Large-Scale Offshore Wind Power in the United States

EXECUTIVE SUMMARY

September 2010

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Executive Summary

Introduction

Offshore wind power is poised to deliver an essential contribution to a clean, robust, and diversified U.S. energy portfolio. Capturing and using this large and inexhaustible resource has the potential to mitigate climate change, improve the environment, increase energy security, and stimulate the U.S. economy.

"Wind power isn't the silver bullet that will solve all our energy challenges—there isn't one. But *it is* a key part of a comprehensive strategy to move us from an economy that runs on fossil fuels to one that relies on more homegrown fuels and clean energy."
President Barack Obama, April 2010

The United States is now deliberating an energy policy that will have a powerful impact on the nation's energy and economic health for decades to come. This report provides a broad understanding of today's wind industry and the offshore resource, as well as the associated technology challenges, economics, permitting procedures, and potential risks and benefits. An appreciation for all sides of these issues will help to build an informed national dialog and shape effective national policies.

Opportunities in Offshore Wind Power

In common with other clean, renewable, domestic sources of energy, offshore wind power can help to build a diversified and geographically distributed U.S. energy mix, offering security against many energy supply emergencies—whether natural or man-made. Wind power also emits no carbon dioxide (CO_2) or other harmful emissions that contribute to climate change, ground-level pollution, or public health issues.

Under conservative assumptions about transmission, fossil fuel supply, and supply chain availability, the United States could feasibly build 54 GW of *offshore wind power* by 2030.
20% Wind Energy by 2030,
U.S. Department of Energy, July 2008

*Based on the model scenario optimizing total delivered cost for conventional and wind resources. For other assumptions, see www.nrel.gov/docs/fy08osti/41869.pdf

The United States' offshore wind energy resources can significantly increase the wind industry's contribution to the nation's clean energy portfolio. The United States is fortunate to possess a large and accessible offshore wind energy resource. Wind speeds tend to increase significantly with distance from land, so offshore wind resources can generate more electricity than wind resources at adjacent land-based sites. The National Renewable Energy Laboratory (NREL) estimates that U.S. offshore winds have a gross potential generating capacity four times greater than the nation's present electric capacity. While this estimate does not consider siting constraints and stakeholder inputs, it clearly indicates that the U.S. offshore wind capacity is not limited by the magnitude of the resource.

Developing the offshore wind resource along U.S. coastlines and in the Great Lakes would help the nation to:

- **Achieve 20% of its electricity from wind by 2030.** In assessing the potential for supplying 20% of U.S. electricity from wind energy by 2030, NREL's least-cost optimization model found that 54 gigawatts (GW)[1] of added wind capacity could come from offshore wind. Achieving 20% wind would provide significant benefits to the nation, such as increased energy security, reduced air and water pollution, and the stimulation of the domestic economy.

- **Revitalize its manufacturing sector.** Building 54 GW of offshore wind energy facilities would generate an estimated $200 billion in new economic activity and create more than 43,000 permanent, well-paid technical jobs in manufacturing, construction, engineering, operations and maintenance. Extrapolating from European studies, NREL estimates that offshore wind will create more than 20 direct jobs for every megawatt produced in the United States.
- **Provide clean power to its coastal demand centers.** High winds abound just off the coasts of 26 states. More specifically, suitable wind resources exist near large urban areas where power demand is steadily growing, electric rates are high, and space for new, land-based generation and transmission facilities is severely limited. These characteristics provide favorable market opportunities for offshore wind to compete effectively in coastal regions.

Status of the Offshore Wind Industry

The United States leads the world in installed, *land-based* wind energy capacity, yet has *no offshore* wind generating capacity to date. Since Denmark's first offshore project in 1991, Europe has held the lead in offshore wind, having installed more than 830 turbines with grid connections to nine European countries (see Figure 1-1). Almost all of the 2,300 megawatts (MW) of installed capacity has been built in shallow waters (less than 30 meters deep). The market is continuing to expand, with Europe planning to add another 1,000 MW in 2010. An additional 50,000 MW is being planned or is under development for 2011 and beyond. Interest in offshore wind is now spreading to Canada, China, and the United States.

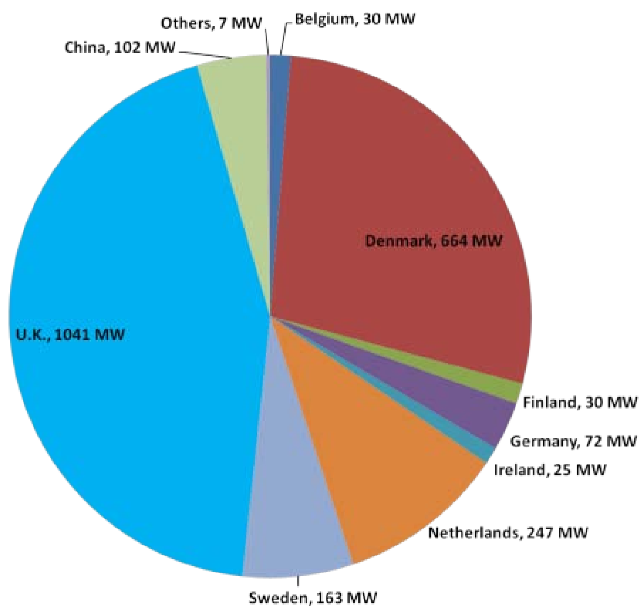


Figure 1-1. Nameplate generating capacity of offshore wind projects (1991–2010)

Although the United States has built no offshore wind projects so far, about 20 projects representing more than 2,000 MW of capacity are in the planning and permitting process. Most of these activities are in the Northeast and Mid-Atlantic regions, although projects are being considered along the Great Lakes, the Gulf of Mexico, and the Pacific Coast. The deep waters off the West Coast, however, pose a technology challenge for the near term.

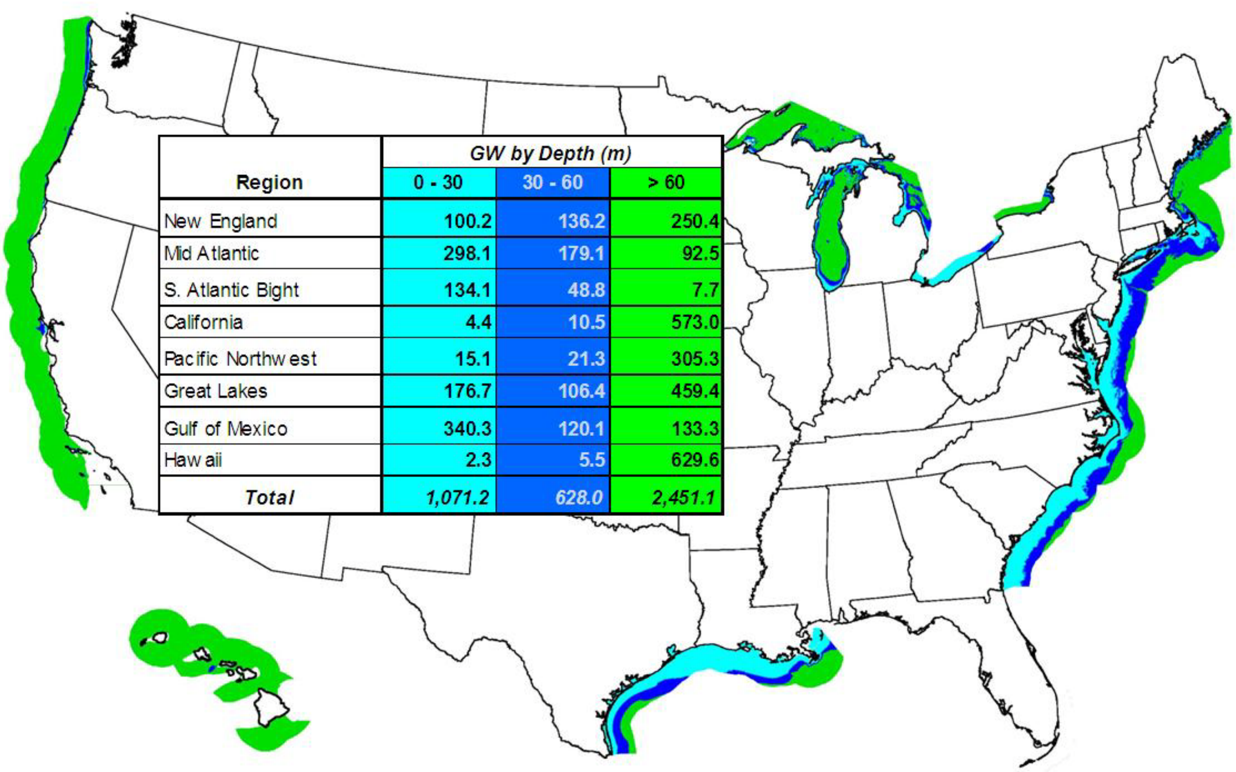
[1] 1 gigawatt = 1,000 megawatts

Untested regulatory and permitting requirements in federal waters (outside the three-nautical-mile state boundary) have posed major hurdles to development, but recent progress is clarifying these processes. Most notably, after 9 years in the permitting process, the Cape Wind project off of Massachusetts was offered the first commercial lease by the Department of Interior in April 2010.The U.S. Department of the Interior bears responsibility for reducing the uncertainties and potential risks to the marine environment and making the federal permitting process more predictable under the Bureau of Ocean Energy Management (In June 2010, the Minerals and Management Service [MMS] was reorganized and renamed Bureau of Ocean Energy Management, Regulation and Enforcement [BOEM]). Some states have been proactive in promoting offshore wind demonstration projects in their own waters close to shore, which may provide a more efficient regulatory path to meet their renewable energy obligations, while jump-starting a new locally grown industry.

A Powerful U.S. Resource

Offshore winds tend to blow harder and more uniformly than on land, providing the potential for increased electricity generation and smoother, steadier operation than land-based wind power systems. The availability of these high offshore winds close to major U.S. coastal cities significantly reduces power transmission issues.

The offshore wind resource in the United States has been sufficiently documented at a gross level to suggest an abundance of potential offshore wind sites as shown in Figure 1-2.



Region	*GW by Depth (m)*		
	0 - 30	30 - 60	> 60
New England	100.2	136.2	250.4
Mid Atlantic	298.1	179.1	92.5
S. Atlantic Bight	134.1	48.8	7.7
California	4.4	10.5	573.0
Pacific Northwest	15.1	21.3	305.3
Great Lakes	176.7	106.4	459.4
Gulf of Mexico	340.3	120.1	133.3
Hawaii	2.3	5.5	629.6
Total	*1,071.2*	*628.0*	*2,451.1*

Figure 1-2. United States offshore wind resource by region and depth for annual average wind speed sites above 7.0 m/s.

The gross resource has been quantified by state, water depth, distance from shore, and wind class throughout a band extending out to 50 nautical miles from the U.S. coastline. This total *gross wind resource* is estimated at more than 4,000 GW, or roughly four times the generating capacity currently carried on the U.S. electric grid. This estimate assumes that one 5-MW wind turbine could be placed on every square kilometer of water with an annual average wind speed above 7.0 meters per second (m/s). As shown in Figure 1-2, this gross resource is distributed across three main depth categories, increasing from 1,071 GW over shallow water (30 meters), to 628 GW over transitional waters (between 30 and 60 meters in depth), and to 2,451 GW over deep water (deeper than 60 meters). However, this wind mapping effort does not currently account for a range of siting restrictions and public concerns. These gross resource values will likely shrink by 60% or more after all environmental and socioeconomic constraints have been taken into account. Further study is also required to determine optimal spacing of turbines based on array effects, which could reduce the density of the potential offshore wind development.

For now, this complex process of identifying suitable sites is left up to state and local authorities, which are working with federal entities to develop a marine spatial planning framework. In spite of the resource potential and benefits to the nation, the development of offshore wind as an energy source for the United States faces several significant challenges and barriers that stem from technology limitations, high cost, regulatory and institutional uncertainties, and potential environmental and social risks. A sustained, nationally focused research and development initiative is needed to address these challenges and inform decision makers and public policies.

Technology Status and Trends

Although Europe now has a decade of experience with offshore wind projects in shallow water, the technology essentially evolved from land-based wind energy systems. Significant opportunities remain for tailoring the technology to better address key differences in the offshore environment. These opportunities are multiplied when deepwater floating system technology is considered, which is now in the very early stages of development.

The opportunities for advancing offshore wind technologies are accompanied by significant challenges. Turbine blades can be much larger without land-based transportation and construction constraints; however, enabling technology is needed to allow the construction of a blade greater than 70-meters in length. The blades may also be allowed to rotate faster offshore, as blade noise is less likely to disturb human habitations. Faster rotors operate at lower torque, which means lighter, less costly drivetrain components. Challenges unique to the offshore environment include resistance to corrosive salt waters, resilience to tropical and extra-tropical storms and waves, and coexistence with marine life and activities. Greater distances from shore create challenges from increased water depth, exposure to more extreme open ocean conditions, long distance electrical transmission on high-voltage submarine cables, turbine maintenance at sea, and accommodation of maintenance personnel.

A primary challenge for offshore wind energy is cost reduction. Developing the necessary support infrastructure implies one-time costs for customized vessels, port and harbor upgrades, new manufacturing facilities, and workforce training. In general, capital costs are twice as high as land-based, but this may be partially offset by potentially higher energy yields—as much as 30% or more. As was experienced with land-based wind systems over the past two decades, offshore wind costs are expected to drop with greater experience, increased deployment, and improved technology. To make offshore wind energy more cost effective, some manufacturers are designing larger wind turbines capable of generating more electricity per turbine. Several manufacturers are considering 10-MW turbine designs, and programs, such as UpWind in the European Union, are developing the tools to allow these larger machines to emerge.

Figure 1-3 provides a brief overview of the technology status in each depth category and some representative design options.

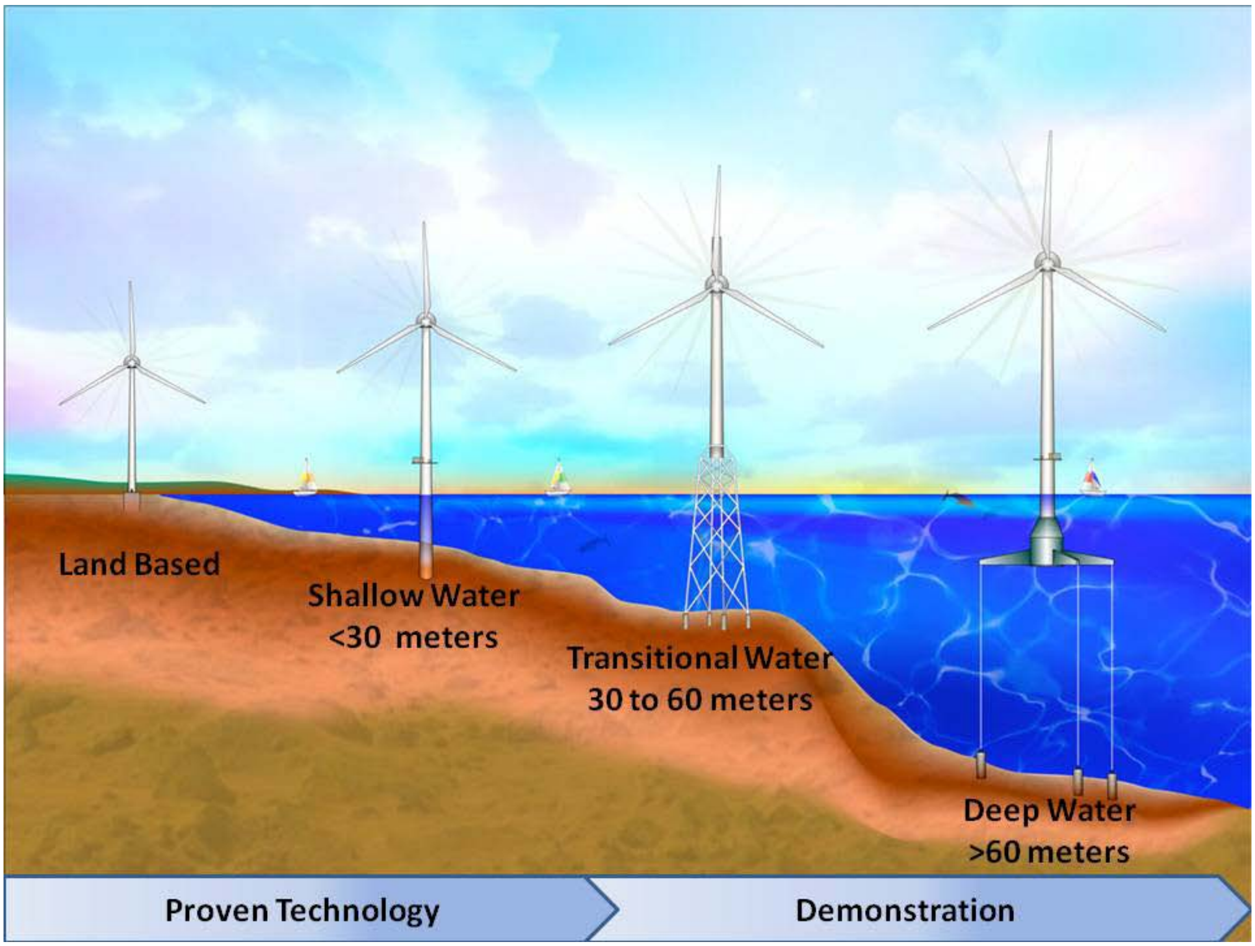


Figure 1-3. Status of offshore wind energy technology

In shallow water, the substructure extends to the sea floor and includes monopoles, gravity bases, and suction buckets. In the transitional depth, new technologies are being created, or adapted from the oil and gas industry, including jacket substructures and multi-pile foundations, which also extend to the sea floor. At some depth it is no longer economically feasible to have a rigid structure fixed to the sea floor, and floating platforms may be required. Three idealized concepts have arisen for floating platform designs, including the semisubmersible, the spar buoy, and the tension-leg platform, each of which use a different method for achieving static stability. Although it is not yet known which of these designs will deliver the best system performance, designers seek platforms that are easy to install and minimize overall turbine loads. To determine this optimized design point, advanced computer simulation models need to be developed and validated. As shown in the figure, most of the projects now reside in shallow water, and only two projects to date use transitional structures. One Norwegian demonstration project, Hywind (launched in 2009), uses a deepwater floating design.

Table 1-1 summarizes the key attributes of the resource and technology needed for large-scale offshore wind development in the United States.

Table 1-1. Summary of Key Project, Resource, and Technology Attributes

Technology Depth Class	Depth	Number of Projects Worldwide	U.S. Gross Offshore Wind Resource above 7.0 m/s (GW)	U.S. Gross Offshore Wind Resource above 8.0 m/s (GW)	Technology Description
Shallow Water	0 – 30m	42	1,071	457	Uses fixed-bottom monopile and gravity-base substructures with proven turbine technology adapted from land-based systems.
Transitional Depth	30m – 60m	2	628	549	Uses fixed-bottom jacket (lattice) or multi-pile substructures to provide stiffer base for turbines; similar to shallow water. New vessels for deeper deployments may be needed.
Deepwater	>60m	1	2,451	1,951	Floating substructures decouple from the bottom and allow site independence, which may allow greater degree of mass production and less work at sea. Typical substructures under consideration include semi-submersibles, spar buoys, and tension-leg platforms. New optimized turbines will be developed.

Economics of Offshore Wind Power

Offshore wind projects are analyzed in terms of their initial installed capital cost (ICC) as well as their life-cycle costs, also known as the levelized cost of energy (LCOE). Cost projections of either type for the U.S. market are difficult because of the many regulatory and technical uncertainties and the lack of U.S. market experience. Although the European market is based on a more developed supporting infrastructure and substantially different regulatory, policy, and physical environments, preliminary analyses of that experience provide some potentially useful insight.

As in the case of land-based projects, the ICC for offshore wind power has been increasing over time. Costs jumped approximately 55% between 2005 and 2007, leading to an estimated average capital investment of $4,250 per kW for an offshore wind project in 2010. The wind turbine itself contributes 44% of this total. In general, capital costs are expected to increase with distance from land and water depth, and decrease as the size of a project increases, as a result of economies of scale. As the technology matures, prices are expected to decline.

The LCOE calculations, or the cost of energy produced over the anticipated 20-year life of a project, are based on a range of factors, many of which are currently unknown and must be projected. In addition to the ICC, these include operations and maintenance (O&M) costs, the cost of financing, amount of energy to be generated, long-term system reliability, and decommissioning costs.

Operation and maintenance costs are higher for offshore wind turbines than for land-based turbines, primarily because of access issues. It is simply more difficult to perform work at sea. Although more research is needed to determine the range of these offshore O&M costs, some reports estimate they are two to three times higher than on land and can reach 20% to 30% of the LCOE.

The LCOE for offshore wind is heavily influenced by the relatively high ICC and the cost of financing. A significant part of the financing cost is based on the perception of financial risk and project uncertainties. These risk perceptions could potentially be lowered through research on virtually all of the factors that make up the LCOE for offshore wind, but the larger impacts will come from confidence built on deployment experience.

Under reasonable economic assumptions, offshore wind can be expected to penetrate the U.S. market on a large scale without introducing substantial new technology—such as large-scale grid storage or smart grid load management. Although these analyses are still preliminary, NREL's Regional Energy Deployment System (ReEDS) model (formerly called the Wind Deployment System [WinDS] model) shows offshore wind penetration of between 54 GW and 89 GW by 2030 when economic scenarios favoring offshore wind are applied. These cases used combinations of cost reductions (resulting from technology improvements and experience), rising natural gas prices (3% annually), heavy constraints on conventional power and new transmission development in congested coastal regions, and national incentive policies. Furthermore, analyses indicate that if wind energy is to supply 20% of the nation's electricity by 2030, offshore wind will be an essential component.

Regulatory Pathways for Siting and Permitting

Although the United States has a long history of managing energy-related extractive industries (e.g., oil and gas) on federal lands and in federal waters, there is no institutional knowledge about offshore wind energy facilities. Offshore wind power is a relatively new energy industry with about a 20-year demonstration history in European seas and less than a 10-year operational history for utility-scale projects. As such, the regulatory and institutional structures for offshore wind energy are just now emerging in the United States.

BOEM was assigned jurisdiction over leasing of federal waters (greater than 3 nautical miles from shore in all but Texas and the west coast of Florida) for ocean energy technologies under the Energy Policy Act of 2005. Secretary Salazar issued the final rule governing easements and rights of way for offshore wind on the outer continental shelf in April 2009. Several projects are now in early permitting stages under BOEM regulations and developer's estimate that approvals may take as long as 7 to 10 years – longer than permitting approvals for most other types of energy facilities

States desiring offshore wind supplies to meet their renewable energy goals and project developers seeking economic development opportunities have identified potential sites in state waters. State projects are typically near shore and have marginally lower wind resources, but there is a perception that state institutions and regulations provide an accelerated approval process. Regardless of these perceptions, state waters will not be able to provide enough sites for large-scale offshore wind power in the United States. To accelerate the deployment of offshore wind energy, the federal government needs to partner strategically with states where offshore wind development is planned or underway. The formation of several BOEM state task forces and the Atlantic Offshore Wind Energy Consortium, involving 10 governors, are steps taken in 2010 that proactively engage interested and affected parties and could help mature the regulatory and stakeholder engagement processes.

Environmental and Socioeconomic Risks

Risks associated with offshore wind energy are not as serious or potentially catastrophic compared with other energy supply technologies. Also wind turbines can be deployed relatively quickly to reduce greenhouse gases, reduce other air emissions and help conserve water resources. Potential risks in deploying offshore wind projects can typically be reduced through development and use of best management practices, mitigation strategies, and adaptive management principles. Although risks are site-specific, research at European installed projects and U.S. baseline studies are building the knowledge base and helping to inform decision makers and the public.

Primary stakeholder concerns regarding offshore wind power facilities include:

Marine animal populations: Although European studies conducted to date suggest that the impacts of offshore wind facilities on marine animal populations are minimal, U.S. studies will be required to gain a better understanding of the potential risks and to mitigate any harmful effects.

Visual effects: Coastal residents in view of an offshore wind farm may voice concerns about visual impacts. More research is needed to better understand coastal communities and their ability to accept changes to the seascape.

Property values: Studies conducted on land-based wind projects show minimal to no impact on real estate prices and property values as a result of the presence of wind turbines; however, extensive studies have not been conducted on coastal communities.

Noise: Based on European studies and experiences to date, the most significant environmental impact stems from the noise associated with pile driving during the construction phase. Mitigation strategies may be effective in reducing this risk. Alternative technology can also be implemented if appropriate to avoid some of the pile driving activity.

Tourism: Impacts on tourism may be a concern to some communities that are dependent on beach vacationers and the resulting local revenues and tax base, but the evidence is ambiguous and actual effects appear to be minimal.

Marine safety: The possibility of a ship colliding with a turbine poses a potentially significant risk to the marine environment from fuel leaks from a disabled ship or to human safety should the turbine collapse. No reported incidents have occurred to date.

Research is also needed to fill gaps in the knowledge base and prioritize risks based on analysis of uncertainties and potential impacts. Several important gaps and uncertainties include visual effects, public perception of deployment risks, endangered and migrating species, conflicting use of military and recreational spaces, and construction impacts. BOEM and other federal and state agencies are beginning to fill these gaps with baseline surveys and studies. Sector-by-sector impact analyses, however, as required with NEPA documentation, are limited in revealing the true risks to the ocean or lake ecologies. Applying an integrated risk framework that compares costs and benefits of deploying offshore wind as opposed to another energy option is needed to inform decisions about the actual risks. Developing prudent siting policies will likely avoid coastal areas with intense competing uses and sensitive habitats and will reflect the sensitivities of multiple stakeholder groups. Siting strategies are needed that go beyond narrow technical appraisals of sites to include collaborative approaches with potential host states and communities. Well-developed risk communication and stakeholder involvement strategies need exploration and are essential to the successful development of offshore wind projects.

Findings and Conclusions

Overall, the opportunities for offshore wind are abundant, yet the barriers and challenges are also significant. In the context of the greater energy, environmental, and economic concerns the nation faces, accelerating the deployment of offshore wind could have tremendous benefits to the United States. Technological needs are generally focused on making offshore wind technology economically feasible and reliable and expanding the resource area to accommodate more regional diversity for future U.S. offshore projects. Prudent siting strategies that involve stakeholders at the site would reduce potential risks. Removing deployment barriers can help support the first projects in the competitive energy supply market, with the objective of reducing long-term uncertainties. In the short term, reducing risk will stimulate economic growth, accelerate permitting time frames, and help address important aspects of climate change mitigation. Although offshore wind alone cannot solve the nation's energy problems, this report concludes that with effective research, policies, and commitment, it can play a significant and vital role in future U.S. energy markets. As a result, it should be considered a necessary part of a diverse sustainable energy portfolio along with energy conservation and efficiencies.

Download the full report at www.nrel.gov/docs/fy10osti/40745.pdf (PDF)

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