remove harmonics from the AC-side voltages, but recent innovations have permitted converters to be designed with much smaller filters or perhaps no filtering at all, thereby significantly helping to reduce the costs of the offshore converters and platform.

The different offshore wind system suppliers have different solutions for the main offshore platforms. Conventional fixed platforms, such as those with which many in the offshore oil industry are familiar, are often used. However, the limitations of transport vessels (because of insufficient availability or lack of lifting capability) have led to the development of (1) platforms that can be floated to site and jacked up to the proper height above the surface and (2) gravity-based, self-installing platforms that can be floated to site and then ballasted in position by filling their legs with gravel, sand, and water. One advantage of the latter option is the ease with which they can be decommissioned at the end of use.

Technology Assessments

In assessing the technology options, several investigations were undertaken to provide pertinent information to the interested parties. These included (1) a broad evaluation of the approximate cost of the equipment necessary to construct an offshore wind power plant and to deliver its energy to the onshore grid; (2) a reliability analysis of several technology options; (3) a comparison of the different technology options and their potential impacts on the onshore grid; and (4) an evaluation of the impacts of different technology options to the production costs of the national interconnections. The highlights of the results are described below.

COSTS

In the process of compiling the information for this report, the authors encountered limited willingness from manufacturers to share potentially proprietary information regarding costs of components that are used in offshore collection and delivery systems. Therefore, publically available information has been utilized for estimating the costs and cost trends of offshore equipment.

Because the offshore wind market in the United States is still new, cost savings are expected as the technology, planning, manufacturing methods, and offshore platforms continue to improve. This may be particularly true for offshore platforms, because they are not currently used by the power industry. Industry efforts to achieve these cost savings are ongoing, and efforts in the United Kingdom and United States are briefly reviewed.

In the United Kingdom, a task force was set up to evaluate potential cost reduction efforts [10] by focusing on the supply chain, innovation, contracting strategies, planning and consenting (permitting), the grid and transmission, and finance. Learning from the U.K. efforts to reduce the cost of offshore wind will help the United States in its own endeavors in offshore wind deployment.

Of course, the United States is already involved in its own efforts to reduce the cost of offshore wind. As previously mentioned, the funding provided by DOE under DE-FOA-0000414, of which NOWEGIS is a part, is intended to help address cost issues. In addition, DOE announced in 2012 that a total of $168 million throughout six years will be awarded to seven advanced technology demonstration projects. These projects utilize innovative technology of installation designs that could reduce the cost of offshore wind deployment. In mid-2014, three of these projects were selected to move forward the second stage of deployment. The DOE advanced technology demonstration projects that were selected to receive funding are as follows:

1. Fishermen’s Energy Atlantic City Wind Farm will utilize innovative bottom-mounted foundation design and environmentally-friendly installation procedures.
2. Principle Power/Deepwater Wind’s WindFloat Pacific project will utilize floating foundation technology for deepwater applications (deeper than 30 m). This project also has the potential to reduce installation costs through local assembly.
3. Dominion Virginia Power’s Virginia Offshore Wind Technology Assessment Program will utilize innovative twisted jacket foundations, which offer the potential for significant cost reductions compared to traditional jacket foundations.

When considering any offshore wind power plant design, it is important to have some idea of the capital costs that can be expected. This information is helpful not only to roughly estimate project costs, but also to identify the components that would provide the largest benefits from cost reduction efforts. To prioritize efforts, it is also useful to categorize these components as either long-term or short-term cost reduction opportunities. Certain cost reductions may appear only after more research and development is carried out (i.e., increased voltage ratings of cross-linked polyethylene, or XLPE, undersea cables) and would fall in the long-term category. Further, continuous monitoring of offshore wind capital costs will help to direct the course of research and development efforts and other appropriate actions into the future.

The more recent version of NREL’s *2011 Cost of Wind Energy Review* report [11] states that there are no major differences in cost between 2010 projects and 2011 projects. With relatively low inflation in the interim, it seems reasonable to assume that costs have not dramatically diverged from where they were when estimated for that report. Based on a literature review, interviews with active offshore wind developers, and global market analysis, the report found that the average cost for an offshore wind installation is $5,600/kW. The complete range was between $4,500/kW and $6,500/kW. These values do not account for issues such as transmission, environmental impacts, military constraints, public policy, consumer costs, energy prices, or public acceptance. An approximate breakdown of the costs for the installed offshore wind is shown in Figure ES-9.

When studying reductions for the total cost of offshore wind installations, the most obvious targets are categories that comprise the largest percentage of the total cost: that is, the turbine installation (including assembly and transport) and support structure. It is especially important to consider costs of the turbines. If similar costs can be maintained with new turbine technology and without drastically affecting the other categories, a gain in efficiency or output power will be realized. Note that the second- and third-highest percentage categories are both contained within the “Balance of Station” section of Figure ES-9. From a cost standpoint, it may be possible that future platforms could affect the support structure as well as their assembly, transport, and installation. This could result in significant cost savings as well.

Although the larger contributors to the overall cost of the installation may have the most impact from a cost reduction standpoint, the smaller percentages shown in Figure ES-9 should not be disregarded. Some of the suggestions that have come out reviews of cost reduction opportunities, such as those from the U.K. report mentioned above, may not easily fall into one of the categories shown in Figure ES-9. These are still important to consider when seeking cost reductions but might have been beyond the scope of the analysis in [11]. It may also be possible that several smaller cost reductions could aggregate to larger cost reductions.

Details about the estimated prices of various components used in offshore wind production, collection, and delivery systems are included in the body of the report.

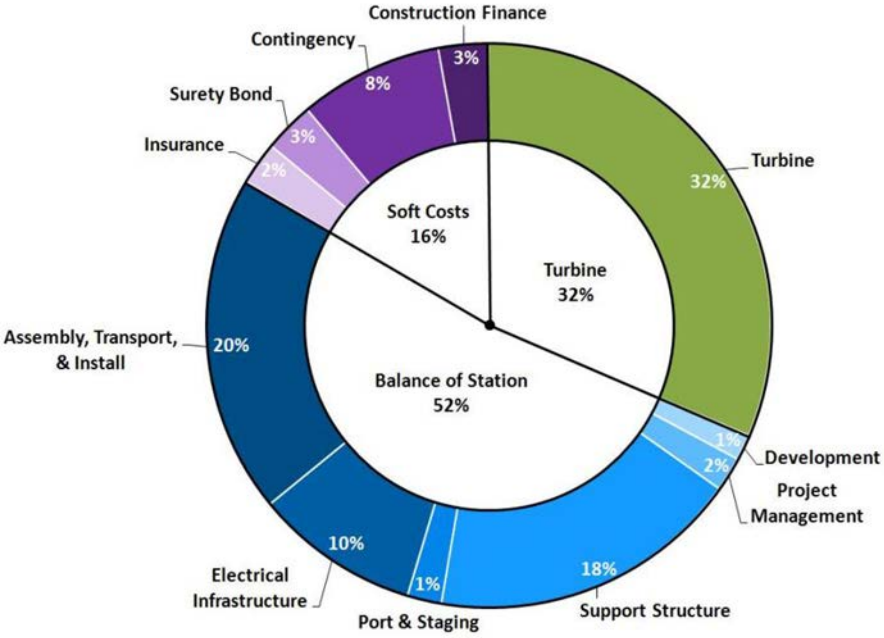


Figure ES-9. Installed capital costs for 2010 reference offshore wind

RELIABILITY

The reliability and risk assessment evaluated the basic reliability characteristics of offshore wind electrical system systems, including HVAC compared to HVDC delivery systems with various connection topologies (radial, split, backbone, and grid – see Figure ES-10) and collector systems with various topologies (radial, bifurcated radial, one-sided ring, and double-sided ring – see Figure ES-11).

The following general conclusions can be made.

Basic HVDC and HVAC Connections

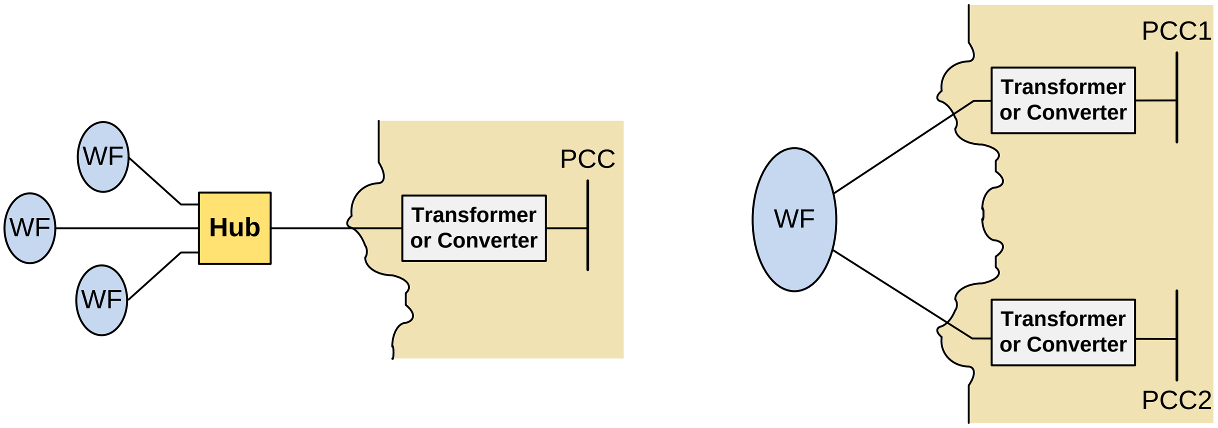
HVAC connections have a higher reliability than that of HVDC connections, with a 30% difference in the estimated expected energy not supplied (EENS) indices for an example case study. The unavailability of delivery capacity and the risk of production loss mainly result from the outage of submarine cables. If power electronic reactive compensators are required for HVAC connections, the difference in EENS indices between HVAC and HVDC connections would become comparable.

Offshore Delivery Systems

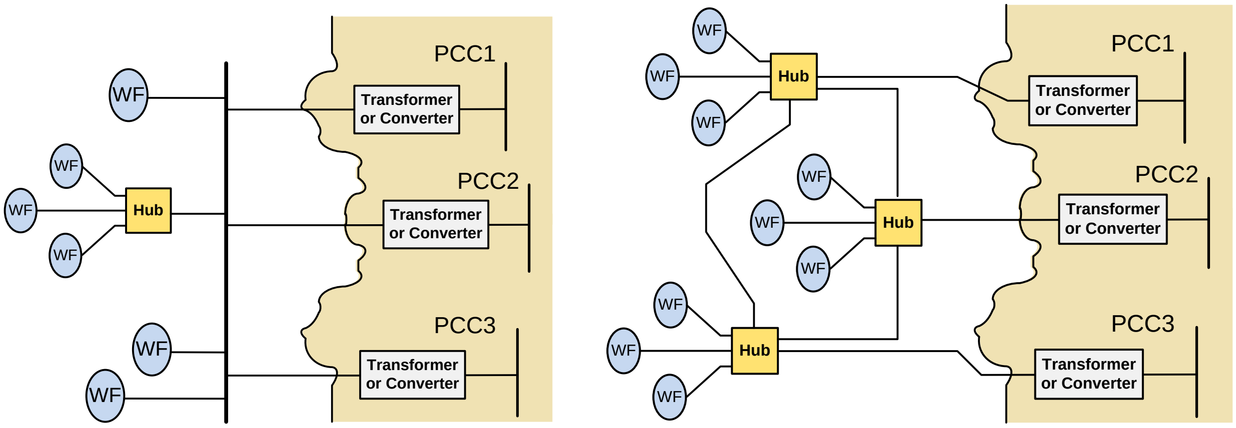
Radial and split delivery systems may be implemented with either HVAC or HVDC technologies. The study approach and results for basic HVAC and HVDC connections were applied to the split connections. It is anticipated that backbone and grid delivery systems would be developed based on HVDC technologies. The risk of production loss of a backbone delivery system would be significantly lower than that of radial connections. It is expected that single-element (N-1) contingencies will be considered in the design of a grid delivery system, so the overall delivery capacity would be affected only by high-order outage events.

Wind Farm Collection Systems

Radial feeder collection topologies are typically used for large offshore wind farms. Ring topologies have a higher reliability than that of radial feeder topologies, with a 50% difference in the estimated EENS indices for an example case study. For installations in which repairing durations for feeder cables are expected to be lower, the difference in EENS indices between the ring and feeder topologies would become comparable. For medium wind farms, cluster collection architectures offer improved reliability than the conventional feeder collection architectures.

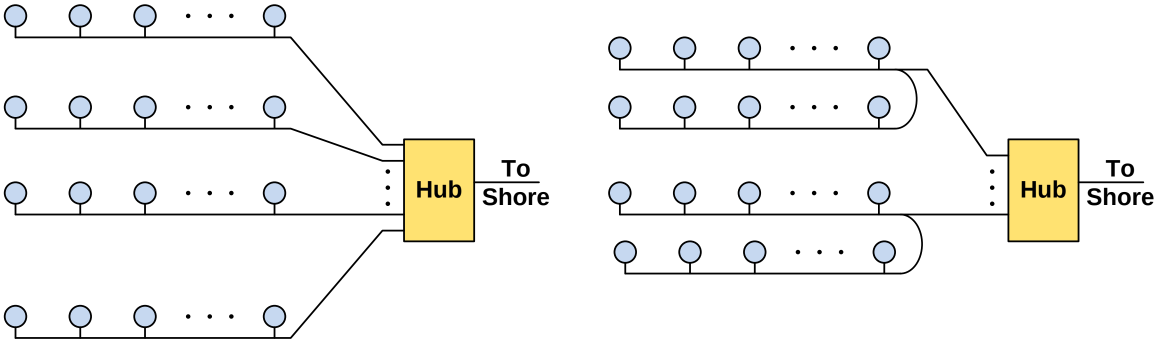


(a) Radial connection ***(b) Split connection***



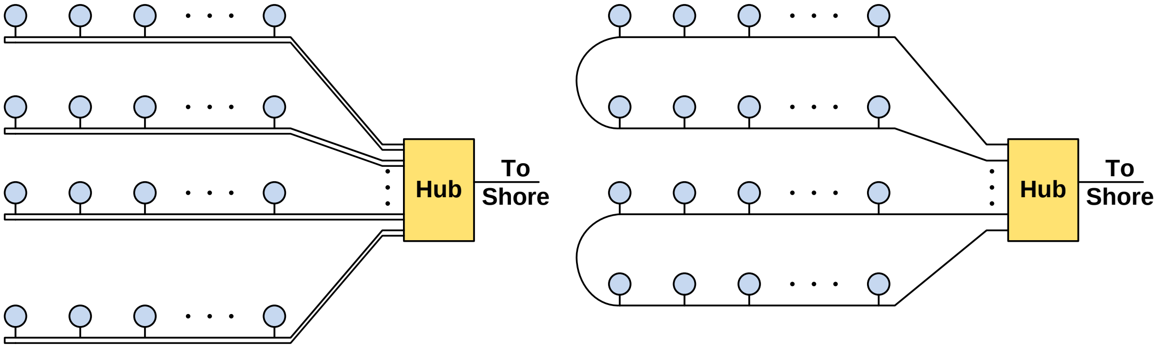
(c) Backbone connection ***(d) Grid connection***

Figure ES-10. Offshore wind farm delivery system options



(a) Radial

(b) Bifurcated radial



(c) Single-sided ring

(d) Double-sided ring

Figure ES-11. Offshore wind farm collector system options

TECHNOLOGY COMPARISON

A base case for evaluation was developed to perform a general topology comparison so that the performance and impact of radial systems could be compared to backbone and grid systems. The base case was a 2030 power flow case provided by ISO-NE that covers the entire Eastern Interconnection, including the areas of New England and the PJM systems. This allowed the impacts to be assessed in the area that is anticipated to have the largest proportion of the offshore wind installations by 2030.

The generalized comparison was performed in the PJM region, with seven substations selected for the interconnection points, as illustrated in Figure ES-12. Each of the substations is nominally 230 kV.

Seven hypothetical wind farms with 1,000 MW installed capacity each, located 30 mi from the nearest interconnecting substation, were assumed in the study. Onshore generation was scaled back to maintain a proper generation-to-load balance. Two scenarios were considered; the first assumed an even distribution of the

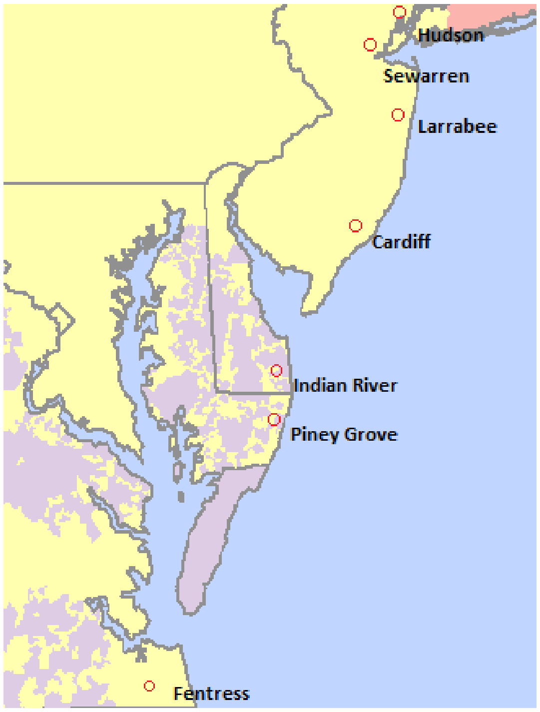


Figure ES-12. Onshore interconnection substations wind generation, and the second assumed an uneven distribution. The average capacity factor for the hypothetical wind farms was assumed to be 50%, for a total of 3,500 MW injected into the onshore grid. In the evenly distributed scenario, this resulted in 500 MW at each site. In the unevenly distributed scenario, the two northernmost farms were assumed to provide zero output, and the two southernmost farms were assumed to provide 100% output.

Steady-state analyses were performed on each of the topology variations in each scenario to evaluate the impacts on the onshore grid by identifying overloaded elements (i.e., thermal violations); these would indicate a need for reinforcements to the grid to accommodate the offshore wind. This high-level evaluation resulted in the following conclusions:

- An offshore radial connection will have the least cost to connect a single wind farm to shore. Losing one circuit or one pole in a radial connection with double HVAC circuits or a bipole HVDC system may cause wind generation curtailment during high wind generation conditions.
- A backbone structure increases the reliability of the offshore system above the radial connections. The seven example offshore substations could be connected together to create a backbone structure that demonstrates this increased reliability by allowing full wind generation delivery to shore during the N-1 contingencies studied here. An HVAC backbone system requires reactive compensation equipment for long-distance connections. This will increase the cost of the system because of the need for the compensation equipment as well as the platforms and their associated ancillary equipment and maintenance; however, compensation will provide some resiliency benefits to the grid.
- An HVDC backbone system demonstrates greater flexibility than an HVAC backbone system, because the power flow amounts and direction in an HVDC system can be controlled (within limits) to provide an effective means of reducing much onshore system congestion.
- Grid systems further increase the reliability of an offshore system. The seven example offshore substations could be connected together to create what is essentially a double backbone with connections at each end, which would demonstrate this increase in reliability. Again, however, reactive compensation equipment would be needed for HVAC grids with long connections between platforms.
- Finally, an HVDC system demonstrates greater flexibility than an HVAC system, because of its ability to control the power flow both on and offshore. The HVDC grid has more capability to do this than the HVDC backbone.

A definitive selection of one system over another cannot be made from this brief evaluation. The final decision will be driven by the overall economics of the system. However, it is strongly urged that policy makers and planners focus on the long-term benefits and costs and not merely on the short-term costs. It is easy to consider only the development costs, but full operating costs should also be analyzed, including maintenance and losses. In addition, careful studies should be made to characterize and quantify the benefits that may result to the entire grid for a given delivery system and design. If the ultimate build-out of an offshore grid is contemplated, early decisions should consider the appropriate technologies that will enable incremental build-out, including whether higher upfront costs may be incurred or justified to support a larger offshore grid investment that might bring additional economic, reliability, and public policy benefits.

In addition to this general assessment, region-specific assessments were performed for the Carolinas, ERCOT, ISO-NE, PJM, and Midcontinent System Operator (MISO). Although the details and results are somewhat varied, note that to accommodate the levels of offshore wind assumed in this studies, all regions required some reinforcements to prevent thermal violations on selected portions of their systems. Although the evaluations were hypothetical, general principles that emerge from the effort include the following:

1. If the load centers are close to shore, the interconnection of offshore wind generation does not appear to cause significant adverse system impacts.
2. If large amounts of offshore generation must flow for long distances through a lower voltage transmission system (e.g., 230 kV and below) to reach the load center, severe voltage problems and significant system overloads along the path may result.
3. An alternative offshore path (e.g., an offshore backbone or offshore grid system) can help to alleviate many the voltage issues and mitigate onshore congestion, making this a possible alternative to onshore transmission reinforcements.
4. Offshore HVDC backbone and grid systems show the potential for increased general control of the flow of offshore wind power.

PRODUCTION COSTS

Offshore wind farms close to major load centers have the unique advantage of delivering clean and low-cost energy close to loads. In the United States, existing transmission congestion issues have limited the economic power delivery to the load centers along the eastern seaboard, resulting in high energy prices in those load centers. Because of this, power supply from offshore wind and economic energy transfer via offshore delivery systems can be an attractive option.

An operational model of the North America electric power system was developed to represent the expected supply, demand, and transmission grid of 2020. The offshore wind farms defined in previous project tasks were included in the simulation model to provide a total capacity of 54 GW.

Production cost simulations were performed with appropriate assumptions to evaluate the value of offshore wind power. By comparing the simulation results to cases with and without offshore wind power, the regional impacts have been estimated in terms of generation outputs and production costs.

Finally, sensitivity analyses were performed on the economic value of offshore wind power under input assumptions. A 20% increase and a 10% decrease in the price of natural gas from the base assumption were both considered. Reductions of the base 54 GW of installed offshore wind capacity to 27 GW and 16 GW were also explored using the base gas price assumption.

The annual generation outputs and production cost savings that resulted when offshore wind was added were used to estimate the value of the offshore wind production. The base results do not include any adjustments for the cost of emissions, so an estimate including the cost of CO_2 at $20 per metric ton was also considered.

The results, in nominal 2020 U.S. dollars, are summarized in Table ES-3. The values of offshore wind shown in the table are national aggregates, but the different interconnections (i.e., the Eastern Interconnection, the Texas Interconnection, and the Western Interconnection) each differed somewhat from the national values.

Table ES-3. Sensitivity of Offshore Wind Value to Penetration Levels

Case Description	Installed Offshore Wind Capacity (GW)	Price of CO_2 Included?	Gas Price Multiplier	Production Cost Savings (B$)	Offshore Wind Generation (TWh)	Value of Offshore Wind ($/MWh)
Base case	**54**	No	1.0	7.68	187.6	40.9
With price of CO_2	**54**	Yes	1.0	10.56	187.6	56.3
High gas price	**54**	No	1.2	8.89	187.6	57.4
Low gas price	**54**	No	0.9	7.18	187.6	38.3
Low offshore wind penetration	**27**	No	1.0	4.26	97.0	43.9
Low offshore wind penetration	**16**	No	1.0	2.65	57.8	45.8

Regulatory Review

Although no offshore wind is presently generating electricity in the United States, approximately 5 GW of projects could be deployed in the next decade. Even so, the industry continues to face challenges because of the high upfront capital costs and regulatory challenges for offshore wind deployment. Depending on the market to which offshore wind will be delivered, the higher upfront capital cost of offshore wind could potentially be offset by the benefit of a zero-cost fuel source that would be dispatched ahead of other resources; thus, offshore wind could create important electrical benefits that should be further evaluated regionally. As a result of these factors, as discussed in Section 6 of NOWEGIS, production cost modeling results suggests that there is an average savings of $41/MWh for deploying 54 GW of offshore wind at 76 sites.

Offshore wind offers multiple benefits (Table ES-4), including (1) energy benefits, such as strong wind resource quality (high capacity factors), generation during peak power periods, and more consistency than less variable onshore wind resources; (2) environmental benefits, such as carbon-free generation by displacing aging coal and natural gas generation in close proximity to load; and (3) economic development benefits, which are incumbent with a new infrastructure-intensive industry. Still, the high capital costs and infrastructure required for commercial-scale offshore wind development and deployment require supportive federal and state policies to jump-start a new industry.

Table ES-4. Key Benefits of Offshore Wind

Key Benefits of Offshore Wind	
Energy	High capacity factors Generation that is coincident with peak power More consistent energy production (low variability) than onshore wind
Environmental	Emission-free electricity Proximity to load centers on the Atlantic Coast Potential to replace aging generation plants
Economic development	Infrastructure investment creates jobs Creation of specialized jobs Assembly required in nearby ports

STATE OF OFFSHORE WIND IN THE UNITED STATES IN 2014

To date, the evolution of a regulatory pathway for the development of offshore wind in the United States has been fraught with uncertainty and delays. In November 2001, Cape Wind filed the first U.S. offshore wind permit application with the U.S. Army Corps of Engineers to deploy a meteorological tower to collect wind speed data in Horse Shoe Shoal in Nantucket Sound, Massachusetts. More than a dozen years later, Cape Wind has persevered and could be the first commercial-scale offshore wind farm to operate in the United States by 2016. Cape Wind has faced innumerable barriers as the first offshore wind project in the United States, including changing regulatory regime, securing a power purchase agreement (PPA) for the sale of electricity, 32 legal challenges, and difficulty financing the estimated $2.6 billion project [12]. For offshore wind resources to be developed at scale, the development and regulatory timeline must continue to be dramatically reduced.

No commercial-scale offshore wind projects currently operate in the United States, but currently, an estimated 5 GW of offshore wind projects are planned for deployment in the United States during the next decade (Table ES-5). Many of the legal, technical, and financial challenges that faced Cape Wind will remain for the first generation of offshore wind projects; however, each successive project will benefit in several ways from the lessons learned during the development of the previous and pioneer projects. Today, the federal permitting process has been streamlined in an initiative called “Smart from the Start.” Compared to the regulatory regime in 2000, there is now a clearly defined federal regulatory process for leasing land for developing alternative energy projects on the Outer Continental Shelf (OCS). Although there are always opportunities to reduce permitting timelines, it is equally important to create a regulatory regime that provides certainty for regulators, project developers, and the entities providing financing.

Table ES-5. Proposed Commercial Offshore Wind Projects* by State

Commercial Offshore Wind Projects by State		
Delaware NRG Bluewater Mid-Atlantic Wind Park	450 MW	NRG Bluewater’s Mid-Atlantic Wind Park received a PPA for 200 MW of power and one of the first offshore wind leases from BOEM in 2010. Delmarva Power canceled the PPA for 200 MW of power. The project is currently on hold. The target completion date is post 2020.
Maine Statoil North America	12 MW	Statoil planned to deploy four 3-MW wind turbines on floating spar buoy structures offshore Boothbay Harbor at a water depth of 460 feet. By utilizing local assembly and towing the turbines to the deep waters off the coast of Maine, the project would have demonstrated floating technology in deep water and an installation methodology that could reduce costs. Statoil announced the cancellation of the project in October 2013.
University of Maine Aqua Ventus	12 MW	DeepCwind Consortium plans to install a pilot floating offshore wind farm with two 6-MW direct-drive turbines on semi-submersible foundations near Monhegan Island. This could help establish a cost-effective alternative to traditional steel foundations through design and local assembly.
Massachusetts Cape Wind	468 MW	Energy Management, Inc., is developing Cape Wind (MW) in Nantucket Sound approximately 6 mi offshore of Cape Cod in federal jurisdictional waters. Cape Wind expects to complete financing in the second half of 2014 and begin construction in 2015. The commercial operation date is 2016. Cape Wind has a PPA with National Grid and NSTAR for 363 MW, or 77.5% of output, at a price of $187/MWh.

Cont. below …

Table ES-5. Proposed Commercial Offshore Wind Projects by State***, Cont.***

Commercial Offshore Wind Projects by State		
New York		
Deepwater One Regional Energy Center	900 MW–1,200 MW	Deepwater One is a regional energy center designed to serve Long Island and New England. It is in the early stages of development. The target completion date is 2019.
Hudson Canyon Wind Farm	1,000 MW	Deepwater describes the Hudson Canyon Wind Farm as a second-generation offshore wind project to be built 35 mi off the western end of Long Island with the ability to serve customers in New York and New Jersey. The target completion date is post 2020.
New Jersey		
Fisherman's Energy Atlantic City Wind Farm	25 MW	Fishermen's Energy plans to install up to six direct-drive turbines in state waters 2.8 mi from Atlantic City, New Jersey. This project offers innovative bottom-mounted foundation design and environmentally-friendly installation procedures. The target operation date is 2016.
Garden State Offshore Energy	1,000 MW	Garden State Offshore Energy is jointly developed by Deepwater Wind and PSE&G Renewable Generation, LLC. It is in the early stages of development. The target completion date is 2019.
Ohio		
Lake Erie Development Corporation	27 MW	LeeDCo plans to install nine 3-megawatt direct-drive wind turbines on "ice breaker" monopole foundations designed to reduce ice loading. The project is based on Lake Erie, 7 mi off the coast of Cleveland.
Rhode Island		
Block Island Wind Farm	30 MW	Deepwater Wind is developing the Block Island Wind Farm, a five-turbine offshore wind project approximately 3 mi southeast of Block Island in Rhode Island state waters. Construction begins in 2015.
Texas		
Baryonyx Rio Grande Wind Farms	1,000 MW	Baryonyx Corp. secured leases from the Texas General Land Office in 2009 for the development of the Rio Grande North and South projects approximately 10 mi from shore and 5 mi from South Padre Island in Texas state waters. The U.S. Army Corps of Engineer environmental permitting is underway. The target completion date is 2019.
Galveston Offshore Wind (Coastal Point Energy)	150 MW	Coastal Point Energy (formerly Wind Energy Systems Technology) secured a lease from the Texas General Land Office. They have deployed a met tower in the Gulf of Mexico and announced the intention to install a 750-kW test turbine.
Virginia		
Dominion Virginia Power Virginia Offshore Wind Technology Assessment Program (VOWTAP)	12 MW	Dominion plans to design, develop, and install two 6-MW direct-drive turbines off the coast of Virginia Beach on innovative "twisted jacket" foundations. This project offers the potential for significant cost reductions compared to traditional jacket foundations by using substantially less steel. DOE awarded $47M for this offshore wind demonstration project.
	5,386 MW	Note: Total capacity includes several projects that are on hold or have been cancelled, but it represents the total possible capacity before 2020.

*Proposed commercial offshore wind projects are projects that have been announced and have initiated steps toward development of the project. This information may change and is based on best available public information, developer statements and media coverage.

To interconnect 54 GW of offshore wind resources, a comprehensive, dual-track federal and state strategy is needed to align state, federal, and other stakeholder interests. DOE has developed a roadmap for the development of gigawatt-scale offshore wind resources in the United States. To realize this vision, both federal and state policies are required to help overcome barriers to offshore wind development—namely development timelines and costs for offshore wind (Table ES-6). As the first generation of offshore wind projects are deployed, state and federal policies that promote offshore wind projects should be evaluated. Newly revised federal permitting by BOEM is still untested, but the improvements in site control and permitting are improvements from a decade ago.

Table ES-6. Key Offshore Wind Barriers

Key Offshore Wind Barriers [13]	
Cost-competitiveness	High capital cost High cost of energy produced by Offshore Wind High financing cost due to risks
Technical and infrastructure	Lack of purpose-built ports and vessels Lack of domestic manufacturing Inexperienced labor Insufficient domestic operations and maintenance capabilities Insufficient offshore transmission infrastructure
Regulatory	Uncertain site-selection process and timeline Fragmented permitting process Environmental and public resistance Uncertain environmental impacts

OFFSHORE WIND DEVELOPMENT FRAMEWORK

Offshore wind development is regulated by multiple federal, state, and local regulatory entities. The purpose of this overview is to provide a summary of the regulatory process for offshore wind development in the United States: (1) site control/leasing, (2) environmental permitting, (3) power contract, and (4) interconnection. A jurisdictional chart for offshore wind in these four areas is given in Table ES-7. Following is a summary of the essential elements necessary for the development of offshore wind. States and regions will pursue policy solutions for each regulatory requirement. These four requirements create a framework to determine whether the current regulatory regime is suitable for the interconnection of 54 GW of offshore wind.

Table ES-7. Offshore Wind Development Framework

Jurisdictional Chart for Offshore Wind Regulation	Project in State Jurisdictional Waters	Project in Federal Jurisdictional Waters
Site control/leasing	State lands or administrative office	BOEM
Environmental permitting	U.S. Army Corps of Engineers is the lead federal agency for permitting in state waters, which will involve coordination with state and other federal agencies.	BOEM has statutory responsibility for ensuring that the major environmental laws are enforced. Other federal agencies involved as well.
Power contract	State PUC approval	State PUC approval
Interconnection	State PUC or state siting board	Federal Energy Regulatory Commission (FERC)

State Site Control

The NOWEGIS results suggest that approximately 8 GW of offshore wind could be developed in state waters in Texas and the Great Lakes in an economically efficient manner. There is an estimated 750 GW of offshore wind potential in U.S. state jurisdictional waters [1]. Although 8 GW represent a smaller portion of total offshore wind developed in the 20% wind scenario, state siting is demonstrably more straightforward than the federal leasing on the OCS. Site control for offshore wind in state jurisdictional waters is a matter of state law. On the OCS, state jurisdictional waters extend 3 nmi for every state, with the exception of Texas and the west coast of Florida. In the eight states bordering the Great Lakes, title to the submerged lands underneath the Great Lakes is governed by state law. For staging offshore wind deployment, approximately 16% (8 GW) of the total 54 GW would deploy in state jurisdictional waters. This includes approximately 2.8 GW in Texas and 6 GW in the Great Lakes.

Although siting is but one step in the offshore wind development process, obtaining a lease or site control from a state can be an expedited process compared to even the improved BOEM federal leasing process. Although there are generally fewer offshore wind resources with potentially higher conflicts in state waters, siting in state jurisdictional waters offers numerous benefits. The first benefit is that a state controls the complexity of the leasing process, which enables states with a strong policy preference for offshore wind to develop an efficient leasing process. In these states, leasing will be pursued through the state lands office, state department of administration, or some other instrumentality of the state that will grant a lease for use of the submerged lands. In Texas, for example, the General Lands Office has the authority to negotiate a lease for use of state submerged lands. The Texas General Lands Office is a model for a one-stop permitting process. In New Jersey, North Carolina, and Rhode Island, for example, the department of administration controls state siting and is responsible for leasing in state waters.

States possess the ability to identify offshore wind as a public policy priority. By recognizing offshore wind development as a state priority, a state can make improvements to the siting, leasing, and permitting process to encourage the development of offshore wind. Several states support the development of offshore wind—most notably where the first generation of demonstration and commercial projects are currently planned on the Atlantic Coast. In Rhode Island, the state entered into a joint development agreement with Deepwater Wind to develop the 30-MW Block Island Wind Farm to provide a stable source of electricity to the Block Island community. Importantly, the agreement committed the state to meet certain obligations and make reasonable efforts to support siting and permitting the wind farm and the 384-MW commercial-scale project. The agreement also commits the state to expedite the permitting and approval process and to help the developer secure one or more PPAs. By focusing on smaller projects to serve a discrete need for electrical services on Block Island, the state is demonstrating its ability to site and permit a larger commercial-scale project in the longer term. Importantly, the development process in Rhode Island combines both the siting and permitting process so that efficiencies may be achieved as well. This is similar to BOEM’s use of WEAs to combine siting and environmental permitting to potentially reduce development timelines. In New Jersey, state siting and permitting have been streamlined to help develop the Atlantic Wind Farm by Fishermen’s Energy.

In the Great Lakes, a consortium of five states is exploring how to promote efficient, expeditious, orderly, and responsible offshore wind development. In 2012, Pennsylvania, Illinois, Michigan, Minnesota, and New York signed a memorandum of understanding (MOU) with 10 federal agencies outlining their respective responsibilities, points of contact, and commitments to collaborate on the creation of a regulatory roadmap within the next 15 months. The Great Lakes Offshore Wind Energy Consortium is an example of the use of an MOU to develop both formal and informal procedures for collaboration across state and federal jurisdictions. Although this MOU does not create demand for offshore wind, nor does it address siting issues, it does recognize the significant role environmental permitting plays in developing a potential offshore wind resource in the Great Lakes in an environmentally responsible manner.

Federal Site Control—BOEM Leasing and Smart from the Start

Federal law recognizes that the U.S. government holds exclusive title to submerged lands on the OCS from 3 nmi out to 12 nmi. Today, the U.S. Department of Interior's (DOI's) BOEM regulates the leasing of traditional and alternative energy on the OCS. BOEM has proposed rules governing the use of the OCS for either research purposes or commercial energy development. During the past five years, BOEM has diligently moved forward with a regulatory process for leasing lands on the OCS for alternative energy development.

In 2010, the DOI launched the Smart from the Start wind energy initiative for the Atlantic OCS to facilitate the siting, leasing, and construction of new projects that are both responsible and rapidly developed [14]. BOEM deserves credit for initiating and implementing the Smart from the Start initiative, because it has reduced needless red tape, identified resources, and realigned the BOEM's core mission to include harnessing the development of conventional oil and gas and renewable energy on the OCS. Smart from the Start builds upon lessons learned from solar development on public lands where public lands were prescreened to minimize environmental and use conflicts to accelerate the development of solar projects on federal lands in the West. The initiative established principles that helped provide direction to the multiple federal agencies involved in regulating offshore wind development without prescribing a regulatory checklist that had to be followed.

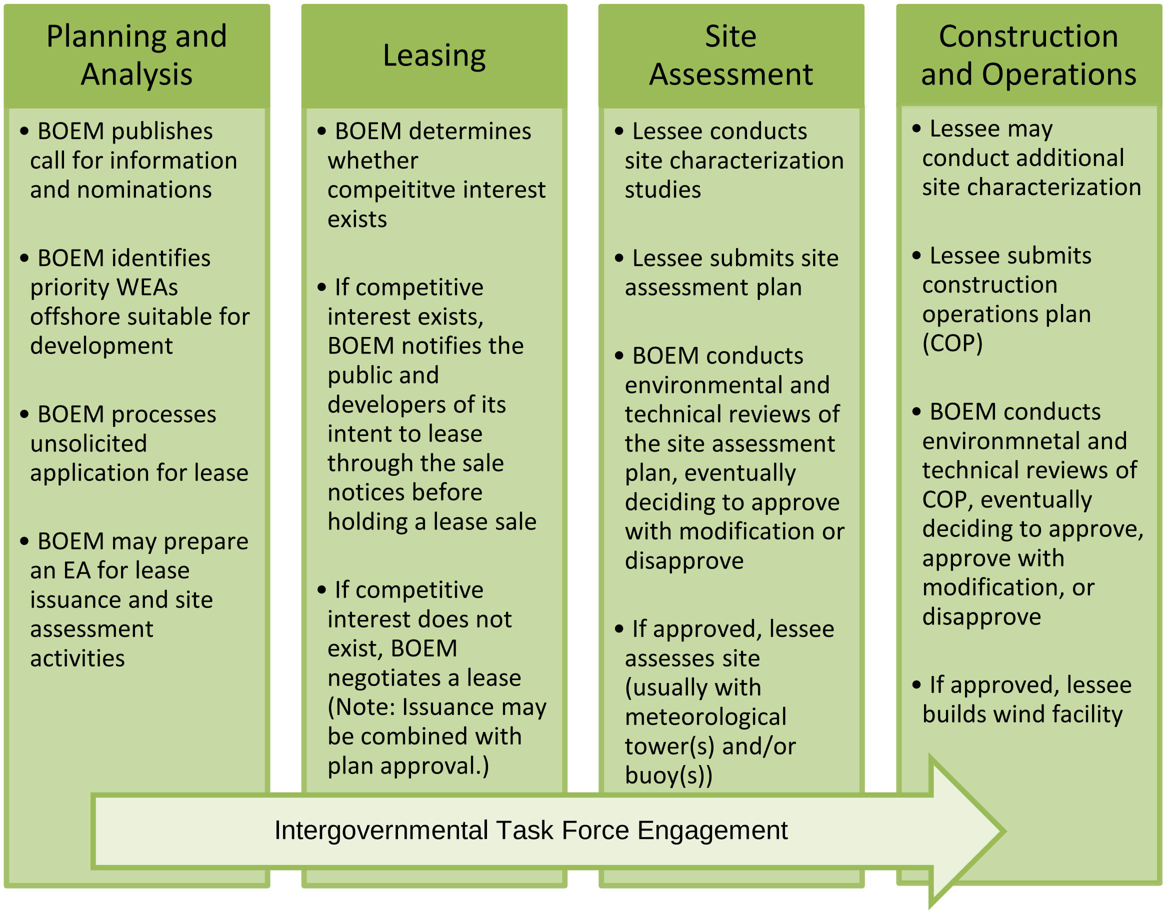


Figure ES-13. BOEM Smart from the Start

Smart from the Smart resulted in the most significant regulatory improvements in the planning and analysis phase of the BOEM regulatory process. Identifying WEAs had two important benefits. First, BOEM prescreened large WEAs that are suitable for offshore wind development on the OCS. Second, this prescreening process helps facilitate site control during the lease process. Prior to Smart from the Start, a developer risked expending significant resources characterizing the potential environmental impacts of an offshore wind farm without yet having legal title to a site. WEAs helped demonstrate the recently approved regulations for gaining site control by developers in advance of extensive environmental analysis.

Since 2009, BOEM has identified six WEAs along the Atlantic OCS for offshore wind development. Identifying WEAs enabled BOEM to combine siting and environmental permitting by performing environmental assessments (EAs), which generally take less time and resources than complete environmental impact statements (EISs) under the National Environmental Policy Act (NEPA). Given the complexity of the environmental permitting process, a deliberate effort to prescreen WEAs for resource development has enabled the elimination of one resource-intensive step in the NEPA process.

In July 2013, BOEM completed its first competitive lease sale for two lease areas off the coast of Rhode Island and Massachusetts. Three companies bid in the process, which lasted one day and included 11 rounds of bidding. Deepwater Wind won the lease sale for a combined 164,750 acres with a $3.8 million bid and executed commercial wind energy leases in September 2013. Deepwater Wind has five years to submit a commercial operations plan before its development rights to the leases will be relinquished. Deepwater's lease is approximately 9 mi from the Rhode Island and Massachusetts coastline and could generate approximately 3,395 MW of offshore wind generation.

In September 2013, BOEM held its second competitive lease sale for an area off the coast of Virginia. Two companies bid in the lease sale, which lasted six rounds and resulted in a $1.6 million sale to Dominion Virginia Power. In November 2013, Dominion executed the lease sale for an area approximately 112,799 acres located approximately 23 mi off the coast of Virginia that could produce 2,000 MW of offshore wind generation.

BOEM has also encouraged the use of research leases to help spur offshore wind development.

Environmental Permitting

The second regulatory requirement for offshore wind is state and federal environmental permitting. To deploy significant amounts of offshore wind, a more efficient environmental permitting process is needed without sacrificing the enforcement of environmental statutes. Permitting Cape Wind took more than a dozen years to complete. This is substantially longer than the estimated 7 yr to 10 yr that was initially recognized as a substantial barrier by the Smart from the Start program.

Power Contract

A PPA is an essential step in the development process for an offshore wind project. Simply put, a PPA ensures that an energy project receives payment for the generation of electricity from the resource. Approvals of PPAs are within the jurisdiction of state public utilities commission (PUCs) that have a statutory duty to regulate the retail sale of electricity. Although this is regulated in different ways in different states, the approval process for a PPA is similar across states.

Traditionally, utilities plan and develop both generation and transmission solutions that maximize the benefit of the electric grid to consumers through a process called integrated resource planning. Under this regulatory compact with a state, utilities have the authority to build power plants and transmission as well as purchase power from third-party developers as available in the market. Most states require utilities to develop or buy power that is at the least cost available to customers. This least-cost mandate varies across jurisdictions, but in every state it reflects the public policy priorities established there.

Throughout the United States, PUCs oversee the development of the generation and distribution network under a mandate that usually includes three public policy drivers: reliable, affordable, and safe electricity.

Although states plan and regulate electricity generation, distribution, and transmission in different ways, each of them is responsible for meeting the policy goals of the state. In nearly all states, the PUC oversees the development of an integrated resource planning process that determines the mix of generation, distribution, and transmission needed to meet the electrical needs of a state. It is through this process that electric infrastructure is approved based on state-specific policies and principles that usually assess the overall cost of the project and the anticipated benefit. Through integrated resource planning, utilities and independent power producers put forth proposals for serving customers.

State legislatures have always responded to economic, environmental, and public health concerns by adjusting which of these factors receives a greater policy emphasis at any given point in time. Historically, states have enacted policies that require the electricity in the state to be developed from certain resources that may benefit the economic, environmental, and/or public health of its citizens. Across different regions in the country, preferences for coal, nuclear, gas, wind, solar, and geothermal are expressed based on the relative cost of developing those resources and the abundance of the resource.

Renewable Portfolio Standards

In states that are pursuing offshore wind development, the traditional cost-benefit analysis has been modified by state law to support renewable energy or offshore wind development. States have done this in a number of ways. The most common policy tool utilized to develop offshore wind resources is an RPS. RPS laws mandate the procurement of certain resource types to promote certain public policy priorities. Currently, 29 states and the District of Columbia have RPS laws, and another 8 states have voluntary goals for renewable energy procurement [15]. In general, one megawatt hour of renewable energy generated creates one renewable energy certificate (REC) that represents the environmental attributes for that resource. RPS laws permit utilities to purchase RECs at a cost that has historically been greater than other least-cost resources available in the market.

By creating demand for renewable energy resources, the NOWEGIS results indicate the deployment of offshore wind in states with either an RPS or a voluntary goal. Several states have an RPS requirement only for general renewable energy resources (Illinois, Indiana, Maine, Massachusetts, Michigan, New York, Ohio, Pennsylvania, Rhode Island, Wisconsin, and Texas), and only Virginia has a voluntary goal. Delaware created a REC multiplier for offshore wind generation that allows RECs to receive 350% of the value of a general REC, which was designed to make offshore wind cost competitive. Note that although Massachusetts does not have either a carve-out or a REC multiplier, it is the only state with a voluntary offshore wind goal (2,000 MW).

Carve-Outs

Other states have created a carve-out for offshore wind that specifically mandates a certain amount of offshore wind resources. New Jersey, Maryland, and Maine each adopted RPS laws with offshore wind carve-outs for certain amounts of offshore wind. In Maryland, the Maryland Offshore Wind Energy Act of 2013 broadens the set of benefits that may be considered in the cost-benefit analysis and establishes a customer cost protection cap of $1.50/month for the 200 MW. The Maine Wind Energy Act established a 300-MW offshore wind carve-out that must be met by 2020 and further directed the PUC to hold a competitive process to award a long-term PPA for an offshore wind pilot project. Maine further established the policy of extending the offshore wind REC (OREC) to support 5 GW of offshore wind by 2030. In New Jersey, the legislature passed the New Jersey Offshore Wind Economic Development Act to create guaranteed income to offshore wind projects. Through a required carve-out for ORECs from the overall RPS requirement, the legislature created demand for up to 1,100 MW of offshore wind energy. The New Jersey legislature broadened the traditional cost-benefit analysis to include a comprehensive net benefits analysis and also created a mechanism to ensure that the application for ORECs is a cost-competitive process overseen by the New Jersey Board of Public Utilities.

Long-Term PPAs

In Massachusetts, Cape Wind secured a 15-year PPA with National Grid for 50% of the output and a 15-year PPA with NSTAR for 27.5% of the output. The price for the PPA is $187/MWh—representing a premium above market rates. However, notwithstanding the premium, analysis performed by Charles River & Associates demonstrated that Cape Wind will be dispatched ahead of other generators because of the zero fuel cost of wind generation. According to analysis performed by Charles River & Associates, even with a premium PPA price of $187/MWh, Cape Wind electricity generation will lower the wholesale electric power prices by $1.86/MWh on average throughout 25 years—totaling $286 million in annual savings or $7.2 billion in savings during the same 25-year-period in New England without Cape Wind. These results are consistent with the potential cost savings demonstrated by the NOWEGIS report in previous sections.

It is important to note that none of the Great Lakes states have passed an offshore wind carve-out or a REC multiplier to promote offshore wind. In contrast to the Atlantic Coast states, Texas and the Great Lakes states have focused on improvements to the regulatory process for siting and permitting offshore wind.

Interconnection

The fourth regulatory requirement for offshore wind deployment is the interconnection process. Although obtaining a commercial lease and permit can be a lengthy process, so, too, can the interconnection process. A developer of an offshore wind project is required to follow federal interconnection regulations as overseen by the Federal Energy Regulatory Commission (FERC). Interconnecting transmission is technically straightforward, but the impact of the new resource on the grid raises questions concerning the cost of interconnecting this power source and who pays for it.

Whether a transmission project is in a competitive market or a vertically integrated utility territory, transmission projects may be paid for in one of three ways: (1) the generator pays for transmission services and includes the cost in the PPA; (2) users pay for transmission services; or (3) all users of the transmission system pay for the transmission project. Depending on the market structure, how the project will be paid for—cost allocation—can be very broad (across a utility territory or across an RTO) or very narrow (the generator or the user of the electricity pays). There are three ways to plan and develop transmission needed for offshore wind projects under the current regulatory regime: (1) generator interconnection process (GIP); (2) merchant transmission; and (3) regional planning projects in RTOs.

In the initial years of deployment, it is likely that offshore wind development will interconnect through the GIP to ensure that transmission is planned and developed for individual projects. Although utilizing the GIP will ensure that all needed upgrades are planned and developed, it requires the generator to pay for 100% of the cost of the transmission line connecting to the grid and any upgrades that could be required as a result of the new generation. The GIP process differs from one RTO or ISO to another, but in all regions the cost burden of connecting offshore wind rests on the generator, with reimbursement policies varying by region

Without a critical mass of offshore wind projects to justify a coordinated offshore grid, the first offshore wind projects will likely be integrated by using GIP procedures and radial transmission lines, which increases the total cost of offshore wind.

A status quo policy will likely result in a combination of many radial connections or split connections to the electric grid, which could complicate both landfall connections and transmission planning along the Atlantic Coast. This result may not lead to development of the most cost-effective or efficient transmission system. In parts of the country with RTOs, states have cooperatively joined together based on the belief that planning generation and transmission across multiple state jurisdictions both fosters competitive markets and results in benefits for all states involved. States and RTO regions will need to continue to study the most cost-effective and efficient ways to interconnect offshore wind in the transmission planning process. However, depending on a number of factors, including proximity of the wind farms to one another, radial lines may be the most optimal electrical connection—albeit expensive for the generators. As a result, a large portion, if not all, of the first several gigawatts of offshore wind in the United States will interconnect to the grid using GIP procedures absent a different policy mechanism for the ownership and development of a coordinated backbone or grid.

In Texas, Competitive Renewable Energy Zones (CREZ) were established by state law to build and pay for 3,600 mi of transmission to efficiently integrate wind development. The Texas CREZ transmission lines have integrated more than 18 GW of onshore wind at a cost that is competitive and paid for by all customers in the Texas market. Additional states could determine that CREZ zones could be established to help reduce the cost of expensive upgrades from the generator interconnection process. Although a state that is developing a project to serve customers *solely* in their state jurisdiction can determine how those costs are shared across customers in their state jurisdiction, the same cannot be said for projects that span two state jurisdictions. It is possible for states to enter into agreements to develop any number of generation and transmission projects, but the issue of who benefits and who pays can create disagreements.

In 2010, a consortium of investors announced the Atlantic Wind Connection (AWC) offshore wind transmission backbone to serve the offshore wind industry. As proposed in 2010, the AWC is an alternative to developing multiple radial interconnections to meet the growing demand for offshore wind on the Atlantic Coast. The AWC would be built in three phases to serve the growing offshore wind industry. Trans-Elect and Atlantic Grid Development estimated the cost of the AWC to be $5 billion, plus financing and permitting costs. The first phase was identified as the New Jersey Energy Link, a 150-mi stretch from northern New Jersey to Rehoboth Beach, Delaware, to be in service by 2016. Despite bringing in additional investors such as Google, Bregal Energy, Marubeni Corporation, and Elia, the AWC is not scheduled to be in service before 2021.

In 2014, the Atlantic Grid Connection announced that the AWC would continue to be developed as a merchant transmission project *without* offshore wind development. The New Jersey Energy Link is moving forward on the basis of being able to provide electrical and economic benefits to the New Jersey electric grid. Although AWC continues to provide the option for an efficient interconnection method for offshore wind, the project developers will continue to develop the project solely on the economic and electrical benefits that the transmission project will deliver, akin to Neptune, Cross Sound Cable, TransBay Cable, and other underwater electric transmission projects.

RECOMMENDATIONS

States that have been successful to date in pursuing offshore wind development have done so by passing state laws that support investment in offshore wind. By recognizing the economic development, environmental, and electrical benefits of offshore wind, states have passed laws that encourage investment in this potential resource. The establishment of RPS laws in 31 states has been a major impetus for utilities' procurement of electricity from land-based wind and solar. During the past decade, the cost of wind has declined 80%, and solar has declined more than 60% in the most recent 5 yr. Different policies can promote offshore wind development in an environmental and economically responsible way; however, states must determine how to balance public policy to enhance environmental, public health, and economic development opportunities with the countervailing need to keep retail electric rates reliable and affordable. A recent report noted that compliance with RPS laws across 29 states and the District of Columbia has resulted in average cost increases of only 0.9% in retail rates over the past three years.

States that determine that offshore wind development offers benefits to their citizenries should first explore the results of state policies adopted on the Atlantic Coast. New Jersey and Maryland passed offshore wind carve-outs that mandate a certain amount of capacity or electricity over a certain time from offshore wind resources. In New Jersey, the board of public utilities has the ability to set the cost for OREC to provide the minimum price structure to support a given project that is seeking approval. In Maryland, cost concerns were addressed by limiting the procurement of offshore wind to 200 MW and broadening the definition of benefits to include employment, taxes, health and environmental benefits, supply chain opportunities, rate-payer impacts, and the long-term effect on energy and capacity markets. In Maine, Massachusetts, Rhode Island, New Jersey, and Maryland, state law broadens the definition of benefits for what a PUC may consider when approving an offshore wind contract.

At the federal level, DOE research and development should continue to evaluate the best way to reduce the installed cost of energy for offshore wind. DOE's advanced technology demonstration projects will deploy three offshore wind projects that will help to demonstrate the electrical potential of offshore wind. These projects will be among the first to pursue the regulatory pathway for offshore wind—siting, environmental permitting, power contracting, and interconnecting to the electric grid. Although these projects face a streamlined BOEM siting and improved environmental permitting regime on the OCS, lessons learned will emerge as each region learns about the potential benefits and costs of offshore wind development. In addition to the three demonstration projects selected in May 2014, four additional projects are candidates to demonstrate how the deployment of offshore wind can be achieved at a reduced cost and timeline. As the first demonstration and commercial projects are deployed, the environmental impacts may be better understood through data collection. Likewise, regulators will have the opportunity to streamline the NEPA permitting process so that concurrent environmental reviews can be conducted with data from other regions, which will help projects avoid and mitigate any potential impacts to important historic, cultural, and environmental resources.

Research and development into reducing the levelized cost of energy (LCOE) should also continue until the offshore wind industry is mature. Nearly all energy sources receive federal and state subsidies for exploration and development. Although some of these provisions in the tax code are permanent, others require annual congressional approval through appropriation requests. For wind and solar, investment tax credits and production tax credits have provided important financial incentives to help deploy these resources at scale and therefore reduce their costs. Policy makers will need to determine whether offshore wind should likewise receive tax credit support to encourage its development. The ebb and flow of wind development follows very closely with congressional support of tax credits throughout the past decade. Similar policy decisions for offshore wind are likely to influence offshore wind development, particularly with the immature state of the industry and the high capital costs associated with offshore installations. The level of public desire for offshore wind and the cost in the overall energy budget will need to be weighed in such political decisions. Congress should explore the inclusion of offshore wind in the investment tax credit extension that is set to expire at the end of 2014. Enacting tax credit support that will extend through 2020 will help support the first generation of offshore wind projects.

State and federal policies will determine whether offshore wind development based on their state policy priorities after comparing the higher costs of offshore wind to the potential benefits of job creation, reduced greenhouse gas emissions, and electrical benefits—projected by this report to be $41/MWh. Although certain regions of the country are endowed with certain energy resources, it is the states that must determine the most cost-effective way to promote and develop their resources—making value judgments about land use, aesthetics, energy security, and environmental health and public health—and develop public policy to support these priorities.

The results of NOWEGIS suggest that the development of offshore wind—even with high capital costs initially—offers states electric benefits projected to be $41/MWh.

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