Technology White Paper

on

Wind Energy Potential on the U.S. Outer Continental Shelf

Minerals Management Service
Renewable Energy and Alternate Use Program
U.S. Department of the Interior

May 2006

WIND ENERGY POTENTIAL ON THE U.S. OUTER CONTINENTAL SHELF

INTRODUCTION

With the passage of the Energy Policy Act of 2005 (EPAct), Public Law 109-58 (H.R. 6), the Minerals Management Service (MMS), a bureau of the U.S. Department of the Interior, was given jurisdiction over Renewable Energy and Alternate Use Program projects, such as wind, wave, ocean current, solar energy, hydrogen generation, and projects that make alternative use of existing oil and natural gas platforms in Federal waters. A new program within MMS has been established to oversee these operations on the U.S. Outer Continental Shelf (OCS). MMS is developing rules to guide the application and permitting process for development of Renewable Energy and Alternate Use Program projects on the OCS. To apply the requirements of the National Environmental Policy Act (NEPA) in the establishment of national offshore alternate energy development policy and a national alternate-energy-related use program and rules, MMS plans to prepare a programmatic environmental impact statement (Programmatic EIS). The Programmatic EIS process will (1) provide for public input concerning the scope of national issues associated with offshore alternate-energy-related use activities; (2) identify, define, and assess generic environmental, sociocultural, and economic impacts associated with offshore alternate-energy-related use activities; (3) evaluate and establish effective mitigation measures and best management practices to avoid, minimize, or compensate for potential impacts; and (4) facilitate future preparation of site-specific NEPA documents—subsequent NEPA documents prepared for site-specific Renewable Energy and Alternate Use Program projects will tier off of the Programmatic EIS and Record of Decision. The Programmatic EIS will evaluate the issues associated with development, including all foreseeable potential monitoring, testing, commercial development, operations, and decommissioning activities in Federal waters on the OCS. Information defining the issues and current technology will be obtained primarily from Federal research organizations, MMS, industry, and other valid sources.

In preparation for the Programmatic EIS, MMS has developed a series of White Papers on topics of interest to the Renewable Energy and Alternate Use Program. The overall objective of the White Papers is to provide sufficient information on the prospective alternative technologies to support assessments of the potential environmental impacts of the technologies and of the viable impact mitigation strategies in the Programmatic EIS. The White Papers also will serve as sources of information for stakeholder outreach.

This paper discusses the generation of energy from wind resources on the OCS. Resource potential and technologies for capturing the energy in the wind are discussed.[1] Major environmental and economic considerations that can be surmised from literature and environmental studies that are available at this time for the development of this energy resource are listed. Companion papers in the series address the generation of energy on the OCS from

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[1] Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not represent its endorsement, recommendation, or favoring by MMS, the United States government, or any agency thereof.

waves, solar radiation, and ocean currents, and the transportation of energy generated on the OCS to onshore as electricity or in the form of hydrogen.

RESOURCE POTENTIAL

The U.S. Department of Energy (DOE) estimates that more than 900,000 MW[2] (close to the total current installed U.S. electrical capacity) of potential wind energy exists off the coasts of the United States, often near major population centers, where energy costs are high and land-based wind development opportunities are limited. Slightly more than half of the country's identified offshore wind potential is located off the New England and Mid-Atlantic Coasts, where water depths generally deepen gradually with distance from the shore. Resources on the Gulf Coast and Great Lakes Regions[3] have not been fully characterized (Offshore Wind Collaborative Organizing Group 2005). Table 1 shows estimated OCS wind energy resources by region for waters less than 30 m deep and waters equal to or greater than 30 m deep in the United States. Development of offshore wind energy technologies has the potential to provide up to 70,000 MW of domestic generating capacity to the nation's electric grid by 2025 (Thresher 2005).

Of the more than 900,000 MW of offshore wind resources beyond 5 nautical miles from shore, slightly more than 10% (98,000 MW) is estimated to be over waters less than 30 m deep. In the near term, existing offshore technologies, which have been used in Europe's shallow waters for more than a decade, may be applicable for these shallow U.S. waters. However, because the remaining OCS resources are over waters that are 30 m or deeper, new technologies (e.g., for towers, foundations, and blades) will be needed to harness the wind in the harsher conditions associated with deeper waters. Harsher conditions generally include higher wind velocities and greater wave action.

Today, more than 600 MW of offshore wind energy capacity is installed worldwide (all in waters less than 30 m deep). Proposed offshore wind facilities through 2010 amount to more than 11,000 MW, with about 500 MW each in the United States and Canada, and the remainder in Europe and Asia (Musial 2005).

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[2] This estimate excludes the offshore zone from the shoreline to 5 nautical miles. It also excludes 67% of the potential area within 5 to 20 nautical miles from shore, to account for shipping lanes and avian, marine mammal, fish, and view shed concerns. For the 20- to 50-nautical-mile zone, the exclusion was reduced to 33% where there are fewer environmental concerns and where wind facilities would not be visible from the shore (Musial and Butterfield 2004).

[3] The Great Lakes are outside the scope of this White Paper.

TABLE 1 Offshore Resource Estimates (MW)

	5 to 20 Nautical Miles			20 to 50 Nautical Miles		
Region	< 30 m deep	=> 30 m deep	% Exclusion	< 30 m	=> 30 m	% Exclusion
New England	9,900	41,600	67	2,700	166,300	33
Mid-Atlantic States	46,500	8,500	67	35,500	170,000	33
California	2,650	57,250	67	0	238,300	33
Pacific Northwest	725	34,075	67	0	93,700	33
Total	59,775	141,425	67	38,200	668,300	33

Source: Musial and Butterfield (2004).

RESOURCE UTILIZATION TECHNOLOGIES

Wind turbines will be used to harness the kinetic energy of the moving air over the oceans on the OCS and convert it to electricity. Offshore winds are less turbulent (because the ocean is flat relative to onshore topography), and they tend to flow at higher speeds than onshore winds, thus allowing turbines to produce more electricity. Because the potential energy produced from the wind is directly proportional to the cube of the wind speed, increased wind speeds of only a few miles per hour can produce a significantly larger amount of electricity. For instance, a turbine at a site with an average wind speed of 16 mph would produce 50% more electricity than at a site with the same turbine and average wind speeds of 14 mph (Offshore Wind 2006).

Historical Perspective

As early as 200 B.C., wind was reportedly used to pump water in China and grind grain in the Middle East. Over the centuries, onshore wind has been harnessed to generate power worldwide. In the nineteenth century, settlers in the United States used windmills to generate electricity for homes and pump water for consumption and crop irrigation; industrialization sparked the development of larger windmills to generate electricity for commercial purposes. Interest in wind energy has waxed and waned with the price of fossil fuels. After the 1973 Arab oil embargo, new ways of converting wind energy into useful power were developed. Many of these approaches have been demonstrated in wind facilities (also known as wind farms, wind power plants, or wind projects), which are groups of turbines that feed electricity into the utility grid. Wind facilities began appearing in California in the 1980s, and, today, the cost of onshore wind-generated electricity is close to that generated from conventional utilities in some locations.

Wind energy is the fastest growing energy source worldwide at about 20 to 30% per year. The worldwide installed capacity of onshore grid-connected wind power is about 40 GW. Turbine sizes have increased over the past two decades. In the mid-1980s, the rotor (blades and hub) diameter was about 20 m; today, rotor diameters are 100 m or more (bigger than the wingspan of a 747 aircraft), with the rotating blades covering an area the size of a football field.

The first offshore wind facilities were installed in the early 1990s in Europe where there was limited land available for onshore wind energy production. The Vindeby Facility in Denmark (Figure 1), completed in 1991, has eleven 450-kW turbines that provide a total capacity of 4.95 MW. Since then, the trend has been to move wind turbines offshore to take advantage of higher wind speeds; smoother, less turbulent airflows; larger amounts of open space; and the ability to build larger, more cost-effective turbines. Today, more than a dozen offshore European wind facilities with turbine ratings of 450 kW to 3.6 MW exist offshore in very shallow (depths of 5 to 12 m) waters. Because of these shallow depths, the offshore turbines installed to date have been able to use conventional land-based designs with upgraded electrical and corrosion control systems, and foundations (concrete bases or steel monopiles) to anchor them to the seabed.

Basic Offshore Wind Technology

A wind turbine can be compared to a fan operating in reverse: rather than using electricity to produce wind, the turbine uses the wind to make electricity. In a wind turbine, the blades capture a small portion of the kinetic energy of incident wind through a process of aerodynamic lift, and the blades spin a shaft that is connected through a set of gears to the center shaft of an electrical generator. As with land-based wind facilities, offshore facilities are likely to consist of a number of turbines operating independently, but delivering their power to onshore customers through a common conduit, typically an undersea cable. The positions of the turbines are selected to ensure that each turbine operates in the wind regime for which it was designed and to prevent the air turbulence that is created by the towers and rotating blades of one turbine from interfering with the efficient operation of nearby turbines. Such careful “micrositing” of turbines within a wind facility helps ensure that the facility, as a whole, operates with the highest possible efficiencies, regardless of wind direction. In some land-based settings, this requires turbines to be separated by as much as 10 rotor diameters from each other. In offshore applications, where only two wind directions are likely to predominate, the distances between turbines arranged in a line can be shortened to as little as two to four rotor diameters without

FIGURE 1 World’s First Offshore Wind Facility, Vindeby, Denmark, 1991 (Source: Siemens 2006)

creating interferences because of turbulence. Principal components of an OCS wind turbine include the following:

- Rotor (blades and blade hub), which is connected through a drive train to the generator;
- Turbine assembly, which includes the gearbox and generator, and is enclosed by a shell or nacelle;
- Tower, which supports the turbine assembly, houses the remaining facility components, and provides sheltered access for personnel; and
- Foundation or structure to support the tower.

Offshore turbines have technical needs not required of onshore turbines because of their exposure to the more demanding climates that exist in offshore locations. Offshore turbines look similar to those onshore, with several design modifications. These include strengthening the tower to cope with wind-wave interactions, protecting the nacelle components from the corrosive nature of sea air, and adding brightly colored access platforms for navigation and maintenance. Offshore turbines are typically equipped with corrosion protection, internal climate control, high-grade exterior paint, and built-in service cranes. To minimize expensive servicing, offshore turbines may have automatic greasing systems to lubricate bearings and blades, and preheating and cooling systems to maintain gear oil temperature within a narrow temperature range. Lightning protection systems minimize the risk of damage from lightning strikes that occur frequently in some locations offshore. There are also navigation and aerial warning lights. Turbines and towers are typically painted light blue or grey to help them blend into the sky. The lower section of the support towers may be painted bright colors (e.g., yellow) to aid in navigation and to highlight the structures for passing vessels.

Offshore wind turbines are also bigger than onshore turbines (to take advantage of the steadier and higher velocity offshore winds and economies of scale). A typical onshore turbine installed today has a tower height of about 60 to 80 m, and blades about 30 to 40 m long; most offshore wind turbines are at the top end of this range. Offshore turbines installed today have power generating capacities of between 2 and 4 MW (Figure 2), with tower heights greater than 61 m and rotor diameters of 76 to 107 m. Turbines of up to 5 MW are being tested.

Figure 3 shows the primary components and dimensions of one of the eighty 2-MW turbines in Denmark’s Horns Rev offshore wind park (the largest capacity offshore wind facility constructed to date).

Figure 4 shows how a European offshore wind park converts wind to electricity and sends it to the onshore grid (BWEA 2006a). After a suitable place for the wind facility is located, piles (1) are driven into the seabed. Once the turbine is assembled, sensors on the turbine detect the wind direction and turn the nacelle to face into the wind, so that the blades can collect the

FIGURE 2 Rotor Assembly for Scroby Sands, United Kingdom Offshore Wind Facility (2-MW turbine) (Source: BWEA 2006c)

maximum amount of energy throughout each diurnal cycle.[4] The moving wind over the aerodynamically shaped blades (2) makes them rotate around a horizontal hub, which is connected to a shaft inside the nacelle (3). This shaft, via a gearbox, powers a generator to convert the energy into electricity. Undersea collection cables (4) take the power from the individual turbines to an offshore transformer (5) that converts the electricity to a high voltage (33 kV) before running it back via an undersea transmission cable 8 to 16 km to connect to the grid at a substation on land (6). At the substation, the outputs of multiple collection cables are combined, brought into phase, and stepped up in voltage for transmission to the onshore grid.

OCS Wind Development in the United States

Because of the relatively vast onshore wind resources that exist in the United States (as opposed to Europe), there has been relatively little U.S. OCS wind development, and there are no commercial wind facilities operating today off the coasts of the United States. In the past few years, interest in offshore wind energy has increased because of a number of factors: offshore wind turbines can generate power closer to high-value coastal load centers than onshore turbines, offshore winds produce more power per unit area, and offshore European wind facilities have demonstrated the feasibility of offshore facilities.

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[4] Diurnal wind cycles result from the differential cooling and heating rates between land and water, thereby generating wind even if there are no storm fronts in the area.

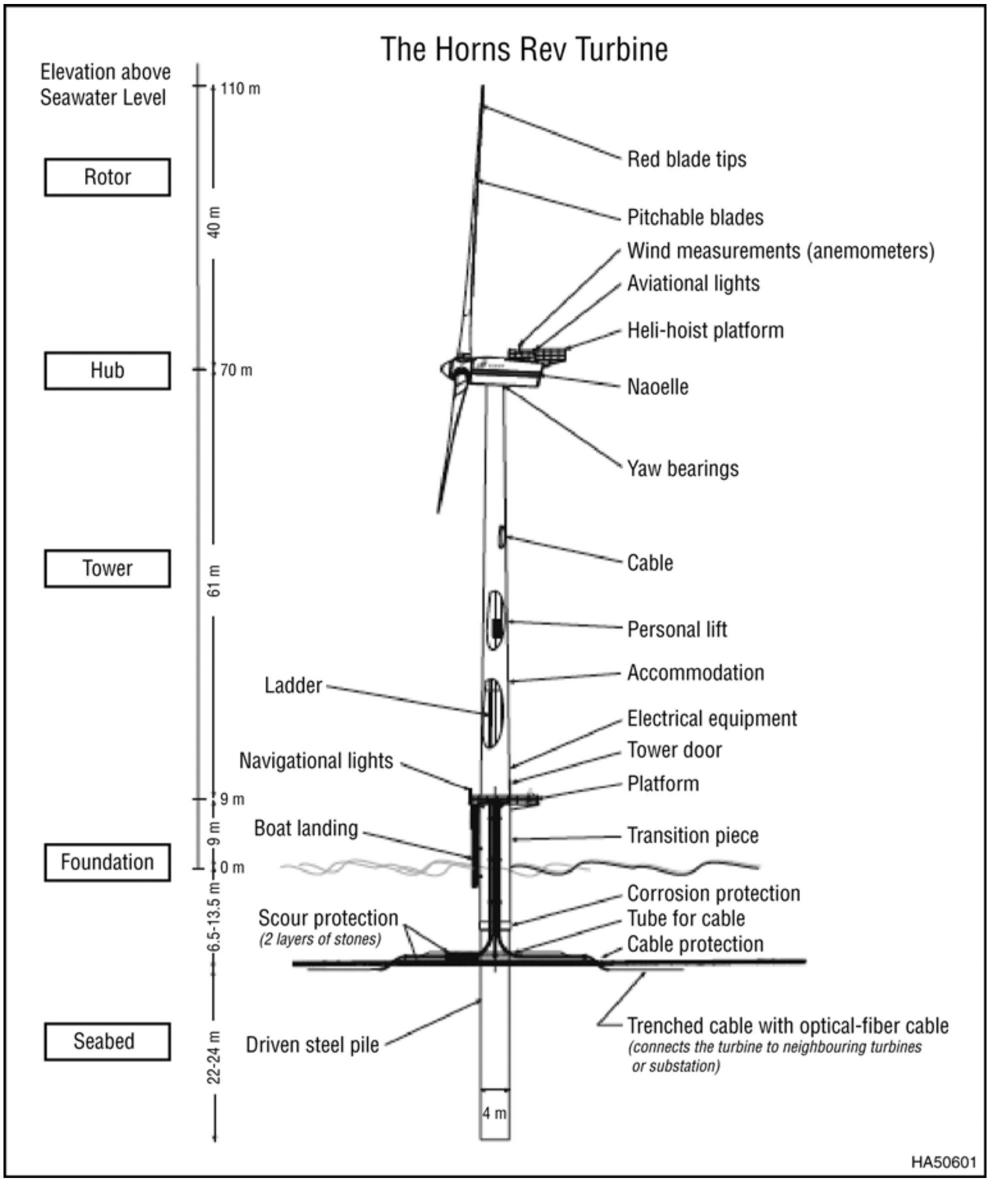

FIGURE 3 Primary Components and Dimensions of One of the 2-MW Turbines in Denmark's Horns Rev Offshore Wind Park (Source: Adapted from Offshore Wind Collaborative Organizing Group 2005)

Today, at least three offshore wind facilities are in the planning stages in the United States:

- Cape Wind facility off the coast of Massachusetts. Developers filed for a permit from the U.S. Army Corps of Engineers in 2001 to build this 130-turbine facility slated to produce up to 420 MW. It is on the OCS (just beyond 5 km offshore), and it would be the largest offshore wind energy facility in the world.

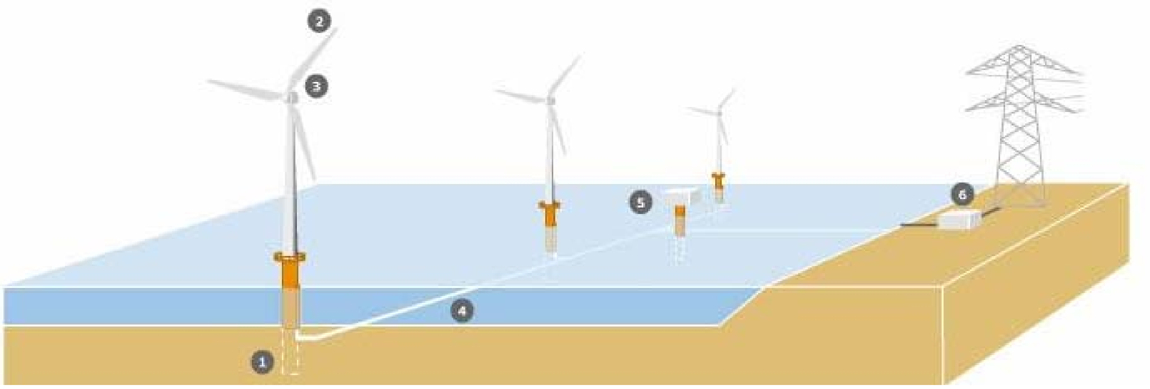

FIGURE 4 Schematic of Offshore Wind Facility (Source: BWEA 2006a)

- Long Island Offshore Wind Park. Off the southern coast of Long Island, New York, and also on the OCS, this facility is planned to consist of 40 turbines producing 140 MW of power. A permit application for this facility was submitted to the Corps in April 2005 (FPL 2006).

- Fifty-turbine facility off the Galveston, Texas coast. While this facility is not in the Northeast, where offshore winds are considered to be the strongest and other energy alternatives are lacking, its developers believe it will be successful because of the area’s experience with other offshore energy development and a more favorable state regulatory environment (Miller 2006). (State of Texas regulatory authority extends to 16 km off the coast, whereas other states’ authorities extend for 5 km.)

Important differences exist between Europe and the United States regarding offshore wind environments. U.S. waters are generally deeper than those off the European coasts, and ocean conditions on the U.S. OCS are more severe than those in Europe. Thus, the technologies designed for European offshore environments will need to be modified to adapt to the harsher U.S. OCS conditions.

U.S. Technology Needs

As wind speeds tend to increase with distance from the shore, turbines built farther offshore will be able to capture more wind energy. However, as the distance from land increases, the costs of building and maintaining the turbines and transmitting the power back to shore also increase sharply. To capture the wind power and reach the economies of scale needed to make the far offshore sites financially viable, it is generally believed that 5-MW or larger turbines will be needed. Technologies will be needed for low-cost mooring and anchor development, for erecting and decommissioning in relatively deeper waters (greater than 30 m), and for improving accessibility and reliability. Ways to store wind energy for later use may also be required. Technologies also will be needed to develop large composite blades, to reduce the weight of the blades, and to improve their ability to withstand variations in turbulence. Reducing blade weights also reduces the structural demands placed on the towers. DOE recently announced plans to develop a multimegawatt offshore wind power system over the next several years that would include innovative construction techniques, rotor designs, drive trains, electrical components, and foundations designed for the harsh offshore environment, while optimizing the total life-cycle cost (DOE 2006).

The extreme requirements placed on tower foundations are important constraints on OCS wind development. Many turbines have been installed on steel monopiles—long, steel tubes that are hammered, drilled, or vibrated into the seabed until secure. Others have been attached to gravity foundations—concrete structures that settle and are stabilized by sand or water. These types of foundations are less suitable for the deeper waters off U.S. coasts. Platforms capable of supporting the turbines in deep water (up to 900 m) will allow access to offshore areas where an estimated 750,000 MW of wind resource potential exists (Thresher 2005).

It is possible that floating structures developed for offshore oil and gas industries can be adapted for wind turbines. A floating structure for a wind turbine must provide sufficient buoyancy to support the weight of the turbine and to restrain pitch, roll, and heave motions caused by wind and wave forces, under normal and storm conditions. At the same time, the offshore floating platforms used by the oil and gas industry have certain requirements that may not be needed by wind turbine platforms. For example, oil and gas platforms often provide permanent residences for offshore personnel and must have additional safety margins and stability for spill prevention that would not be required for wind turbines. Finally, oil and gas platforms are deployed in water depths up to 2,438 m; wind turbines would probably not need to be sited in waters deeper than 183 m. Figure 5 shows several platform concepts for the relatively deep waters.

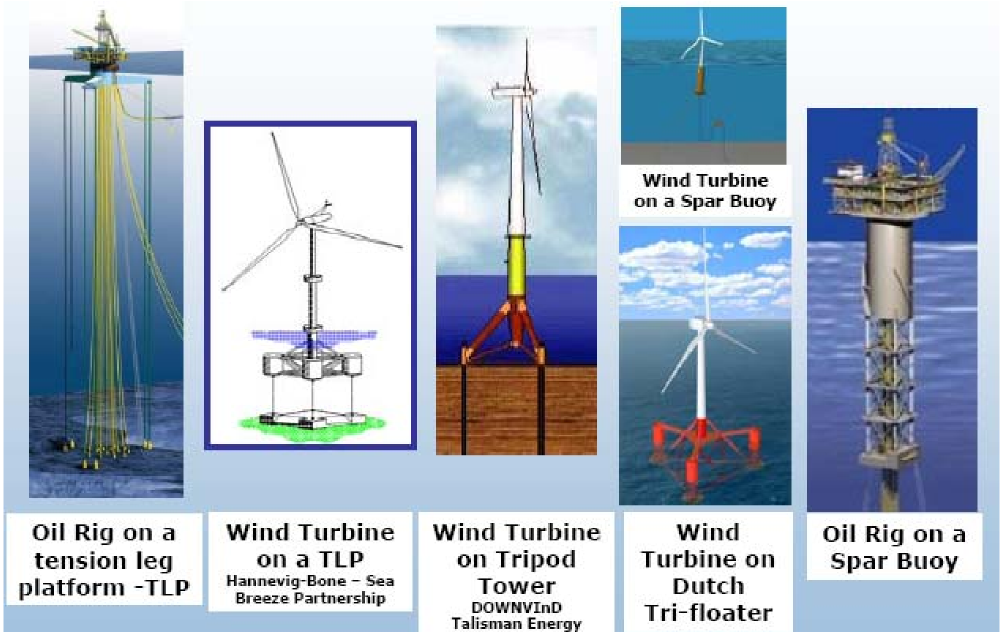

FIGURE 5 Offshore Platform Concepts (Source: Musial 2005)

Integration with Other OCS Energy Technologies

There have been proposals to combine tidal and wind power and install tidal stream turbines on the bases of offshore wind turbines. The hybridization of wind and wave energy could enhance cost competitiveness with onshore wind facilities because of synergies that include single permitting; shared foundation/mooring infrastructure; shared deployment and operation maintenance with common facilities, equipment, and personnel; and higher capacity. However, marine-based renewable energy technologies are all at relatively earlier stages of development than offshore wind, so such amalgamated facilities are not imminent.

Integration with Onshore Energy Technologies/Systems

Wind resources vary by the minute, hour, day, month, and year, and these variations can affect the onshore electric power generation, transmission, and distribution systems with which they interface. Since the electricity coming into the power system is variable, there may be times when it could potentially overload the system, and there may be times when its anticipated contribution falls short. However, grids are designed to compensate for loss-of-load contingencies when large power plant units suddenly become unavailable. Utility studies have indicated that wind can readily be absorbed in an integrated network until the wind capacity accounts for about 20% of maximum demand. Beyond this, some changes to operational practice may be needed. Integrating variable output is easier when it is part of large power systems that can take advantage of the natural diversity of variable sources. A large geographical spread of wind power will reduce variability, increase predictability, and decrease the number of instance with near zero or peak output.

Grid connection of offshore wind facilities is not a major technical problem per se, because the relevant technologies are well known. But integrating large wind facilities with the grid could present challenges. With smaller facilities, wind turbines could go off the system when the grid became unstable. Once the grid stabilized, they would resynchronize and come back online. With large wind facilities comprising a significant part of the generation capacity in some areas, the objective now is to make the wind facilities act more like thermal units from a power distribution level (Gadomski 2005). Large OCS facilities, could in principle, provide the same ancillary services that conventional generators offer today to help ensure system stability. Wind turbine manufacturers are investing in technologies to smooth sudden bursts and even out short-term fluctuations in wind-generated power.

Wind-generated electricity must be conditioned and phased properly before it is introduced into the grid. That is, its voltage, frequency, and other electrical parameters must be made compatible with the conditions existing on the grid. Procedures for such interconnections need to be considered and established to accommodate power generated in offshore wind facilities.

The feasibility of using electricity generated by offshore wind turbines to produce hydrogen as an alternative to connecting that electrical power to an existing onshore power grid is also being investigated. Hydrogen would be produced through the electrolysis of desalinated seawater by using electricity produced by the wind. It could then be transported to shore as pure hydrogen in its molecular form (H_2) either as compressed gas or as liquid via pipeline, tanker, or a ship, or via a hydrogen carrier that would use materials to transport hydrogen in a form other than free H_2 molecules. (See the White Paper on the transportation of energy generated on the U.S. OCS to onshore for more details.) Some of the electricity produced by the turbine also could be used to provide the power needed to run reverse osmosis or distillation systems.

ENVIRONMENTAL CONSIDERATIONS

Potential environmental impacts associated with the development and utilization of wind energy resources on the U.S. OCS will be fully investigated in the Programmatic EIS. Impacts on major environmental resources, including human health and safety, air and water quality, ecology, socioeconomics, waste management, resource requirements, and cultural resources, will be analyzed individually and cumulatively with other facilities potentially affecting each environmental resource. The following paragraphs highlight potential environmental considerations for each phase of OCS wind energy development.

Construction

Construction time for offshore facilities to date has been about 6 months, but this would be longer for the larger facilities that would be built on the U.S. OCS. (Construction time for the Cape Wind facility is estimated to be about 2 years.) During construction, key concerns are sedimentation, noise, and vibration. Construction practices such as soft-start pile driving, bubble curtains, and other proven best practice methodologies can help mitigate noise and vibration. During construction, there is a risk that oil or other harmful substances could be spilled and thus deteriorate water quality.

Operations

OCS wind turbines are expected to have an operational life of 20 to 25 years. However, it may be possible to install new turbines on existing foundations so that a given wind facility may remain operational beyond the life expectancy of its component turbines. Potential impacts on the environment that may occur during operations are highlighted below.

- *Marine life*. Foundations can act as artificial reefs with a resultant increase in fish populations from the new food supply. These increases in fish population may also have stimulating effects on bird populations in the area, which could promote collisions between birds and towers or rotors.

- *Migrating birds*. In addition to potential collisions (bird strikes), it is possible that the birds would need to consume more energy to avoid collisions and maintain their orientation when navigating around the turbines. Tower illumination may also cause navigational disorientation for birds.

- *Interference with navigation for endangered and threatened species*. Electromagnetic fields created by the electric cables running from the turbines and underwater noises and vibrations could affect orientation and navigational ability.

- *Potential alteration of natural environments and diminution of habitats*. Underwater support pilings, anchoring devices, scour-protection materials, and electromagnetic fields could cause a decrease in benthic communities, alter natural environments, and possibly affect migration patterns.

- *Emissions*. Each unit of electricity generated from the wind that substitutes for a unit generated from fossil fuels helps reduce greenhouses gases, pollutants, and waste products that result from fossil fuel use.

- *Conflict with Other Sea Space Uses*. Wind turbines on the OCS may interfere with commercial shipping and fishing and recreational boating. It is possible that wind turbine energy facilities may disrupt air traffic control and maritime radar systems.

- *Visual impacts for systems that are close to the shore*.[5] (At greater distances, visibility impacts are reduced.)

- *Noise*. Newer wind turbine generators produce less sound than older turbines, but impacts of low frequency sound near the turbines on mammals would need to be investigated.

Decommissioning

After an OCS turbine has reached its useful life, it would be dismantled and decommissioned—a process expected to take about 6 months. Removal of turbine components including blades, nacelle, tower, and containerized transformer, is anticipated to be largely a reversal of the installation process and would be subject to the same constraints. Ultimate decommissioning of a facility may range from complete removal of all components — including cabling, foundations, and scour protection — to dismantling and using the decommissioned equipment for artificial reefs. Environmental impacts would vary depending on approach. They would likely be similar in nature to those found in other phases of development and use, although they may be more significant in terms of degree.

A number of measures can be employed to mitigate potential effects. Environmental impacts associated with OCS wind development should be evaluated in conjunction with the impacts of other energy technologies over the entire life cycle of operations.

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[5] The OCS generally begins 5 km from the shoreline. Thus, projects that are less than 5 km from the shoreline would not be OCS facilities but would be within state jurisdiction.

Siting Constraints

In selecting OCS wind facility locations, developers will need to consider how candidate areas are already used to avoid potential conflicts. In addition to minimizing the types of potential environmental impacts identified above, potential siting issues that need to be considered include the following:

- Shipping lanes,
- Excavation of raw materials in OCS areas,
- Existing areas used for disposal of dredged materials and other wastes,
- Pipelines,
- Commercial and recreational fishing areas,
- Low-flying aircraft flight patterns,
- Military operations and radar systems, and
- Migration patterns for birds and mammals.

ECONOMIC CONSIDERATIONS

The economic viability of an offshore wind facility depends on whether the costs can be offset by high-quality wind resources and high productivity. In the last 20 years, the costs of creating energy from wind have dropped significantly. According to DOE, advanced turbines have reduced the price from \$0.40/kWh to \$0.04 to \$0.06/kWh today for onshore wind. This compares with natural gas at \$0.04 to \$0.05kWh, but it is still more expensive than hydro (\$0.03 to \$0.04/kWh) and coal (\$0.02 to \$0.03kWh) (Pellerin 2005). Offshore wind facility costs today are generally between \$0.08 and \$0.15/kWh — almost double that of onshore facilities (Offshore Wind Collaborative Organizing Group 2005). These costs are for wind facilities located in the shallow (less than 30 m deep) areas of the coasts of Europe, where development costs are less than would be expected in the deeper, harsher U.S. OCS waters. To date, most offshore wind facilities have been developed with some kind of government support.[6] Nonetheless, by 2012 and beyond, DOE envisions 5-MW and larger machines generating power for \$0.05/kWh (DOE 2006).

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[6] For example, the United Kingdom's offshore projects are being developed in two rounds. The first round, consisting of 13 offshore wind facilities, was announced in 2001; all of these received government grants. Of these, three are in operation, one is under construction, and two have been put on hold indefinitely because the developer no longer believes they are economically viable. The remaining seven are experiencing delays. The second round was to have benefited from experience and economies of scale so that government support would not be necessary. However, developers say that costs have actually risen by one-third, and that it is doubtful that the second round of projects can proceed without government support (Webb 2006).

The costs of OCS wind energy development are higher than those for onshore wind for several reasons, including the need for more expensive foundations, protection against salt spray and corrosion, and transporting and installing at sea. Power collection and transmission costs may also be higher for OCS applications. Overall, capital investment requirements may be 30 to 60% higher for OCS applications than for onshore facilities (DWIA 2006). Operation and maintenance (O&M) costs are higher because of site remoteness and potentially unfavorable weather conditions. Annual O&M costs for offshore wind facilities are estimated to be roughly 1.5 to 2.0% of the initial capital investment. These increases are partially offset by energy yields that are up to 30% higher than onshore yields (BWEA 2006b), economies of scale,[7] and close proximity to high-value load centers. Also, prices are expected to drop as technology improves and more experience is gained. For example, the capital costs for onshore wind development have decreased an average of 15% for every doubling of capacity (Offshore Wind Collaborative Organizing Group 2005).

At the just-completed 2006 annual offshore conference of the British Wind Energy Association (BWEA), however, information was presented indicating that the costs of building offshore facilities have increased by 33% and are nearly double the costs of building onshore facilities. The increasing costs of steel and the demand from Asia and the United States for wind facilities have pushed up the price of turbines and limited the availability of the equipment needed to install them (Webb 2006).

Construction and accessibility are the leading cost drivers for wind facilities, and these costs are much higher at sea. The majority of costs in offshore facilities are in the facility components, including the foundation/support structure, installation, and transmission, whereas for onshore facilities, most of the costs are in the turbines. Depth of water is an important contributor, with each additional meter of tower height adding an estimated $2,000 to the capital cost (DWIA 2006). Although there is no long-term experience with OCS facilities, current estimates are that rebuilding some of the major components after about 25 years of operation could be necessary for efficient operation. Current estimates indicate that such costs would be on the order of 25% of the initial capital investment (DWIA 2006).

SUMMARY

OCS wind energy has the potential to provide 900,000 MW, which is close to the total currently installed U.S. electrical capacity. Much of this potential is near high-energy demand areas with limited energy resources. OCS wind turbines and technologies are based on onshore wind technologies, but they are generally larger and more expensive (because of marine conditions). The largest OCS wind turbines in commercial operation today are 3.6 MW, and development is underway for 5 MW-offshore turbines that are expected to generate electricity for costs of about $0.05/kWh. To use the greater wind resource potentials that exist in the far offshore areas, technological advances will be needed to reduce the weight of turbines and to develop safe and cost-effective platforms to harness the wind that is available over deeper

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[7] The physical constraints of transporting large components such as blades do not apply to the same degree offshore, and the cost of installation offshore is much the same regardless of the size of turbines.

waters. Potential advantages of OCS wind energy are that the fuel has no cost, harnessing the energy produces no emissions, the power is produced domestically, and a significant amount of renewable energy that is relatively close to high-energy demand centers is harnessed.

Potential impediments for near-term utilization include the need for new technologies to capture the resource in larger amounts and higher costs relative to onshore technologies. Environmental considerations will need to be addressed. For offshore applications to be commercially competitive there is a need to overcome current depth limits, improve accessibility and reliability, develop design methods, establish safety and environmental standards, and demonstrate the technology at a commercial scale.

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