Large-Scale Offshore Wind Power in the United States

ASSESSMENT OF OPPORTUNITIES AND BARRIERS

September 2010

NATIONAL RENEWABLE ENERGY LABORATORY

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Acronyms and Abbreviations

ANSI	American National Standards Institute
AOWEC	Atlantic Offshore Wind Energy Consortium
API	American Petroleum Institute
AWEA	American Wind Energy Association
BACI	Before and After Construction Impact
BOEM	Bureau of Ocean Energy Management, Regulation and Enforcement
BOS	balance of station
CAD	Canadian dollar
CA-OWEE	Concerted Action on Offshore Wind Energy in Europe
CEQ	Council on Environmental Quality
C-MAN	Coastal-Marine Automated Network
CESA	Clean Energy States Alliance
CMSP	coastal and marine spatial planning
CO_2	carbon dioxide
COD	Concerted Action for Offshore Wind Energy Deployment
COE	cost of energy
CVA	certified verification agent
CWA	Clean Water Act
CZMA	Coastal Zone Management Act
DKK	Danish krone (currency)
DNV	Det Norske Veritas
DOE	U.S. Department of Energy
DOI	U.S. Department of the Interior
EA	environmental assessment
EEZ	exclusive economic zone
EIA	Energy Information Administration
EIS	environmental impact statement
EMFs	electromagnetic fields
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act of 2005
ESP	electric service platform
EU	European Union
EWEA	European Wind Energy Association
FDR	Facility Design Report
FEIS	Final Environmental Impact Statement
FERC	Federal Energy Regulatory Commission
FIR	Fabrication and Installation Report
FIT	feed-in tariff

FLOWW	Fisheries Liaison with Offshore Wind and Wet Renewables
FONSI	Finding of No Significant Impact
FWS	U.S. Fish & Wildlife Service
GAP	General Activities Plan
GDP	gross domestic product
GHGs	greenhouse gases
GIS	geographic information system
GL	Germanischer Lloyd
GLWC	Great Lakes Wind Collaborative
GLO	General Land Office (Texas)
GW	gigawatts
GWEC	Global Wind Energy Council
Hg	mercury
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IHAs	Incidental Harassment Authorizations
IPCC	Intergovernmental Panel on Climate Change
ISO	International Standards Organization
JWGL	JW Great Lakes Wind, LLC
km	kilometer
km^2	square kilometer
kV	kilovolt
kW	kilowatt
kWh	kilowatt-hour
LCOE	levelized cost of energy
LEEDCo	Lake Erie Energy Development Corporation
LOS Convention	United Nations Convention on the Law of the Sea
m	meter
MASSCEC	Massachusetts Clean Energy Center
MBTA	Migratory Bird Treaty Act
met	meteorological
MIT	Massachusetts Institute of Technology
MLLW	mean lower low water
mm	millimeter
MMPA	Marine Mammal Protection Act
MMS	Minerals Management Service
MOU	memorandum of understanding
MTC	Massachusetts Technology Collaborative

NAERC	North American Electric Reliability Council
NAS	National Academies of Science
NEMS	National Energy Modeling System
NEPA	National Environmental Policy Act
NERI	National Environmental Research Institute
NGOs	nongovernmental organizations
NHPA	National Historic Preservation Act
NIST	National Institute of Standards and Technology
NJCEP	New Jersey Commerce, Economic Growth, and Tourism Commission
NJDEP	New Jersey Department of Environmental Protection
nm	nautical mile
NMFS	National Marine Fisheries Service (also NOAA Fisheries)
NRC	National Research Council
NREL	National Renewable Energy Laboratory
NOAA	National Oceanic and Atmospheric Administration
NOK	Norwegian krone (currency)
NO_x	nitrogen oxides
NWS	National Weather Service
NYPA	New York Power Authority
O&M	operations and maintenance
OCS	Outer Continental Shelf
OCSLA	Outer Continental Shelf Lands Act
OECD	Organisation for Economic Co-operation
OEM	original equipment manufacturer
OffshoreWindDC	Offshore Wind Development Coalition
OVC	other variable costs
OWWG	Offshore Wind Working Group
PPA	power purchase agreement
PEIS	Programmatic Environmental Impact Statement
PINCS	inspection procedures
ppb	parts per billion
ppm	parts per million
PSC	Public Service Commission
R&D	research and development
RECs	renewable energy credits
RECOFF	Requirements for Offshore Wind Turbines
ReEDS	Regional Energy Deployment System
REF	Renewable Energy Futures
RFI	request for information
RFP	request for proposals
RGGI	Regional Greenhouse Gas Initiative
RIPUC	Rhode Island Public Utilities Commission
Risø DTU	Risø DTU National Laboratory for Sustainable Energy

ROD	Record of Decision
rpm	revolutions per minute
RPS	renewable portfolio standard
s	second
sap	Site Assessment Plan
SAMP	Special Area Management Plan
SCADA	supervisory control and data acquisition
SEPAs	State Environmental Policy Acts
SO_2	sulfur dioxide
SRES	Special Report on Emission Scenarios (IPCC)
TC88	Technical Committee 88
TLP	tension-leg platform
TRB	Transportation Research Board
TWh	terawatt-hour
UNC	University of North Carolina
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USACE	U.S. Army Corps of Engineers
USOWC	U.S. Offshore Wind Collaborative
V	volt
VLA	vertical-load anchors
WinDS	Wind Deployment System or
WWPP	Wind &Water Power Program (DOE)

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1.0 Executive Summary

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.

1.1 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.

---

[1] 1 gigawatt = 1,000 megawatts

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.

1.2 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.

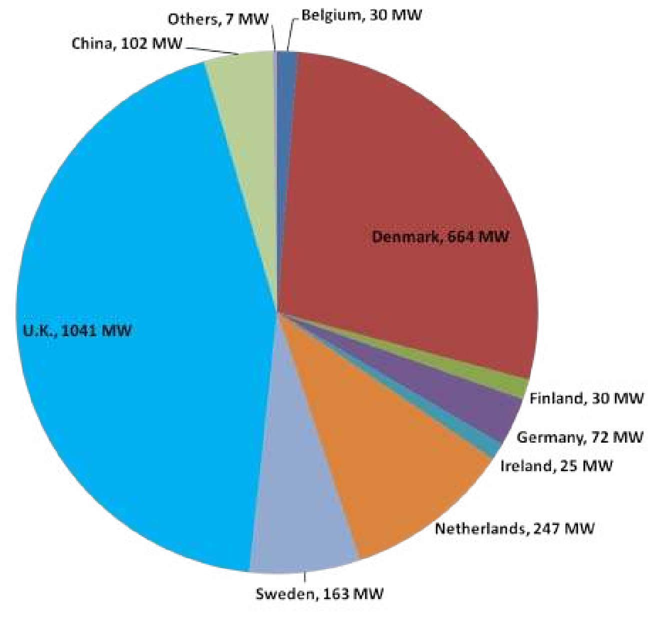


Figure 1-1. Nameplate generating capacity of offshore wind projects (1991–2010)

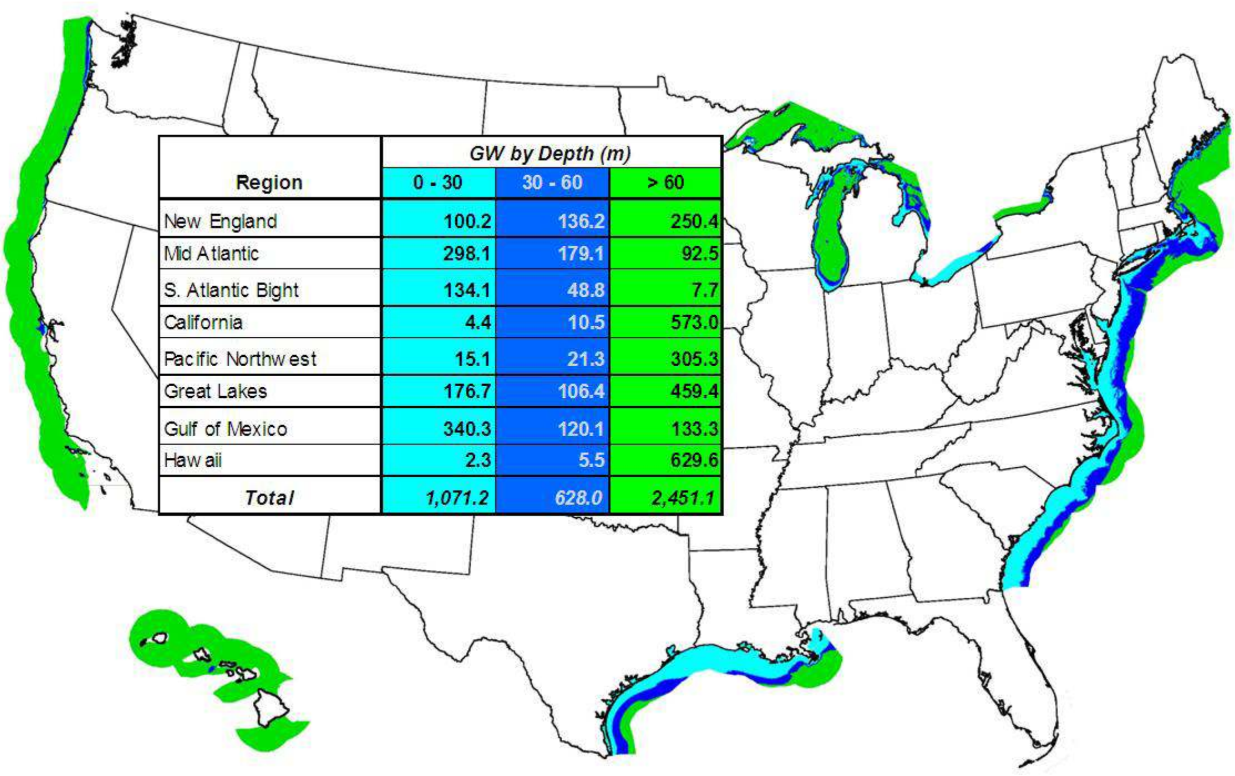
Although the United States has built no offshore wind projects so far, about 20 projects representing more than 2,000 MW of capacity are in the planning and permitting process. Most of these activities are in the Northeast and Mid-Atlantic regions, although projects are being considered along the Great 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.

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.

1.3 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.

1.4 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.

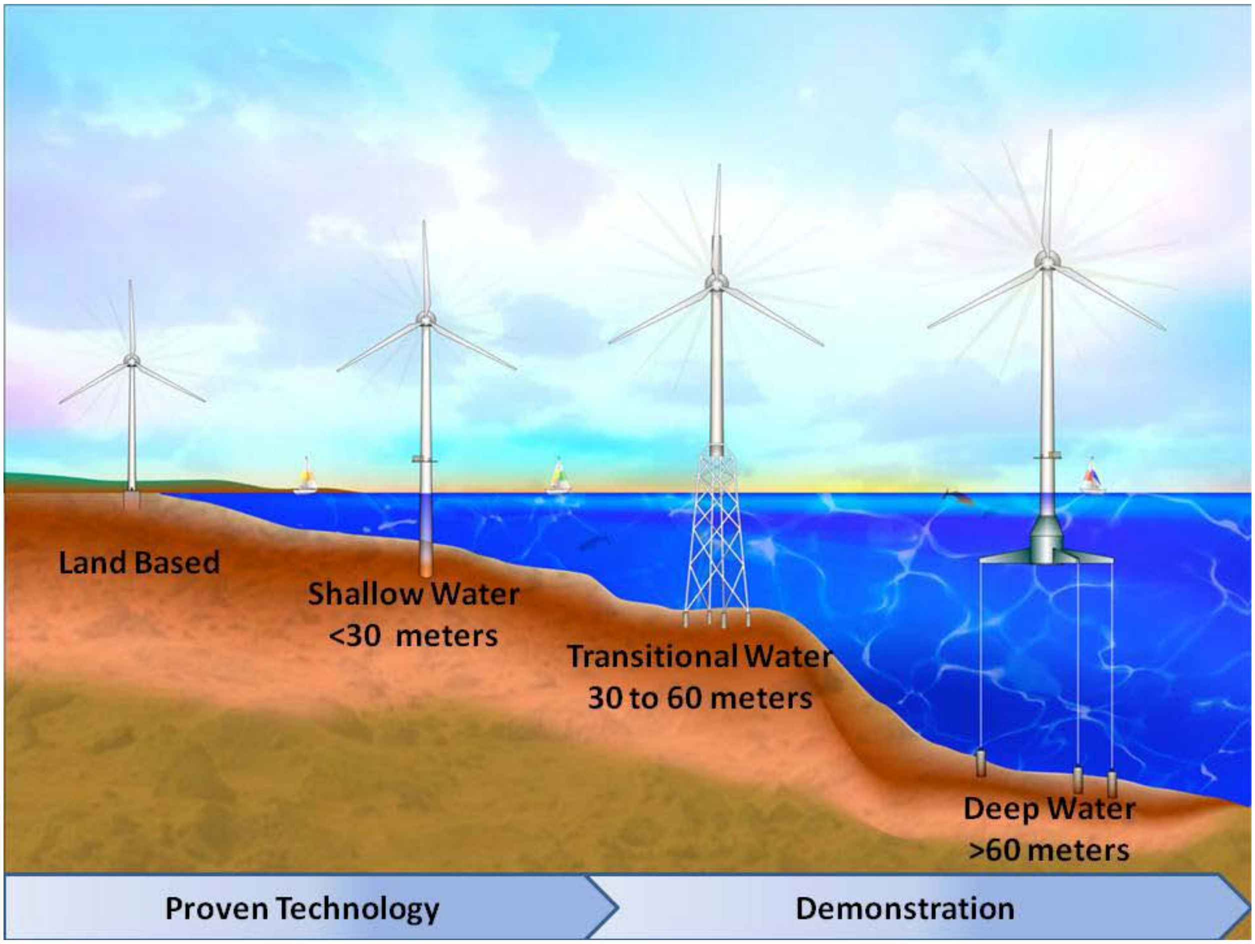


Figure 1-3. Status of offshore wind energy technology

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.

1.5 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.

1.6 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.

1.7 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.

1.8 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.

2.0 Rationale for Offshore Wind

The world and the nation face an unprecedented convergence of three interwoven dilemmas: energy supply shortages resulting from depletion of global fossil energy supplies; environmental consequences of fossil fuel emissions; and a worldwide economic crisis that threatens the livelihood of millions.

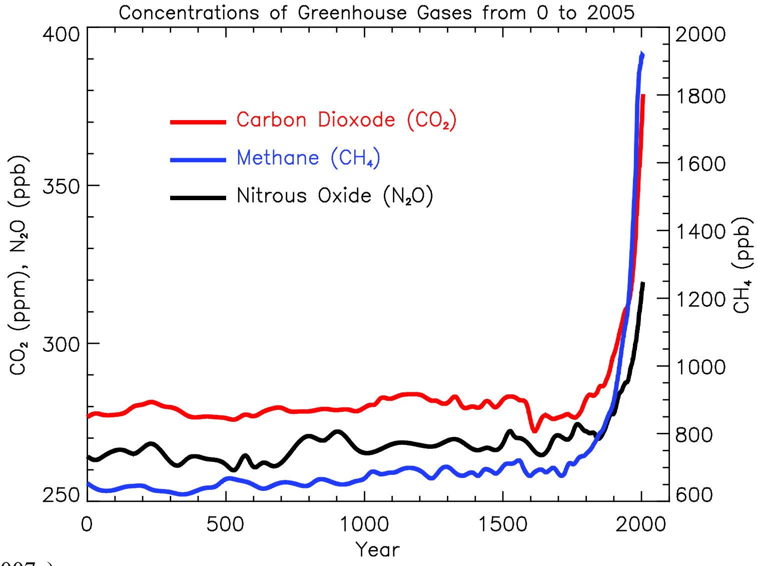
2.1 Energy Supply

The United States remains dependent on fossil fuels that are decreasing in supply and are increasingly imported from unstable and unreliable nations. The Energy Information Administration (EIA) forecasts that global energy consumption will rise 49% from 2007 levels by 2035, with the majority of the increase in non-OECD (Organisation for Economic Co-operation) countries (EIA 2010a). Energy consumption at such elevated levels will likely test the resource extraction and distribution capabilities of the global fossil fuels market. Strains on supply are likely to increase the prices of fossil fuel resources and leave the U.S. economy exposed to international market volatility. Reliance on foreign energy resources has significant implications for the national security situation, transferring wealth to several despotic regimes and leaving our economy vulnerable to the decisions of these governments (House Select Committee on Energy Independence and Global Warming 2010).

2.2 The Environment

Fossil power generation technologies have significant impacts on both public health and on our environment. Fossil fuel generation plants emit 39% of carbon dioxide (CO_2) emissions, 22% of nitrogen oxide (NO_x) emissions, 69% of sulfur dioxide (SO_2) emissions, and 40% of mercury (Hg) emissions in the United States (Jacobson and High 2008). A report by the National Academy of Sciences found that burning fossil fuels for transportation and for electricity generation costs the United States $120 billion a year, primarily in health damages. The nonclimate damages caused by coal-fired power plants are estimated at $62 billion per year or about 3.2 cents per generated kWh (National Research Council of the National Academies 2010).

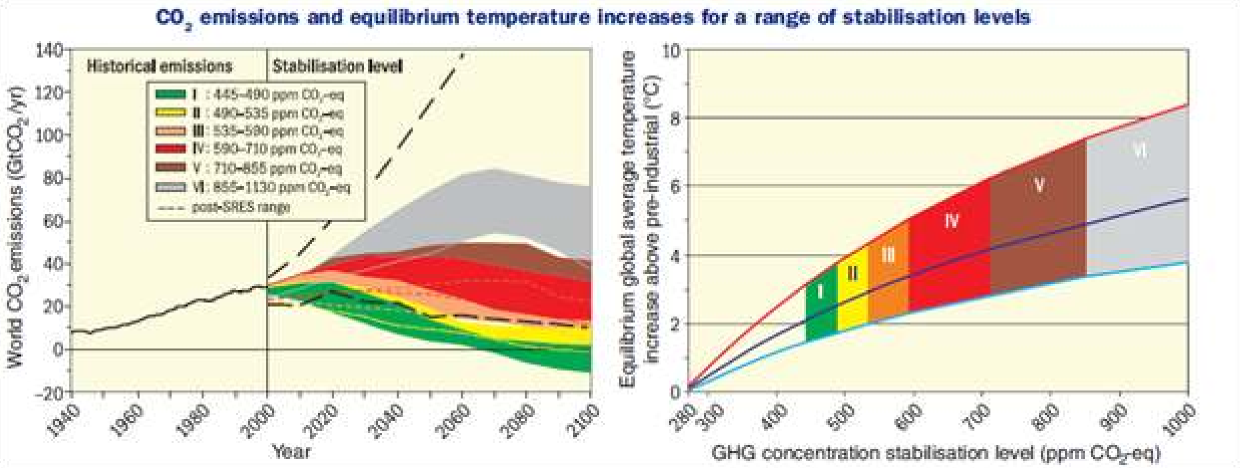
A more widely publicized externality of fossil fuel generation is the emission of greenhouse gases (GHGs) that are linked to global climate change. Concentrations of CO_2 in the atmosphere are rising steadily, primarily because of human consumption of fossil fuels (see Figure 2-1). The Intergovernmental Panel on Climate Change (IPCC) suggests that mitigation measures be taken to stabilize CO_2 at 550 ppm (which implies an 80% reduction in fossil fuel emissions) by 2050 (approximately double preindustrial levels). Even with these mitigation measures, another IPCC report posits the likelihood of a global temperature rise somewhere between 2°C and 4°C by 2050 (see Figure 2-2).



Source: Solomon et al. (2007a).

Figure 2-1. Concentrations of important long-lived greenhouse gases in the atmosphere (given in ppm and ppb)

Furthermore, the IPCC's Summary for Policy Makers (IPCC Core Writing Team 2007) states that "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level."



Source: Adapted from IPCC Core Writing Team. (2007).Notes: SRES = Special Report on Emission Scenarios (IPCC)

Figure 2-2. Global CO2 emissions for 1940 to 2000 and emissions ranges for categories of stabilization scenarios from 2000 to 2100 are shown in the left panel. The relationship between the stabilization target and global average temperature increase above preindustrial levels is shown in the right panel.

Although there is no panacea for the predicament posed by global climate change, a major part of the solution must include the reduction of carbon emissions into the atmosphere. Increasing the use of renewable energy will help to reduce these emissions.

2.3 The Economy

The nation is also recovering from the most significant economic downturn since the Great Depression. Economists are raising concerns about a return to economic slowdown (gross domestic product [GDP] growth fell from 3.7% in the first quarter of 2010 to 2.4% in the second quarter of 2010) and the prospect of a jobless recovery (as of this writing, the unemployment rate is at 9.5%, down just 0.6 percentage points from its high of 10.1% in October 2009; see Bureau of Economic Analysis 2010; Bureau of Labor Statistics 2010). In addition, the U.S. manufacturing sector, traditionally a source of economic strength, has been buffeted by the outsourcing of production operations overseas and, more recently, the recession. Data from the Bureau of Labor Statistics show that the manufacturing industry as a whole lost more than 4.1 million jobs between 1998 and 2008 and suggest that the sector will lose an additional 1.2 million jobs by 2018 (Bureau of Labor Statistics 2009). A continued decline in manufacturing activity will likely increase our nation's trade deficit; eliminate stable, high-wage jobs for skilled domestic workers; and generally reduce the potential for robust economic growth.

2.4 The Contribution of Offshore Wind

Offshore wind has the potential to address all three issues: the energy supply, the environment, and the economy. Offshore wind uses the vast renewable wind resources adjacent to the ocean perimeter of the United States, which are domestic, indigenous, inexhaustible energy supplies in close proximity to our urban energy load centers. Offshore wind turbines can convert the strong ocean winds into clean, renewable power with no harmful emissions. Offshore wind has the potential to contribute significantly to the revitalization of the U.S. manufacturing sector, which will help strengthen both the economies of coastal states and the U.S. economy as a whole.

Recognizing these issues, the Obama administration has strengthened the nation's commitment to renewable energy and clarified some of the actions needed to reduce our dependence on fossil fuels and bring emission levels in line with IPCC recommendations. The administration has set forth the following specific clean energy actions for the United States (White House 2009):

- Double this nation's supply of renewable energy in the next 3 years.
- Invest $15 billion per year to develop technologies like wind power and solar power, advanced biofuels, clean coal, and more fuel-efficient cars and trucks.
- Cut our carbon pollution by about 80% by 2050, and create millions of new jobs.
- Lease federal waters for projects to generate electricity from wind, as well as from ocean currents and other renewable sources.
- Put the nation on the path to generating 20% or more of our energy from renewable sources by 2020.

As a contributor to the overall solutions, the offshore wind resource in the United States has the potential to deliver substantial amounts of clean electricity to U.S. consumers. The National Renewable Energy Laboratory (NREL) estimates that the gross U.S. offshore wind resource over all water depths, in regions with annual average wind speeds greater than 8.0 m/s, is 2,957 GW (1 GW = 1,000 MW).[2] If average winds of 7.0 m/s are included, the estimated wind resource grows to 4,150 GW (Heimiller et al. 2010; see also Section 4). This is approximately four times the electricity generating capacity of the U.S. electric grid. Although these numbers provide only an upper bound, they demonstrate that for 54-GW offshore wind scenarios like those defined in the U.S. Department of Energy's (DOE) *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply* (the "20% report" or the "20% scenario), the offshore wind resource supply is not the primary issue determining deployment (DOE 2008).[3]

Wind speeds generally increase significantly with distance from the coast, resulting in a higher annual energy production than a similar turbine sited on land. Table 2-1 shows how sites with higher wind speeds—such as those found offshore—translate into high energy production. The table illustrates that an increase of two wind power classes (the difference that can be reasonably expected between a typical "Class 4" land-based site and a typical "Class 6" offshore site) would result in a gain of about 29% in annual average energy production for an NREL reference wind turbine (Jonkman et al. 2009).

Table 2-1. Energy Production by Wind Power Class

Average Annual Wind Speed (m/s)	**Wind Power Class**	**Change in Energy Production Relative to Class 4 Site**[a] (%)
5.6–6.4	2	–34
6.4–7.0	3	–15
7.0–7.5	4	0
7.5–8.0	5	+13
8.0–8.8	6	+29
8.8–9.5	7	+45

Source: Elliott et al. 1987.

[a] The relative change in energy production was computed using NREL's 5-MW reference wind turbine parameters, varying only the annual average wind speed. Actual turbine performance could be optimized for site-specific design conditions.

In addition to being plentiful, the offshore wind resource of the United States is broadly distributed. Thirty U.S. states border an ocean or Great Lake. The offshore wind resource exists within reasonable distances from major urban load centers, reducing the need for long-distance power transmission. These urban areas are home to much of the U.S. population; have the highest electricity prices in the nation; and currently depend heavily on a high-carbon, volatile supply of imported fossil fuels. According to the EIA (2007), the 28 coastal states in the lower 48 states[4] generate 75% of the nation's electricity (3,108 TWh of 4,157 TWh generated nationally in 2007).[5] The electricity generated in the U.S. coastal states represents 16.6% of the

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[2] This estimate is based on wind speeds at a 90-m elevation (hub height of the reference wind turbine) and includes all regions out to 50 nm. The estimate assumes that 5 MW (or about 1 turbine) of installed capacity would be installed in every square kilometer. This estimate includes the coastal regions for all of the lower 48 contiguous states with no exclusions.

[3] These resource estimates do not assume any exclusion areas where wind development would not be allowed. Judging from land-based experience, exclusion zones would result in at least a 60% reduction of the available resource.

[4] Alaska and Hawaii, although remote, have abundant offshore resources and could become electrically self-sufficient using offshore wind in conjunction with other renewables, along with smart grid and storage technologies. These states are treated separately, though, because they are isolated and cannot distribute power to other states.

[5] Electric energy generation figures published by the EIA can provide a rough estimate of the energy consumed by the same state. In some cases generation is transmitted across state boundaries or generation can take place behind the meter, as in large

world's total electricity (world electric energy generation was approximately 18.77 TWh in 2007; EIA 2010a). As such, the electricity consumption of U.S. coastal states has a large impact on the world's carbon emissions. These states could significantly reduce global GHG emissions if they choose to adopt renewable energy solutions such as offshore wind.

In coastal areas of the United States, offshore resources tend to dwarf the land-based wind component. Most coastal states do not have optimal land-based wind energy resources with the exception of a few: California, Oregon, Texas, Washington, and Maine. If offshore and land-based wind resources are counted together, coastal states would have sufficient wind resources to make wind energy a significant part of their electricity profiles (see sections 3 and 4). For many of these states, offshore wind is the most abundant indigenous energy source and the only commercial option for renewable power generation. This is especially true in some southern states where land-based resources become scarcer with decreasing latitude. Most other alternatives involve importing energy across state lines, which would require building up interstate transmission corridors or depending even more on fossil-fueled electricity generation.

U.S. wind energy generated offshore has the potential to compete economically in highly populated coastal energy markets where land-based wind energy is less available. Figure 2-3 shows that the offshore resource tends to be geographically located near states with high electric utility rates (EIA 2007). Figure 2-3, which is based on retail energy prices obtained from the EIA, also shows that the Mid-Atlantic and northeastern states have significantly higher electricity prices than the national average of \$0.099/kWh.[6] These prices are higher than inland and southern retail electricity prices, where energy prices are generally lower because of a fuel mix that relies heavily on imported coal and nuclear generation. The Pacific Northwest also has low electricity prices resulting from abundant hydropower resources (UCS 2010).

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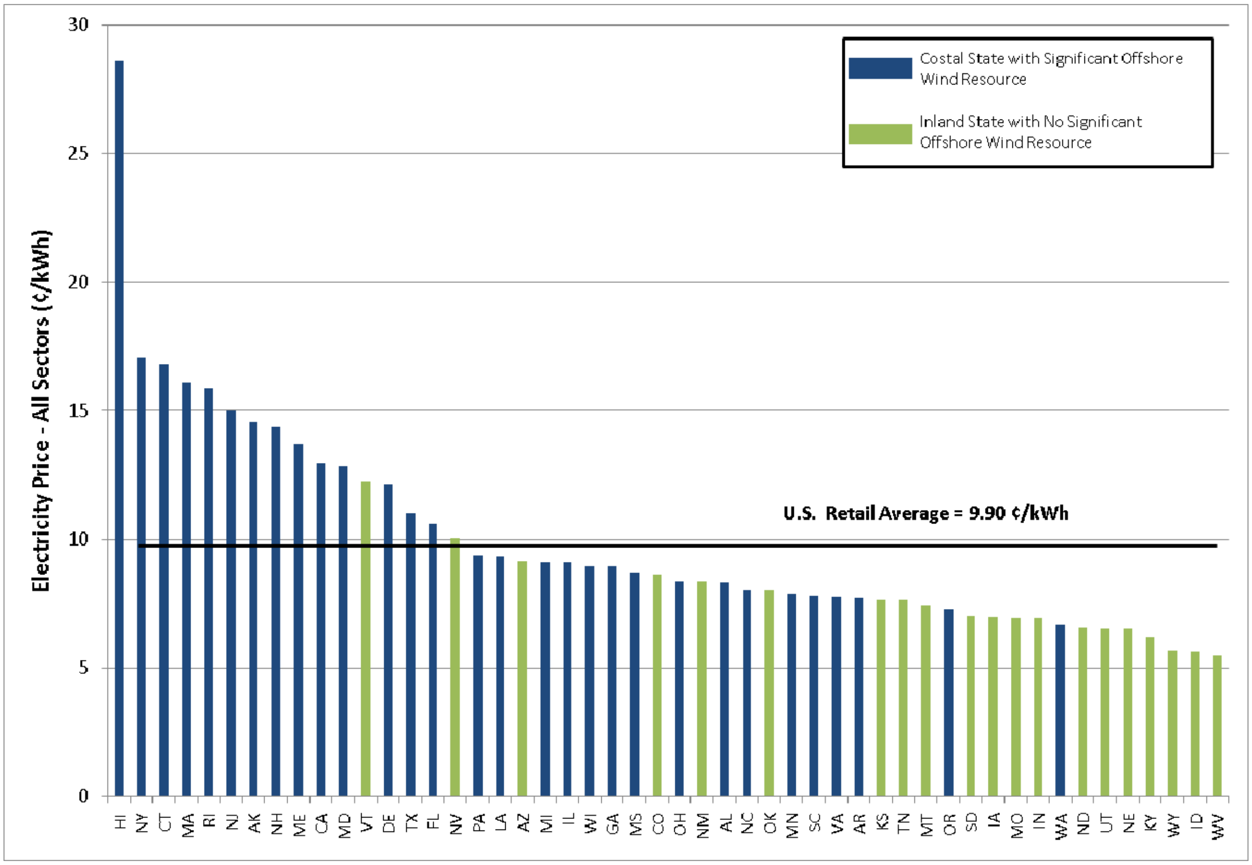
industrial facilities. Electric energy generation exceeds the energy consumption based on EIA retail sales. Generation is a better metric for stating total U.S. electricity demand.

[6] Ideally, the cost of offshore wind should be compared to wholesale electricity price data, not retail price data, though these metrics are expected to follow the same trends. This analysis does not address the fact that many external costs (e.g., public health, emissions, and nuclear waste disposal) are not included in the market price of energy



Source: EIA 2007.

Figure 2-3. Coastal versus inland state electric rates (2008)

Regionally high electricity costs in congested offshore areas, more energetic wind regimes, and closer proximity to grid interconnects might allow offshore wind to compete, even at higher initial costs, in many coastal areas. Although capital costs for offshore wind energy will remain higher than those of land-based wind energy systems, unique regional market conditions and enhanced offshore turbine performance will, at least partially, offset the difference.

Increasing the percentage of renewable energy generation in our nation's fuel mix has the potential to significantly reduce harmful emissions. Although offshore wind projects have high capital costs, they have no fuel costs and low operating costs. These characteristics allow the turbines to produce energy at a much lower marginal cost than fossil-fuel power plants. As a result, offshore wind turbines displace power that otherwise would have been generated by the fossil-fuel plants and avoid any emissions that would have resulted from the combustion of the fuel. The specific type of displaced generation will vary by region and is dependent on the mix of generation in the area (Jacobson and High 2008).

DOE's Wind and Water Power Program has led a number of initiatives to drive down the cost of wind energy through sustained technology innovations (NWTC 2006a, 2006b). These targeted cost reduction programs are partially responsible for the dramatic reduction in the cost of land-based wind energy and subsequent acceleration in deployment. During the past two decades, land-based wind energy has seen a tenfold reduction in cost and is now competitive with fossil-fuel and nuclear power generation. Over the same time period, deployment has increased from 1,800 MW in 1990 to 35,603 MW at the end of 2009 (AWEA 2010).

Although cost-competitiveness remains an important driver for wind energy deployment, the industry faces new challenges that must be overcome if current wind energy growth rates are to be sustained and projections of 20% wind energy by 2030 are to be met (see DOE 2008). The availability of electric transmission, the firm delivery of generated wind capacity, the long-term cost and reliability of the turbine equipment, and the availability of critical supply chain growth all challenge the nation's ability to meet these projections.

Fifty-four gigawatts of offshore wind will be required to achieve the 20% scenario. But other recent studies present detailed and compelling analyses indicating that 20% or 30% wind electricity cannot be realized in the United States without developing both land-based and offshore wind resources (see, for example, EnerNex 2010). Offshore resources must be developed in high wind-energy penetration scenarios mainly because of transmission constraints and load balancing concerns.

Offshore wind projects offer a number of cost reduction opportunities and advantages that are unique when compared to land-based projects. These opportunities include fewer restraints on turbine size, reduced transmission requirements, and the ability to site projects farther from human use areas.

The generation cost of offshore wind could be lowered by taking advantage of larger turbines than those typically employed for land-based wind energy. Most wind turbine manufacturers are preparing 5-MW offshore machines for large-scale commercial deployment and several manufacturers have designs in the range of 8 to 10 MW on the drawing board. The shipping and lifting capacities of marine equipment and vessels still far exceed the installation requirements for the current generation of multimegawatt offshore wind turbines. In contrast, the size of land-based turbines is restricted by the capacity limits of the existing transportation and erection equipment. The capacity limits of the existing equipment is causing the growth of land-based wind turbines to level off. This is a significant advantage for offshore wind because larger machines could significantly lower the installation and balance-of-station (BOS) costs, per kilowatt, for offshore wind projects. The challenges of building larger machines, however, have not been fully explored (see Section 5).

The 20% scenario estimates that 305 GW of installed wind power (land-based and offshore combined) would avoid 825 million metric tons of CO_2 in 2030 for a cumulative total of 7,600 million tons of CO_2 from 2010 to 2030. For comparison, the U.S. electric sector currently emits about 2,500 million metric tons of CO_2 per year (EIA 2010b).

Developing a domestic wind industry offers a viable way to revitalize our domestic manufacturing sector and create high-paying, stable jobs while increasing the nation's competitiveness in twenty-first century energy technologies. In the 20% scenario, 54 GW of offshore wind would create more than $200 billion in new economic activity with a high percentage of that revenue remaining in the local economies. This offshore wind power development would create many benefits beyond the $200 billion in revenues because the power generated would have no fuel price variability, no emissions, and no significant use of water resources. Finally, offshore wind development would reduce dependence on foreign energy resources (DOE 2008).

Most of the labor for offshore wind will draw from local and regional sources that cannot be easily outsourced overseas. Analysis done at NREL, extrapolated from European studies (EWEA 2009), estimates that offshore wind will create approximately 20.7 direct jobs per annual megawatt in the United States. In addition, approximately 0.8 jobs would be created for every cumulative megawatt of offshore wind in operation. If 54 GW were installed under the 20% scenario, more than 43,000 permanent operations and maintenance (O&M) jobs and more than 1.1 million job-years would be required to manufacture and install the turbines (GWEC et al. 2008; Musial 2007).

Land-based wind resources are generally located far from population centers and require significant transmission capacity to deliver electricity to load centers. Recent evidence shows that the development of high-quality land-based wind sites is being constrained by limited access to transmission and that the output of operational wind farms is increasingly being curtailed by system operators as a way of reducing congestion (Piwko et al. 2005; Fink et al. 2009). These examples suggest that transmission will be a primary near-term barrier to large-scale development of land-based wind projects in the United States. Although the nation needs to develop both land-based and offshore resources, offshore wind is less likely to be affected by congestion in the transmission system. Offshore wind resources are located close to coastal urban load centers. attribute that could be very valuable to utilities in helping to alleviate transmission constraints.

Both land-based and offshore wind projects face issues associated with their visible impact. Aesthetic concerns may continue to be an issue whenever turbines can be seen from populated areas but offshore wind projects have the advantage of being located farther from inhabited areas than most land-based projects. With the development of new technology for deeper waters, offshore wind turbines could eventually be sited far enough from shore to virtually eliminate visual impacts. Offshore wind turbines also have the potential to eliminate human objections to sounds from turbines because most projects would be sited beyond the threshold of sound propagation. Public concerns about other factors such as the effects on local tourism, rights to private use of the public commons, and possible avian collisions with turbines suggest that further studies on these impacts will be necessary (Kempton et al. 2005). Wide-ranging environmental and social issues have been investigated in existing European wind farms for more than 10 years, and no significant environmental impacts have been identified (see Section 8; see also Nielsen 2003; DONG Energy 2006). As a result, public concerns about offshore wind can be expected to wane as consumers gain comfort with this technology. Studies have shown that when the public is faced with an energy choice between offshore wind and other forms of electricity generation, offshore wind energy is considered preferable (Firestone, Kempton, and Krueger 2009).

2.5 Findings and Conclusions

Looking toward the future, offshore wind appears to be a leading contender to provide a substantial portion of a low-carbon energy supply. In 2007, the European Union (EU) and the European Wind Energy Association (EWEA) established aggressive targets to install 40 GW of offshore wind by 2020 and 150 GW by 2030. In the United States, there are no offshore wind projects yet but interest is growing with greater than 2,000 MW of offshore wind in the detailed planning, site development, and approval process (see Section 3). Based on the U.S. experience to date, regulatory and permitting issues will have a large effect on the pace at which offshore development can progress. The Minerals Management Service (MMS; renamed the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEM) in June 2010) has traditionally taken a cautious approach to permitting and certification for offshore wind projects. The MMS published the final rules for wind energy development on the Outer Continental Shelf in April 2009 (MMS 2010). Multiple agencies and industry members are now looking at the implications of this rule with respect to the total regulatory process time frame and further clarifications are expected as experience with the process is gained.

Although offshore wind development is sure to benefit from continued innovation associated with land-based growth, experience has shown that offshore wind cannot be simply extrapolated from land-based experience alone. Establishing a competitive, mature offshore wind industry in the United States will require dedicated investment in technology research specific to offshore conditions. European countries have already installed more than 2,000 MW of offshore capacity and the experiences gained from these initial deployments are supporting new technology developments that have the potential to lower costs (see sections 5 and 6). Offshore wind faces many near-term technical and regulatory challenges that must be addressed before the technology can compete broadly in U.S. energy markets. The remainder of this report focuses on these challenges.

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3.0 Industry Overview and U.S Activities

3.1 Historical Context

The first documented offshore wind energy generation concept was proposed by Hermann Honnef in 1932 (Honnef 1932). The first detailed study was done by Ismael Dambolena. Dambolena did his Ph.D. dissertation at the University of Massachusetts at Amherst in 1972, where he studied under Professor William E. Heronemus (Dambolena 1972). Heronemus is largely credited with having the vision for large-scale offshore wind turbines for bulk power generation just before the rebirth of the modern wind turbine (Heronemous 1972). In the 1970s Heronemus foresaw thousands of floating "windships" off the eastern coast of the United States, but it was not until the early 1990s, after the land-based wind industry had achieved some commercial success, that the mainstream research community began to investigate offshore wind energy again. While the first offshore pilot projects were being installed in the 1990s, some researchers continued to pursue floating-technology concepts in the laboratory (Henderson and Patel 2003; Heronemus and Stoddard 2003; Jamieson 2003; Halfpenny 2000;).

Not surprisingly, the first full-scale applications of offshore wind turbines used fixed-bottom substructures in the shallow waters of the North and Baltic seas. Initial development of the offshore resource was driven largely by the commercial aspirations of the European wind industry, whose proponents saw the oceans as an obvious solution to the shortage of land-based sites (GWEC and Greenpeace International 2005). To date, all large-scale projects have used shallow-water technology, but deepwater technology is moving closer to commercialization. More than 2,000 MW of offshore wind projects are proposed in the United States, indicating substantial private sector interest. As in Europe, U.S. developers are aiming to site projects in shallow water, building from the European experience.

3.2 Current Offshore Wind Activity

The first offshore wind farm was installed in Vindeby, Denmark in 1991. Since then, the industry has slowly grown in northwest Europe as developers and operators gained experience with offshore wind turbine implementation and operational requirements. As shown in Table 3-1, approximately 42 projects have been installed and most are still operating. The total installed capacity is estimated at 2,377 MW (4C Offshore Ltd 2010; Alpha Ventus 2010; C-Power NV 2010; Centrica Energy 2010; DONG Energy 2010a, 2010b; Japan for Sustainability 2010; NoordzeeWind 2010; Offshore Center Denmark 2010; Prinses Amalia Windpark 2010; Statoil ASA 2010; Vindpark Vänern 2010; Blue H. USA 2009; E-ON UK 2009; EWEA 2009a; Invest in Denmark 2009; RWE Npower Renewables 2009; OWE 2008). Most installations have been in water depths of less than 30 m.

Figure 3-1 shows the installed capacity of each significant project by the year in which the project was completed. Figure 3-2 shows the installed capacity of offshore wind by country. Figure 3-3 is a bubble plot of each project showing capacity, water depth, and distance from shore, along with the year the project was installed. Note that most projects are located close to shore and in shallow water below 30 m in depth. New technologies being developed to extend this design space are discussed in Section 5.

Table 3-1. Summary of Current Offshore Projects Installed as of the Second Quarter of 2010

Country	Project	Rated Capacity (MW)	Average Water Depth (m)	Average Distance Offshore (km)	Number of Turbines	Turbine Capacity (MW)	Turbine Manufacturer	Year Online
Belgium	Thornton Bank	30	20	29	6	5	Repower	2008
China	Donghai Bridge	102	10	10.5	34	3	Sinovel	2010
Denmark	Vindeby	5	4	3	11	0.45	Bonus	1991
	Tunø Knob	5	3	6	10	0.5	Vestas	1995
	Middelgrunden	40	8	3	20	2	Bonus	2000
	Horns Rev	160	10	16	80	2	Vestas	2002
	Samsø	23	20	3.5	10	2.3	Bonus	2002
	Frederickshavn	10.6	3	1	4	2.65	Vestas/Bonus/ Nordex	2003
	Nysted	165.6	8	8	72	2.3	Bonus	2003
	Ronland	17.2	Unknown	Unknown	8	2.3 /2	Bonus/Vestas	2003
	Horns Rev 2	209	13	30	91	2.3	Siemens	2009
	Sprogø	21	11	1	7	3	Vestas	2009
	Avedøre	7.2	2	0.1	2	3.6	Siemens	2009
Finland	Kemi Ajos I + II	30	0	1	10	3	WinWinD	2008
Germany	Ems-Emdem	4.5	3	0.1	1	4.5	Enercon	2004
	Breitling	2.3	2	0.5	1	2.3	Nordex	2006
	Hooksiel	5	5	0.5	1	5	Enercon	2008
	Alpha Ventus	60	30	45	12	5	Repower	2009
Ireland	Arklow Bank	25.2	15	10	7	3.6	GE	2004
Italy	Brindisi	0.08	108	20	1	0.08	Blue H	2008
Japan	Setana	1.32	10	0.2	2	0.66	Vestas	2004
Netherlands	Lely	2	7.5	0.8	4	0.5	Nedwind	1994
	Irene Vorrink	16.8	2	0.1	28	0.6	Nordtank	1996
	Egmond aan Zee	108	20	10	36	3	Vestas	2006
	Prinses Amalia	120	22	23	60	2	Vestas	2008
Norway	Hywind	2.3	100	10	1	2.3	Siemens	2009
Sweden	Bockstigen	2.8	7	3	6	0.3	Windworld	1998
	Utgrunden	10.5	7	7	7	1.425	Enron/GE Wind Energy	2000
	Yttre Stengrund	10	10	4	10	2	NEG-Micon	2001
	Lillgrund	110	6	10	48	2.3	Siemens	2007
	Vanern	30	7	4	10	3	WinWind	2010
United Kingdom	Blyth	4	6	1	2	2	Vestas	2000
	North Hoyle	60	9	8	30	2	Vestas	2003
	Scroby Sands	60	6	3	30	2	Vestas	2003
	Kentish Flats	90	5	9	30	3	Vestas	2005
	Barrow-in-Furness	90	15	7	30	3	Vestas	2006
	Beatrice	10	45	25	2	5	Repower	2007
	Burbo	90	10	5	25	3.6	Siemens	2007
	Lynn/Inner Dowsing	194.4	10	5	54	3.6	Siemens	2009
	Rhyl Flats	90	8	8	25	3.6	Siemens	2009
	Robin Rigg	180	5	9.5	30	3	Vestas	2009
	Gunfleet Sands	173	8	7	48	3.6	Siemens	2010

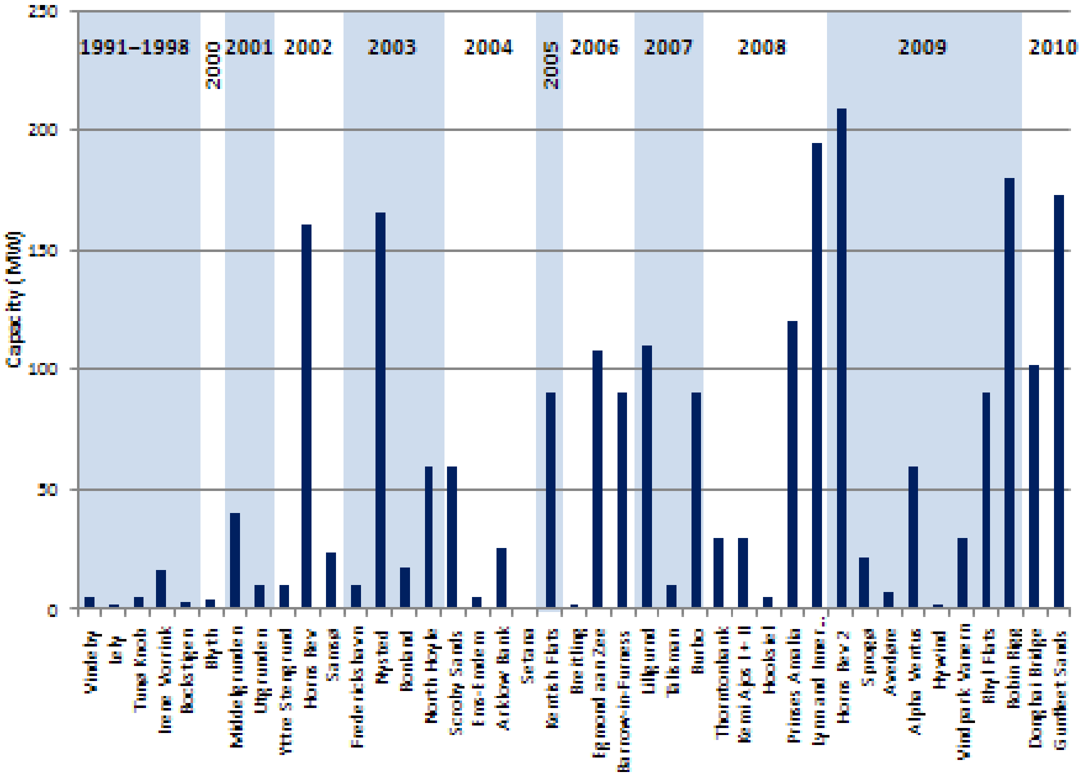


Figure 3-1. Nameplate generating capacity of offshore wind projects (1991–2010)

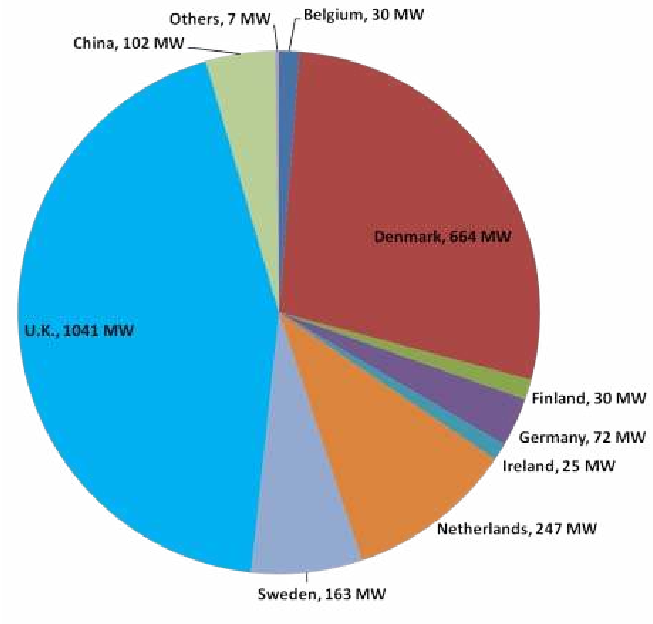
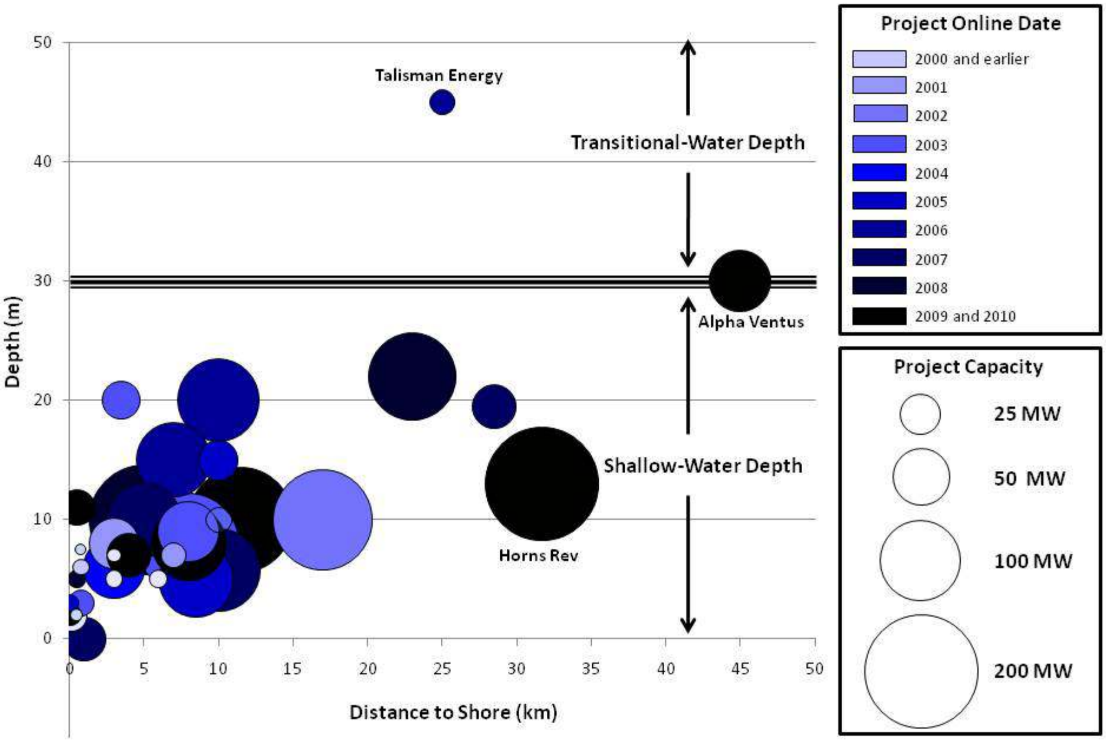


Figure 3-2. Installed offshore wind capacity by country (January 2010)



Note: Does not include experimental deepwater projects (e.g., Hywind)

Figure 3-3. Offshore projects showing capacity, water depth, and distance to shore

Figure 3-4. Middelgrunden Wind Plant
(HC Sorensen, Middelgrunden Wind Turbine Cooperative, NREL/Pix 17855)

Middelgrunden is a 40-MW demonstration project that was installed just 3 km east of the center of Copenhagen in 2001. At the time, it was the largest offshore wind farm in the world. It led the way for two larger 160-MW projects, Horns Rev I in 2002 and Nysted in 2003. Figure 3-4 shows photos of Horns Rev I and Middelgrunden.

These projects experienced some cost overruns and higher than expected failure rates resulting from wind and wave exposure that proved more severe than anticipated, along with an immature basis for planning and executing the projects. These issues displaced some of the initial enthusiasm for offshore wind energy development. As a result, 2005 was a slow year for offshore wind with only one offshore wind project installed. Manufacturers and developers placed considerable effort on understanding and correcting the problems associated with this first phase of projects. The growth of offshore wind remained slow through

2008, but eight new projects were installed in 2009 (see Figure 3-1), indicating a rejuvenation of offshore development. Note also that the first Asian project was installed recently in China.

3.3 Worldwide Offshore Wind Projections

The use of energy from offshore wind resources has shown inconsistent growth throughout the world, but there are indications that the growth trend may begin to smooth out and accelerate (Table 3-2). European nations connected 584 MW of offshore wind capacity to the electrical grid in 2009, an increase of 56% over the previous year. European nations have a long history of harnessing wind energy, and Europe has been the leader in offshore wind. Several other countries, though, have begun looking toward offshore wind to meet their energy needs, including Canada, China, and the United States.

3.3.1 Europe

Recently, the need to decrease carbon emissions; stabilize energy costs; and increase the use of indigenous, reliable energy sources has created an urgency in Europe that is resulting in a concerted effort to generate more energy from the wind. With almost 2,300 MW of installed capacity, Europe leads the world in offshore wind energy production (Table 3-2). After the first offshore wind project was installed off the coast of Denmark in 1991, more than 830 turbines have been installed and connected to the grid in nine European countries (EWEA 2010a). The market is continuing to expand with at least 1,000 MW expected to be installed during 2010. Of the hundreds of projects that are currently navigating some layer of the permitting process, at least 52 have been given consent and at least 16 are under construction. As seen in Table 3-2, Germany and the United Kingdom are expected to lead this growth. According to the European Wind Energy Association (EWEA), 50 GW of offshore wind energy projects are in some stage of permitting and construction and at least 100,000 MW of projects are in some stage of planning and development (EWEA 2009b). If 100 GW of capacity were installed, 8.7% to 11% of the European Union's (EU) electricity demand would be met by offshore wind, and 202 million metric tons of carbon dioxide (CO_2) per year would be eliminated (EWEA 2010a). For the long term, the EU has set goals for offshore wind installations to reach 40 GW by 2020 and 150 GW by 2030.

Table 3-2. Offshore Development in Permitting and Under Construction

Country	**Permitting, Approved, or Under Construction** (MW)	**In Operation** (MW)
Belgium	1,194	30
Canada	1,826	0
China	201	102
Denmark	653	664
Estonia	1,000	0
Finland	1,306	30
France	1,455	0
Germany	25,411	72
Greece	1,101	0
Ireland	1,530	25

Italy	2,526	0
Japan	0	1
Maldives	75	0
Netherlands	3,969	247
Norway	565	2
Romania	500	0
Spain	70	0
Sweden	3,346	163
United Kingdom	6,085	1,041
United States	~2,000	0
Total	54,813	2,377

Source: 4C Offshore Ltd. 2010.

3.3.2 Other Parts of the World

Other than European nations, only a few countries have offshore wind projects in operation and/or development (Table 3-2). In Asia, China and Japan have operating offshore projects. China has several projects in development and one project has been approved in the Maldives. Other Asian countries, including South Korea and Taiwan, are still in the planning stages. In North America, Canada and the United States have several projects in development. The following subsections summarize efforts in other countries, and Section 3.4 covers the status of offshore wind in the United States.

China: China deployed its first offshore wind turbine in 2007 and recently completed construction on its first offshore wind farm, the 102-MW Donghai Bridge project. By 2020, the Chinese government plans to increase the use of alternatives to fossil fuels to generate 15% of the nation's total energy consumption (GOV.cn 2010). Offshore wind energy has the potential to generate more than 750 GW of China's energy, which is almost three times the wind energy potential on land (see http://english.gov.cn/). In January 2010, China's National Energy Bureau and the State Oceanic Administration enacted an interim measure on the management of offshore wind farm development. Highlights of this measure include the following:

- Offshore wind must be developed through public tender.
- Chinese-funded enterprises must be the developers or have majority ownership.
- Developers must start construction within two years of winning the tender.

Japan: Japan has put a strong policy framework in place for renewable energy development, including a renewable portfolio standard (RPS), power purchase agreements (PPAs), and subsidies for field testing and business. But extreme weather, economic downturns, a volatile legal system, and grid issues have decreased investment in both land-based and offshore wind energy. Recently, however, there have been indications that interest in offshore wind has been renewed (GWEC 2010).

The Republic of Maldives: The Republic of Maldives, a group of islands in the Indian Ocean, relies heavily on fossil fuel imports to meet its energy needs. The government has set a goal of becoming carbon neutral within the next decade. The production of energy from offshore wind farms is expected to supply 40% of the nation's energy needs by 2013 (Miadhu 2010).

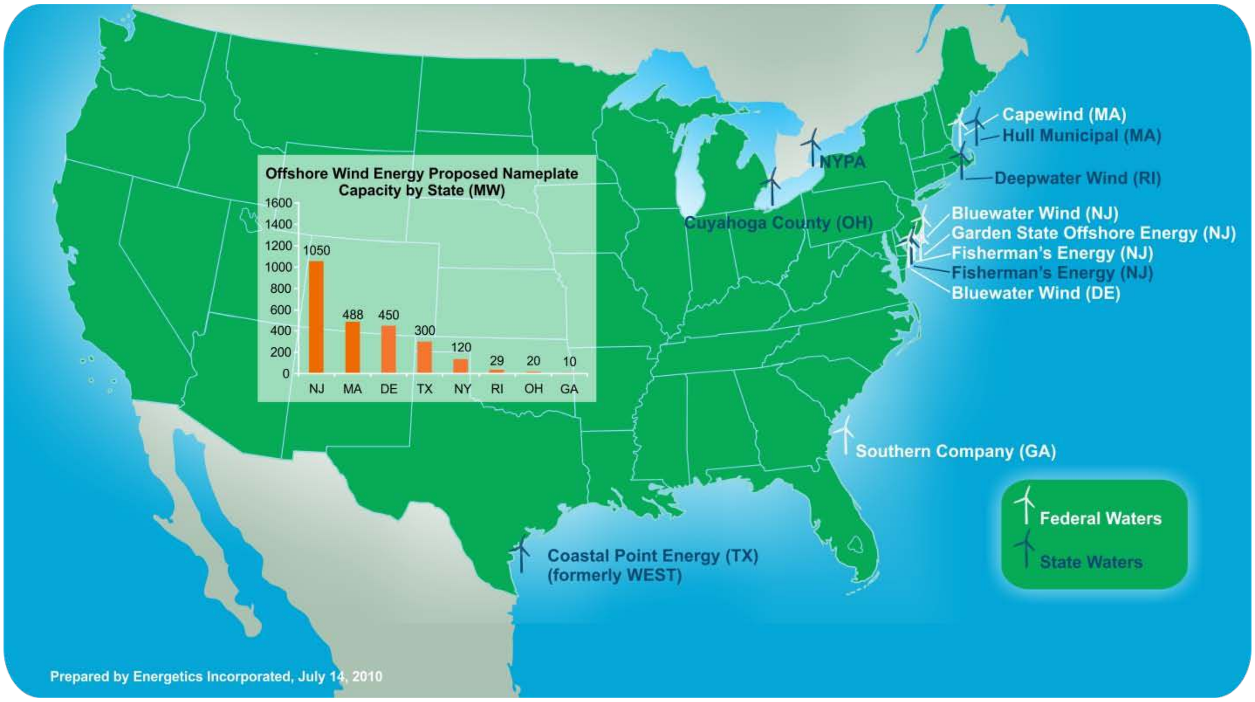
Canada: As a signatory to the Kyoto Protocol, Canada is committed to reducing its carbon emissions to below 1990 levels, and the country has been steadily increasing its energy production from land-based wind resources. Now, several offshore wind energy projects are in phases of development in the Great Lakes region as well as in coastal areas. For the last few years, the Canadian government has encouraged wind energy through the ecoENERGY for Renewable Power program. This program provides production incentives of 1 cent/kWh for the first 10 years of production (GWEC 2010). In addition, most provinces have set targets for wind energy development. Several provinces are also in the process of signing PPAs (GWEC 2010).

The Province of Ontario launched a feed-in tariff program in late 2009 as an incentive to developers and to meet its goal of phasing out coal plants by 2014 (Wood 2010). The program provides inflation adjusted payments of 19 cents/kWh for offshore wind over a 20 year period (Ontario Power Authority 2010). The provincial government of Ontario has also set distinct rules for the offshore wind industry. In Ontario, the construction permitting process is limited to 6 months, and the government offers projects priority connection rights to the grid (Wood 2010).

In turn, the provincial government envisions that the 20 GW of proposed projects (in different stages of development) in the Great Lakes area will create $253.5 billion in gross economic activity and more than 65,000 jobs, but the expected time frame could not be verified (Wood 2010).

3.4 U.S. Offshore Wind Project Overview

Figure 3-5 shows the13 projects that have advanced significantly in the U.S. permitting process at press time for this report. As the map indicates, most of the initial activity is concentrated in the Northeast and Mid-Atlantic regions. Despite this, offshore wind is being considered in most U.S. coastal regions including the Great Lakes, the Gulf of Mexico, and the West Coast. The depth of the water on the West Coast, however, will preclude near-term development in spite of a very good wind resource because deepwater wind turbine designs are not currently commercially available.



Prepared by Energetics Incorporated, July 14, 2010

Figure 3-5. Proposed U.S. offshore wind projects and capacity showing projects with significant progress

Proposed U.S. offshore wind projects can be divided into two regulatory groups; those in federal waters (i.e., outside the 3-nm state boundary) and those under state jurisdiction (see Section 7 for ocean jurisdictions). This distinction dominates the current and near-term market today because of the perceived differences in regulatory uncertainty and timing. State projects are typically near shore and have marginally lower wind resources, but some developers are willing to accept these disadvantages to avoid the perceived regulatory delays associated with the federal process through the BOEM. For large-scale offshore wind development, there are not enough viable sites in state waters to achieve the 54 GW of offshore wind described by the U.S. Department of Energy's (DOE) 20% by 2030 wind scenario (DOE 2008). In the short term, it remains to be seen if states will pave an accelerated path to regulatory approval. Long-term solutions lie with the U.S. Department of the Interior (DOI), which is responsible for reducing the uncertainties associated with potential risks to the marine environment, and making the Bureau of Ocean Energy Management, Regulation and Enforcement's (BOEM; formerly the Minerals Management Service [MMS]) permitting process more predictable (see Section 8).

Two projects in federal waters were granted special status under the Energy Policy Act of 2005 (EPAct), which was initiated in part to address the need for offshore wind energy regulations and establish a federal program. Currently, Cape Wind (off Cape Cod, Massachusetts) is the only project that still holds that status; however, the project was in the approval process for 9 years. On April 29, 2010, Secretary of the Interior Ken Salazar, granted Cape Wind a commercial lease in federal waters (McConville 2010). Because the project was proposed before federal rules emerged, Cape Wind had to comply with the original ad hoc rules of the U.S. Army Corps of Engineers (USACE) as well as the new BOEM rules (see Section 7). The exact permitting and agency consultation timelines for offshore projects that proceed along a normal course in the federal BOEM process are currently unknown because no project has gone through it. The apparent timeline is much longer than the siting of other energy facilities on the Outer Continental Shelf.

Table 3-3 describes most of the U.S. offshore wind development projects. Although many more proposals have been made, the projects listed in the table are more advanced, meeting one or more of the following criteria: they have been approved by their state, received an interim lease from BOEM (2010), or granted a BOEM lease.

Table 3-3. Selected Offshore Wind Energy Projects (Federal and State Waters)

Developer and Location	**Name-plate Capacity** (MW)	**Estimate Number of Turbines**	**Distance from Shore** (mi)	**Project Status** (as of June 2010)
Projects with BOEM Lease (Federal)				
Cape Wind Associates, Nantucket Sound, MA	468	130	5.2–13.8	In 2001, the permitting process began under the USACE. In 2005, MMS gained regulatory authority and issued a final environmental impact statement (EIS) in 2009. Also in 2009, the state and local permitting process was finalized and a long-term PPA was negotiated with National Grid. In April 2010 the project was approved and a commercial lease offered. For further information, see Section 7.
NRG Bluewater Wind, Atlantic City, NJ	350	TBD	15–18	In June 2009, MMS awarded NRG Bluewater Wind an interim limited lease.[a] It has also received a meteorological (met) tower rebate from the state, and has since begun baseline surveys (NRG Bluewater Wind 2010a).
Garden State Offshore Energy (GSOE), Avalon, NJ	350	96	16	GSOE is a subsidiary of the Public Service Enterprise Group and Deepwater Wind. GSOE won a competitive solicitation by the New Jersey Board of Public Utilities in the fall of 2008 and received a met tower rebate from the state. MMS awarded an interim limited lease in June 2009, and the developers began conducting baseline surveys shortly thereafter (GSOE 2008).

Developer and Location	Name-plate Capacity (MW)	Estimate Number of Turbines	Distance from Shore (mi)	Project Status (as of June 2010)
Fishermen's Energy, Atlantic City, NJ	330	66	8	MMS awarded an interim limited lease in June 2009. Fishermen’s Energy received a met tower rebate from the state and began baseline surveys in August 2009. Fishermen’s proposes to develop the projects in two phases (Fishermen’s Energy 2007).
NRG Bluewater Wind, Rehoboth Beach, DE	450	60–200	11.5	In 2008, NRG Bluewater Wind and Delmarva Power negotiated a PPA for 200 MW. In 2009, MMS awarded an interim limited lease and NRG Bluewater Wind began conducting geophysical studies for a met tower installation. The project is anticipated to be 450 MW; 293 MW has been initially contracted (NRG Bluewater Wind 2010b).
Southern Company, Savannah, GA	10	3–5	TBD	In 2007, a 2-year collaborative study with the Georgia Institute of Technology concluded that conditions were favorable but costs and the regulatory environment were preclusive. In 2008, Southern Company was offered an interim limited lease that has not yet been executed (Georgia Institute for Technology and Southern Company 2005).
Projects in State Waters				
Hull Municipal Light Plant (HMLP), Hull, MA	12–20	4	1.5	In 2007, Hull received funding from the Massachusetts Technology Collaborative to support permitting and siting analyses for a community project. In 2009, Hull received roughly $1.5 million in funding through Congressionally Directed Projects in 2009 (Manwell 2007).

Developer and Location	**Name-plate Capacity** (MW)	**Estimate Number of Turbines**	**Distance from Shore** (mi)	**Project Status** (as of June 2010)
Deepwater Wind, Block Island, RI	29	8	3	In 2008 Deepwater awarded a competitive solicitation for a project. In 2009, Deepwater began studies for demonstration project in state waters. National Grid has agreed to a 20-year PPA (Deepwater Wind 2010).
Fishermen's Energy, Atlantic City, NJ	20	6	3	Fishermen’s Atlantic City Offshore Wind Farm is the first phase of a two-phase project (see federal project described previously). The wind farm is located in the New Jersey Ecological Baseline Study area. State permits are under review (Fishermen’s Energy 2007).
University of North Carolina (UNC), Chapel Hill/Duke Energy, Pamlico Sound, NC	3-9	3	5–10	In June 2009, UNC completed a study for the North Carolina General Assembly on offshore wind. In October 2009, Duke Energy signed a contract with UNC Chapel Hill to install turbines in the Pamlico Sound (Duke Energy 2010). Three turbine demonstration projects were cancelled in August 2010. It is not clear how this will be resolved.
Coastal Point Energy (formerly W.E.S.T.), Galveston, TX	300	63	9	Coastal Point signed its first lease with Texas General Land Office (GLO) in 2005. Texas GLO awarded four competitively leased areas in 2007. A met tower was installed and began collecting data in 2007. The developer plans to begin construction on a project in 2010 (Baryonyx Corporation 2009).
Lake Erie Energy Development Corporation (LEEDCo), Cuyahoga County, Lake Erie, OH	20	3–7	3	The Great Lakes Energy Development Task Force spearheaded research on a demonstration project in Lake Erie. JW Great Lakes Wind released a final feasibility study for the Great Lakes Wind Energy Center in April 2009. The task force established LEEDCo, which recently completed an agreement to purchase five 4.0-MW turbines from General Electric (Cuyahoga County Department of Development 2010).

Developer and Location	Name-plate Capacity (MW)	Estimate Number of Turbines	Distance from Shore (mi)	Project Status (as of June 2010)
New York Power Authority (NYPA), Lake Erie or Lake Ontario	At least 120	40–166	TBD	In 2009, NYPA selected five firms to perform technical studies. In December 2009, NYPA issued a request for proposals (RFP) to select developers for projects of at least 120 MW (and up to 500 MW) in the state waters of Lake Erie or Ontario. They received five responses to the RFP (NYPA 2010).

Source: Energetics Incorporated. Offshore Wind Energy Database. Unpublished.

[a] An interim limited lease term is 5 years. It does not allow for turbine construction and does not guarantee that a commercial lease will be granted.

3.5 U.S. Policy Overview

For both federal and state offshore wind projects, a primary impetus for offshore wind development appears to stem from the desire to develop a zero-emissions generation technology that will increase energy security, attract economic development, and improve environmental quality. These factors are driving policies at both the state and federal level. Federal production tax incentives and government loan guarantees have helped stimulate interest for both land-based and offshore wind energy. Some states are beginning to develop climate change legislation that will price CO_2 emissions and, in some cases, require utilities to transition from fossil fuels to clean renewable energy options. Many states with near-term potential for offshore wind have enacted an RPS, mandating that utilities obtain a certain percentage their retail electricity sales from renewable energy or renewable energy credits (DSIRE 2010). Studies estimate that an additional 61 GW of renewable capacity will be needed to fulfill current state RPS requirements (see, for example, Wiser and Barbose 2008). States in New England and the Mid-Atlantic region currently meet the majority of their RPS goals with wind, biomass, and solar (Wiser and Barbose 2009). For many states in the Northeast, offshore wind may be the only cost- effective utility-scale resource available to meet RPS goals (NREL 2010). New Jersey is the first state to pass a renewable energy certificate specifically for offshore wind and has proposed potential goals of 1,000 MW of by 2012 and 3,000 MW by 2020 (NJPBU 2009). Maine is facilitating the development of the next generation of deepwater floating turbines and foundations, and has announced goals “to install at least 2,000 megawatts of wind capacity by 2015 and at least 3,000 megawatts by 2020, 300 of which could be located in coastal waters” (Maine Wind Energy Act 2003).

One of the major barriers to efficiently deploying large-scale offshore wind is the long-term planning process of traditional utility markets and the lack of incentives to make a transition to low-carbon fuels. A recent study by ISO New England, Inc. (2009) found that focusing investment on offshore wind could be the most cost-effective use of new and existing transmission. Additionally, as described in Section 2, high regional electric costs make offshore wind attractive (Dhanju and Firestone 2009;EIA 2009). In the Northeast, ten coastal states are involved in the Regional Greenhouse Gas Initiative (RGGI), a “cap-and-trade” system to regulate CO_2 emissions in the electricity sector. Auction revenues from such a system are often used to offer financial incentives to renewable energy projects (Clarke et al. 2009).

3.5.1 National and Regional Organizations

Several groups aimed at coordinating stakeholder efforts have formed to overcome the technical, economic, regulatory, environmental, and public perception barriers to offshore wind power development in the United States. These organizations help to connect state governments, industry representatives, academics, and clean energy advocates and allow these stakeholders to pool their resources and expertise. Selected groups are described in more detail in the list that follows:

U.S. Offshore Wind Collaborative: The USOWC was originally formed by three partners—the Massachusetts Technology Collaborative (MTC), GE Wind Energy, and DOE—to tackle offshore stakeholder concerns that arose in response to the issues surrounding the development of Cape Wind. USOWC is an interdisciplinary nonprofit organization directed at facilitating the development and growth of a U.S. offshore wind industry (USOWC 2010).

American Wind Energy Association Offshore Wind Working Group: AWEA formed a subcommittee called the Offshore Wind Working Group (OWWG), which primarily coordinates information exchange among offshore wind stakeholders.

Offshore Wind Development Coalition: OffshoreWind DC was founded in July 2010 in cooperation with AWEA and a group of seven U.S. offshore wind developers to promote offshore wind energy through advocacy and education (AWEA 2010).

Atlantic Offshore Wind Energy Consortium: The AOWEC was formed by the governors of 10 eastern costal states to facilitate cooperation between federal (DOI) and state governments on issues related to developing offshore wind on the Atlantic Outer Continental Shelf. Maine, New Hampshire, Massachusetts, Rhode Island, New York, New Jersey, Delaware, Maryland, Virginia, and North Carolina are currently AOWEC members (Vickery and Bullin 2010).

Great Lakes Wind Collaborative: GLWC is a regional organization working to facilitate the development of offshore wind projects in the Great Lakes. The group is staffed by the Great Lakes Commission and includes a broad coalition of stakeholders who are examining the technical, environmental, regulatory, educational, and financial issues related to the deployment of both land-based and offshore wind. The GLWC Offshore Wind Workgroup has produced siting principles for offshore wind in the Great Lakes (The Great Lakes Commission 2010).

3.5.2 State Initiatives

Thirty U.S. states border an ocean or Great Lake, and each has a unique demand for energy and a unique resource potential. As a result, each has responded differently to offshore wind at this early stage of development. Table 3-4 gives an overview of some of the state activities that are under way in several coastal states. The table is not, however, an exhaustive list for all states because the number of organizations continues to grow at a rapid rate. One of the ways to compare the states to each other is by looking at their energy use and comparing it to the available offshore resource. Column 2 of Table 3-4 gives figures for the total generation of electricity for each coastal state in 2008 (EIA 2008). Column 3 presents the ratio of the gross wind resource potential for offshore wind[7] in each state as a percentage of the total generation of electricity in that state. This ratio gives a rough indication of how much of the state's electric energy needs could be met by offshore wind and should only be used for qualitative evaluations. For example, in states with extensive high wind resources, such as California, Massachusetts, and Maine, the percentages of resource potential from offshore wind exceed the total generation for those states. As a result, we could expect a higher dependence on offshore wind in these states than in low wind states, such as Florida, Alabama, and Mississippi, which show virtually no potential. In future analyses, offshore wind sites with wind speeds below 8.0 m/s could be considered, which would greatly improve this picture for some southern states.

The table also presents some policy information by state. Of 29 U.S. states that have adopted an RPS, 22 border an ocean or Great Lake. Column 4 in Table 3-4 shows the RPS parameters for these states (DSIRE 2010).

Table 3-4. Electric Energy Use and Offshore Wind Energy State Activity

State	Total State Generation (MWh)	Resource Potential as a Percentage of Total Electric Generation	Renewable Portfolio Standards (percentage; year)[a]	State Offshore Wind Studies and Planning Initiatives
Alabama	145,869,895	NA[d]		
Alaska	6,774,834	NA[d]		
California	207,984,263	634	33; 2020	
Connecticut	30,409,473	2	27; 2020	
Delaware	7,523,839	430	20; 2020	Integrated Resource Plan results in RFP from Delmarva Power; Planning/deployment memorandum of understanding (MOU) with Virginia and Maryland; MMS EA on Delaware Interim Lease; MMS RFI for Competitive Leasing
Florida	219,636,818	NA[d]		
Georgia	136,173,395	6		Georgia Tech/Southern Company resource and feasibility study State Funded Marine Mapping Report
Hawaii	11,376,385	9,452	40; 2030	Interisland Cable Project
Illinois	199,475,178	32	25; 2025	
Indiana	129,510,294	4		
Louisiana	92,453,141	0		
Maine	17,094,919	2,776	40; 2017	Ocean Energy Task Force; Gulf of Maine Offshore Wind Energy Development Initiative; Governor's Task Force on Wind Power Development; Report of Governor's Task Force;

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[7] Resource potential from offshore wind is based on winds above 8.0 m/s and a net capacity factor of 0.37. The figures include all windy waters without taking territorial exclusions into account.

				Legislative Directive (L.D.) 1465 directs Department of Conservation in choosing testing sites
Maryland	47,360,953	227	20; 2022	Request for Expressions of Interest and Information; Planning/deployment MOU with Delaware and Virginia; Maryland's Offshore Wind Power Potential
Massachusetts	42,505,478	1,498	22.1; 2020 New renewable energy percentages: 15 in 2020 + 1 annually thereafter	Ocean Management Plan; Ocean Management Initiative
Michigan	114,989,806	1,045	10; 2015 + 1,100 MW[a]	Great Lakes Wind Council; Report of the Michigan Great Lakes Wind Council; Planning for Offshore Wind Developments in Michigan's Great Lakes; Grand Valley State University—West Michigan Wind Assessment
Minnesota	54,763,360	0	25; 2025 Xcel: 30; 2020	
Mississippi	48,205,711	0		
New Hampshire	22,876,992	43	25; 2025	
New Jersey	63,674,789	456	22.5; 2021	Blue Ribbon Panel; Ocean/Wind Power Ecological Baseline Studies; New Jersey Offshore Wind Energy Feasibility Study; MMS EA on New Jersey Interim Lease
New York	140,322,100	277	29; 2015	Long Island-New York City Offshore Wind project; NYPA Ongoing Project Studies
North Carolina	125,239,063	693	Investor-owned utilities: 12.5; 2021 Cooperatives and municipalities: 10; 2018	UNC Coastal Wind Study (commissioned by General Assembly); Governor's Scientific Advisory Panel on Offshore Energy
Ohio	153,412,251	62	12; 2024	The Great Lakes Energy Development Task Force; Cuyahoga County Feasibility Study
Oregon	58,718,438	1,160	Large utilities: 25; 2025[b] Small utilities: 5–10; 2025	
Pennsylvania	222,350,925	12	~18; 2021[c]	
Rhode Island	7,387,266	1,048	16; 2019	The Rhode Island Ocean Special Area Management Plan (SAMP); RI WINDS siting study;

				Offshore Wind Stakeholders Final Report
South Carolina	100,978,005	263		SC Offshore Wind Collaborative; Palmetto Wind Research Project; Ocean and Coastal Resource Management Plan; Wind Energy Production Farms Feasibility Study Committee; Regulatory Task Force for Coastal Clean Energy
Texas	404,787,781	115	5,880 MW; 2015 10,000 MW; 2025	Lease process with Texas GLO
Virginia	72,678,531	320	15; 2025[b]	Planning/deployment MOU with Delaware and Maryland; Virginia Coastal Energy Research Consortium Final Report of Offshore Wind Energy and Economic Potential for Offshore Wind in Virginia; Mapping and GIS Analysis in support of Clean Energy Development Offshore in Virginia
Washington	110,828,451	267	15; 2020[b]	
Wisconsin	63,479,555	413	10; 2015	PSC Feasibility Study

[a] RPS includes a goal for a percentage of renewable energy and the year it must be achieved unless otherwise noted.

[b] Extra credit for solar or customer-sited renewables

[c] Includes nonrenewable alternative sources

[d] not analyzed

Notes: EA = environmental assessment; RFI = request for information; GIS = geographic information system; PSC = Public Service Commission

Many of the states where interest in offshore development is building have begun various planning processes to integrate wind, and some governors have explicitly funded and approved offshore wind plans, studies, and projects (Table 3-4, column 5). Links given in the table indicate that several states have instituted panels or task forces to make recommendations on offshore wind, undertaken feasibility studies to estimate wind resource areas in the sea, and/or undertaken initiatives in ocean management planning.

Several states such as Delaware, Rhode Island, and New York are incorporating PPAs into their competitive solicitations. Other states (e.g., Maine and Rhode Island) are requiring utilities to buy more clean energy. This movement toward binding contracts and PPAs is important for creating sustained demand, utility commitments, and financial incentives. Selected state activities are described in more detail in the paragraphs that follow.

New Jersey: New Jersey became involved in offshore wind in part because several private developer proposals received media and community attention around 2004. In response, the governor imposed an 18-month moratorium on offshore wind. During that time, a blue-ribbon panel was formed to identify and weigh the economic and environmental costs and benefits of wind compared with other energy sources (State of New Jersey 2006). The panel's findings led to recommendations for further baseline studies and the development of a demonstration project of up to 350 MW. In July 2010, the New Jersey Department of Environmental Protection (NJDEP) released the final ecological baseline study, intended to fill major data gaps for birds, sea turtles, marine mammals, and other natural resources and their environments in the designated study area (Geo-Marine 2010; NJDEP 2010). In addition, the New Jersey Commerce, Economic Growth, and Tourism Commission (NJCEP; 2009) conducted public opinion studies of offshore wind. In 2008, New Jersey issued an RFP seeking interested developers to begin the first demonstration project. Several proposals were received and three developers were considered competitive. All three developers have now secured MMS interim limited leases to install met towers. The current goal of New Jersey's Energy Master Plan is to install 1,000 MW of offshore wind capacity by 2012 and 3,000 MW of capacity by 2020 to help meet the state's RPS goals. New Jersey currently has developer proposals for 1,050 MW of offshore wind. The state has also passed the Offshore Wind Economic Development Act, which creates an offshore wind renewable energy certificate program and will provide financial assistance and tax credits for the development of key renewable energy infrastructure (North American Wind Power 2010).

Rhode Island: Rhode Island wants to explore the integration of offshore wind into its electricity portfolio. The state has used ocean spatial planning to identify the best areas for offshore wind development. Technical wind resource data and water depths were coupled with information on financial feasibility, environmental risks, and public acceptance to identify the ten best areas for offshore wind. The Rhode Island Coastal Resources Management Council (2009) is developing an ocean special area management plan (SAMP) that will be an important component in siting offshore wind projects. In April 2008, Rhode Island's Office of Energy Resources issued an RFP to develop a demonstration project in state waters off the coast near Block Island (State of Rhode Island, Office of the Governor 2009). In January 2009, Deepwater Wind signed a joint development agreement with the state. In December 2009, the developer negotiated a 20-year PPA with National Grid. In March 2010, the Rhode Island Public Utilities Commission (RIPUC) rejected this agreement because of cost concerns. Demonstrating political support for offshore wind, the Rhode Island legislature subsequently passed H 8083A and S 2819A, which required Deepwater and National Grid to file a new PPA with the RIPUC (Isensee 2009; Kuffner 2009). The commission approved the revised PPA on August 12, 2010. Rhode Island has proposals for installing 428 MW of offshore wind energy, which represents approximately 15% of its electric energy needs.

Massachusetts: Cape Wind was the first offshore wind project proposed in the United States. Despite opinion polls showing that state residents overwhelmingly support the project, the project has been met with significant opposition. After 9 years of regulatory review, Cape Wind finally received federal permits in April 2010 and signed a PPA with National Grid in May 2010. Though the project is likely to face further legal challenges from opponents, the developers aim to start construction in 2011 and complete the project by the end of 2012.

Another significant Massachusetts initiative was initiated by DOE's Wind and Water Power Program (WWPP), which competitively selected the MTC to develop a Wind Blade Technology Testing Center in partnership with the National Renewable Energy Laboratory (NREL). MTC was awarded $25 million in funding from the American Recovery and Reinvestment Act of 2009 to accelerate development (EERE 2009).

Massachusetts has also developed an ocean management plan that establishes three categories of management area: prohibited, regional energy, and multiuse. The plan allows for commercial-scale wind projects only in specified areas (Massachusetts Office of Energy and Environmental Affairs 2009). In June 2009, the governor's office set a goal of developing 2,000 MW of wind by 2020 (Sullivan et al. 2009). Massachusetts has proposals for installing up to 688 MW of offshore wind.

Delaware: Delaware initiated legislation and policies to encourage offshore wind which resulted in a PPA between Delmarva Power and NRG Bluewater Wind. The state legislature passed several laws, including HR-6, which amended the Electric Utility Retail Customer Supply Act of 2006. This required utilities to consider energy efficiency, renewable energy, price stability, and environmental impact ahead of fossil-fuel sources (Firestone and Kempton 2006). The PPA guarantees financial returns and certainty for novel resource development and is seen as a path to move offshore wind energy forward (Dhanju and Firestone 2009). Throughout the process of allocating a PPA, NRG Bluewater Wind partnered with the University of Delaware to create a stakeholder dialogue process that engaged the community on the prospect of offshore wind power, which ultimately aided in the final award to NRG Bluewater Wind (Kempton 2009). In addition to supporting the NRG Bluewater Wind project, the energy plan calls for developing business and research related to wind energy, and supporting a center of excellence in offshore wind at the University of Delaware. Delaware has proposals for installing 450 MW of offshore wind. An important milestone was the issuance of a Request for Interest for an area off Delaware that begins the commercial wind leasing process (MMS 2010).

Maine: Maine is facilitating the development of deepwater floating turbines and substructures. In June 2009, the state legislature passed a legislative directive (LD 1465) recommended by the Ocean Energy Task Force, which was established by Governor Baldacci in 2008. The legislation called for the identification of ocean energy testing areas in coastal state waters for the development of a Maine Offshore Wind Energy Research Center in concert with the University of Maine. As directed by the legislation, the state Department of Conservation selected sites through the University of Maine's Offshore Wind Energy Geographic Information System and solicited stakeholder input (Maine Ocean Energy Task Force 2009). Under a comprehensive, multiphase initiative known as DeepCwind, the University of Maine has plans to develop one of the test sites in state waters. At the site, a one-third-scale deepwater floating offshore turbine prototype will be built for the purpose of developing the design tools needed for full-scale commercial development. The new state legislation calls for a speedy permitting process and for applicants to submit site plans, fish and wildlife monitoring plans, and navigation plans. The University of Maine has received federal funding of approximately $12 million from DOE, Congress, and the National Institute of Standards and Technology (NIST) for this project (Dagher 2010). On June 8, 2010, voters in Maine approved an additional $11 million for the DeepCwind project.

The Great Lakes: To date, no offshore wind turbines have been sited in freshwater, particularly a potable water source such as the Great Lakes. Developing the offshore resource in the Great Lakes will pose engineering challenges like ice floes that will impose substantial forces on turbine bases, floats, and mooring lines (Public Service Commission of Wisconsin 2009a). Additionally, large vessel access to the Great Lakes is more restricted than at ocean sites, which creates supply and logistical challenges. Specifically, the lock system that allows access to the Great Lakes limits the breadth of vessels to 24.4 m (Steward 2010). Many turbine installation vessels exceed this limitation, complicating the logistics of offshore wind project development (A2SEA 2010).

Despite the challenges, state leaders and renewable energy advocates perceive tremendous benefits from siting wind on the lakes—including greater energy potential than land-based options, proximity to load centers, balancing heavy dependence on fossil fuels for current supply, and the potential for creating jobs and manufacturing supply chains to support a new industry. A number of stakeholder organizations are exploring offshore wind in the region and tackling the permitting and siting issues. Individual states and municipalities, such as Michigan and Cuyahoga County, Ohio, have also formed stakeholder groups addressing area-specific offshore wind energy development. The Michigan Great Lakes Wind Council, created by Governor Granholm in early 2009, produced a report about developing offshore wind in Michigan waters. The report estimates the local wind resource potential and the regulatory changes needed to facilitate permitting, leasing, construction, and monitoring of offshore wind projects. The governor has extended the council's charter through December 31, 2010 (Michigan Great Lakes Wind Council 2010). In Ohio, the Great Lakes Wind Energy Task Force was formed in Cuyahoga County to advise the county on the development of wind projects in Lake Erie, the shallowest of the Great Lakes (Cuyahoga County Department of Development 2010). In 2007, the Cuyahoga Task Force recommended the creation of a Great Lakes Wind Research Center, which would include a demonstration project of several turbines and produce 5 to 20 MW of power. In 2008, the Cuyahoga County Board of County Commissioners approved a contract for more than $1 million with JW Great Lakes Wind, LLC (JWGL) to examine the legal, technical, environmental, economic, and financial aspects of developing a Great Lakes Wind Energy Center. JWGL issued its report in 2009 (JWGL 2009). In addition, the PSC of Wisconsin commissioned a feasibility study that identifies options for meeting major challenges to offshore wind (PSC of Wisconsin 2009b). At this stage, many uncertainties exist along the path forward for the eight states along the Great Lakes, and many of the needs and requirements of the stakeholders in federal waters will be the same along these coasts.

One significant development for Canadian prospects is the new Ontario feed-in tariff or FIT program. This is North America's first comprehensive guaranteed pricing structure for renewable electricity production. It offers stable prices under long-term contracts for energy generated from renewable sources, including offshore wind. It provides a guaranteed price of CAD$190/MWh over 20 years (subject to consumer price index inflation; see Ontario Power Authority 2010). These types of financial incentives are intended to spur development and establish a predictable financial pathway for offshore wind deployments. Development on the Canadian side could have a synergistic impact on progress attained by U.S. developers in the Great Lakes region.

Texas: Texas has the most land-based wind installed of any state, with almost 10,000 MW in operation (Wiser and Bollinger 2009). Texas is the only state that has a regulatory framework for leasing renewable energy resources in its state waters, which extend out to 9 nm from shore. In 2001, the Texas GLO began evaluating state lands, including offshore areas, for the development of wind using detailed GIS layered data (Texas GLO 2007). The Texas GLO has initiated leases for the rights to develop offshore wind (noncompetitive; see Dhanju and Firestone 2009) and conducted a competitive leasing program as well. Leases were awarded to Coastal Point Energy (formerly Wind Energy Systems Technology, W.E.S.T.) on four tracts of land (Snyder and Kaiser 2009; Texas GLO 2009). In July 2009, the Texas GLO held another lease sale, and two offshore tracts were awarded to Baryonyx Corporation for development (Baryonyx 2009). The Texas GLO has predicted that Texas will have the first operational offshore turbine in the United States (Beniwal 2010). Texas has proposals for installing more than 300 MW of near-term offshore wind energy projects and both Costal Point Energy and Baryonyx have indicated that their projects will be larger than 1 GW when all phases are fully operational.

3.6 Description of Offshore Wind Supply Chain

The United States could benefit from new manufacturing and employment opportunities that an expanding offshore wind industry could potentially drive and sustain along our coastlines and lakeshores. Although densely populated areas near high load centers limit the land use options for alternative energy supplies, offshore wind can promote jobs and economic activity from domestic supply chains, which is a prime motivation for state leaders to advocate for offshore deployments in and adjacent to their waters.

3.6.1 Turbine Suppliers

Only two major turbine manufacturers, Siemens and Vestas, contributed substantially to new offshore wind capacity in 2008 (EWEA 2010b), but several new offshore turbines are now nearing commercial viability. Both Repower Systems AG (majority ownership by Suzlon) and Multibrid (majority ownership by Areva) installed commercial 5-MW turbines with the Alpha Ventus project in Germany.[8] Sinovel also entered the market in 2009 with the SL3000, the first offshore wind turbine made in China. Most recently, General Electric reentered the offshore wind market with the announcement of its 4.0-MW direct drive turbine, which is still under development in Europe (GE Power & Water, Renewable Energy 2010). Table 3-5 lists the current manufacturers of offshore wind turbines.

Table 3-5. Commercial Offshore Wind Turbines

Turbine Manufacturer	Turbine Model and Rated Power (in MW)	Date Available	Offshore Operating Status
Siemens	SWT2.0—2.0	2000	Commercially inactive
Vestas	V80—2.0	2000	Commercially inactive
General Electric	GE 3.6 —3.6-	2003	Commercially inactive
Siemens	SWT2.3—2.3	2003	Commercial
Vestas	V90—3.0	2004	Commercial
Siemens	SWT3.6—3.6	2005	Commercial
Repower	5M—5.0	2005	45-m Water Depth Demonstration Commercial at Alpha Ventus, Thornton Bank
Multibrid	M5000— 5.0	2005	Onshore 2005 Commercial at Alpha Ventus 2009
Sinovel	SL3000—3.0	2009	First Chinese Offshore Project—102 MW installed
BARD	BARD—5.0	2010	Installations at BARD Offshore 1 project began in March 2010
General Electric	GE 4.0/110—4.0	2012	Commercial sales announced, no prototype experience

Most of the offshore wind turbines in operation are marinized versions of proven land-based turbine designs with upgraded electrical systems and corrosion systems, which are placed on free-standing concrete gravity bases or steel monopile foundations. Offshore turbine designs are likely to increasingly decouple from land-based technology as original equipment manufacturers

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[8] Note that Repower had previously demonstrated its 5-MW wind turbine in the Beatrice Fields in the Talisman Energy DOWNVInD project, which was installed in 45 m of water in 2006.

(OEMs) explore the possibilities of larger turbines and optimize the technology for offshore application (see Section 5).

3.6.2 Key Components

Offshore wind turbines are generally larger than land-based machines. As a result, a large portion of the project costs results from transporting very large parts from component manufacturers to the OEM assembly plant and then to the installation site. This is especially true for some key components, such as blades and tower sections, which tend to limit land-based turbine size.

In addition, offshore wind turbine components can be expensive to fabricate in existing facilities that are designed to manufacture land-based machines. Building new, specialized manufacturing facilities presents a significant opportunity to reduce the costs of manufacturing blades, towers, and other components.

These factors are likely to drive OEMs to build new manufacturing facilities. In Europe, OEMs have already begun to cluster manufacturing plants in cities that are well situated to support the logistics and fabrication requirements for offshore deployment (Williams 2010). In addition to improving the turbine supply chain and positioning manufacturers to achieve cost improvements, construction of these new, specialized manufacturing facilities is bringing valuable manufacturing jobs to European coastal communities. This experience is likely to be repeated in the United States as the offshore wind industry grows because high transportation costs favor local production. To maximize the benefits, manufacturers will probably construct facilities in locations with access to ports suitable for offshore logistics and a high concentration of underutilized skilled labor. These locations will likely be centrally located in the proposed development regions.

3.6.3 Balance of Station

More than half of the installed capital cost of an offshore wind project goes to the balance of station (BOS). Included under the BOS umbrella are the turbine substructure, the electrical distribution, substation, and grid connection; logistics and installation; and geotechnical, regulatory, and permitting activities (see Section 6). These parts and services are generally sourced from the local supply chain that comprises traditional construction and fabrication labor. Because BOS represents such a large part of project costs, considerable effort will be directed at attempting to reduce these costs through the homogeny of foundation design and mass production.

3.6.4 Vessels, Harbors, and Local Economic Activity

The lack of suitable vessels for moving, constructing, installing, and maintaining offshore wind turbines may present a short-term barrier to development (AWEA 2009). Currently oil and gas vessels are the most applicable for use in the offshore wind industry because they have some of the critical attributes needed for the construction and installation phases. Most of these vessels are located in the Gulf of Mexico, would require at least some modifications or upgrades to perform as needed, and may not be available to the wind industry because the demand for offshore oil exploration and development is high. Potential near-term construction of new, specialized vessels dedicated to offshore wind will likely be restricted by the cost of building such a vessel (capital outlay estimated at more than $100 million). Such a high initial investment makes it unclear who will build these first ships considering the current levels of uncertainty about the future offshore wind build-out. Europeans built their first dedicated offshore heavy-lift wind construction ships after their offshore wind project installations ramped up in the early part of the last decade.

It is highly unlikely that these ships would be available to construct projects in the United States given the high demand in Europe (~50 GW in the permitting pipeline). Even if these vessels were available, they could not operate in the United States because of the Jones Act. This act, also known as the Merchant Marine Act of 1920, requires that all goods transported between U.S. ports be carried in U.S.-flagged ships that were built domestically, owned by U.S. citizens, and crewed by personnel authorized to work in the United States. The purpose of the law is to support the U.S. merchant marine industry and to sustain national security preparedness. The effect for offshore wind development is that only vessels qualified under the Jones Act will be able to transport, construct, install, and maintain offshore wind turbines (Online Lawyer Source 2010).

Although the Jones Act provisions might represent a short-term barrier to offshore wind development, the act also creates a substantial opportunity for domestic shipbuilders. The construction of the initial dedicated offshore wind vessel might require either a large-scale wind project with sufficient capital investment to offset the upfront costs for a specialized vessel or evidence of a large, probable U.S. development pipeline.

Effective development of offshore wind projects requires the use of ports that meet specific requirements. Port facilities must have quaysides 200 to 300 m long that can accommodate vessels up to 140 m in length with a 45-m beam and a draft of 6 m. Quayside infrastructure must be capable of offloading rotors, nacelles, towers, and foundations. Port facilities must also have significant lay-down acreage; experience suggests that each turbine requires between three-quarters and one acre of land per turbine for lay-down and preassembly (BVG Associates 2009; AWS Truewind 2009).

3.7 Findings and Conclusions

The development of offshore wind resources is seen by many nations—including the United Kingdom and Germany—as an integral component of decreasing their carbon emissions while meeting their energy needs. Globally, 2,377 MW of offshore wind is in operation with another gigawatt to be added by the end of 2010. In Europe alone, more than 50 GW of capacity is in some phase of development. Several Asian countries including China, Japan, and the Maldives are also developing their offshore resources. In North America, several provinces in Canada are actively pursuing offshore wind development.

In the United States, more than 2,000 MW of offshore wind projects are in the permitting process but none have yet been installed. Uncertainty and projections of lengthy timelines have motivated states to encourage offshore wind development in their near-shore waters. By doing this, state governments hope to lock in early manufacturing investments, which would strategically position them to capture the economic benefits of the future offshore wind build-out. In many instances, state-sponsored projects appear to be moving ahead of projects under federal agency jurisdiction. Projects in state waters face a unique set of challenges including a patchwork of rules and permits, along with gaps in leasing, zoning, and fee structures for using the seabed. Siting projects in state waters could accelerate the deployment of offshore wind energy, but this must be done carefully to avoid problems related to regulatory uncertainties, aesthetic issues (arising from the close proximity to the coast),[9] and other public concerns about uses of the coastal waters (see Section 7).

A positive trend is the coalescence of regional entities directing efforts to assuage public and regulatory concerns and minimize siting conflicts arising from offshore wind development. Several groups, such as the USOWC, AWEA's OWWG, the AOWEC, OffshoreWindDC, the Clean Energy States Alliance (CESA), and the GLWC are building stakeholder relationships. Maryland, Virginia, and Delaware have also signed an MOU to collaborate on offshore wind issues. Many groups have identified a need to coordinate offshore issues among the states, but they will need federal leadership, technical guidance, and financial resources.

The global offshore wind supply chain has expanded substantially with the buildup of installed capacity in Europe and the huge amount of projects in the global development pipeline. A number of OEMs are in the process of releasing new models of offshore turbines for commercial operation, giving project developers more options. These new turbine models generally have greater capacity than the current generation of turbines and represent a shift away from adapting land-based turbine designs to handle the environmental stresses of offshore deployment. Even though the United States has not yet developed an offshore wind project, the logistical requirements of transporting offshore machines would encourage OEMs to build up U.S. manufacturing operations as soon as a long-term pipeline of likely project emerges. The nation's economy would benefit from the new manufacturing and employment opportunities that an expanding offshore wind industry could deliver to our coastlines and lakeshores.

Despite short-term uncertainty, the long-term prospects for offshore wind appear to be solid. Large offshore resources exist in close proximity to the varied coastal regions of the United States (see Section 4) and the technology to harvest these wind resources is commercially available (see Section 5). As a result, the United States could feasibly build 54 GW of offshore wind by 2030 under conservative assumptions about transmission, fossil-fuel supplies, and supply chain availability.

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[9] All coastal states with the exception of Texas and Florida have territorial waters that extend 3 nm from the coastline. Texas and Florida's territorial waters extend 9 nm off the coast.

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4.0 Offshore Wind Energy Resources in the United States

The National Renewable Energy Laboratory (NREL) first estimated the offshore wind resources of the United States in 2003. These data, which were reported in several technical papers (see, for example, Musial and Butterfield 2004, 2005), demonstrated that the U.S. offshore wind energy resources were very large, with an estimated potential gross resource nearly equal to the total generating capacity of the national grid. These data were conservative because they did not include key areas such as Hawaii, the southeastern coast, or the Gulf of Mexico. In addition, they contained generalized assumptions about wind energy exclusions areas that were not fully developed.

The data contained in this report have been updated and improved since the early studies. The resource potential reported in this section includes the wind resource in the lower 48 contiguous United States, except for Florida, Alabama, and Mississippi, which were not assessed in this version of the analysis. In addition, wherever possible, the offshore data were regenerated for a 90-m height reference to more accurately reflect the resource at hub heights closer to those where offshore turbines will operate. This new resource estimate does not assess exclusion areas—areas where wind turbines cannot be built—which allow for competing uses of the ocean, lakes, and seabed and would be a substantial fraction of the gross resource. Exclusion areas should be defined in cooperation with state or regional stakeholders, and the authors felt that an attempt to estimate them here on a cursory level could be misleading. As a result, the resource numbers reported here are the gross resource estimates of all the windy water, and are therefore higher than what is actually extractable. These numbers form the foundation for computing the potential deployment on a state-by-state basis. It should also be noted that establishing and maintaining the most accurate estimate of the wind resource is a continuous process requiring refinements and updates as better models are developed and the techniques for estimating and measuring wind characteristics are improved. This analysis is likely to be updated in future reports as better data become available.

4.1 Wind Resource Methodology

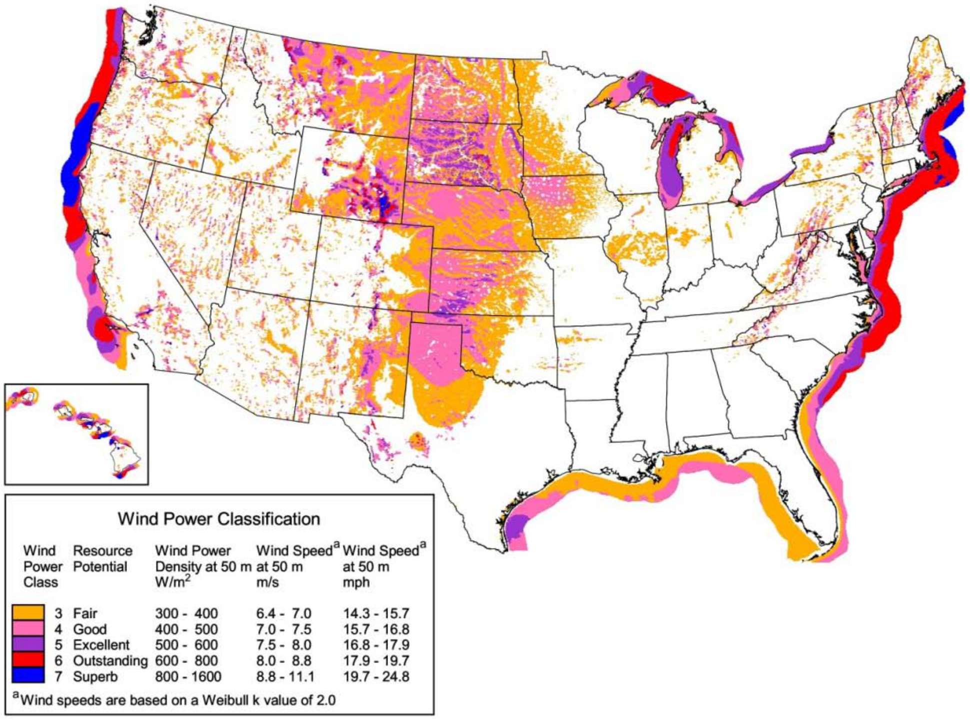
This section describes how the offshore U.S. wind resource maps were created and how the map data were converted to estimates of the wind potential. The offshore potential estimates are presented by region and individual state.

4.1.1 Mesoscale Modeling

The most comprehensive estimates of the wind energy resource potential in the United States come from wind resource maps generated from mesoscale wind models. Mesoscale weather prediction models are used to determine the wind resource potential over wide geographic areas on the scale of 100 km or more. This methodology has been validated extensively for land-based applications in the United States against actual anemometer data. To a more limited extent, the methodology has been validated for coastal and offshore areas using data from weather buoys, U.S. Coast Guard stations, and satellite imagery. Although these models have not been fully validated in all climatological conditions, they are more accurate than the earlier boundary-layer prediction methods used in conjunction with measured data. The models continue to be updated and refined as new data become available.

These models use inputs from synthesized historical weather databases to determine averages and frequency distributions for wind speed, direction, and wind power density at various elevations on annual, monthly, and daily time scales. The modeling results presented in this report are a composite of different regional model runs using the most current version of the model at the time the runs were made. Examining these offshore regions out to 50 nm shows an abundance of wind energy potential in the offshore regions over the continental shelf. Florida, Alabama, and Mississippi have not yet been included in the mesoscale modeling, and the lack of alternative tall tower wind measurements for this region precluded resource estimates at the 90-m height for this analysis. The offshore wind resource for these states will be estimated in later studies but are not expected to make a large contribution to the national offshore wind resource.

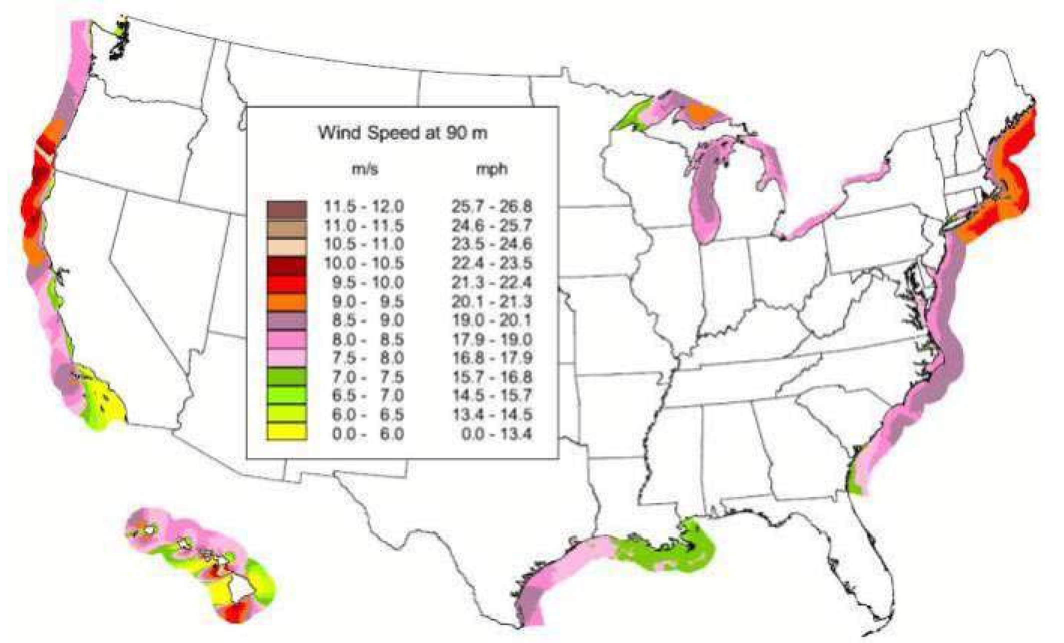
Figures 4-1 and 4-2 are two maps of the national offshore resource. Figure 4-1 shows the national distribution of the offshore and land-based wind resource by *power class* at 50 m above the surface (Elliott et al. 1987). For this map, NREL meteorologists empirically estimated the offshore resource for Florida, Alabama, and Mississippi. These are included to present a comparison of the land-based and offshore resource in this region. Figure 4-2 shows the national offshore *wind speed* at 90 m above the surface. Noticeable horizontal discontinuities of the wind speed at several state borders result from using different versions of the mesoscale models, both on land and offshore, over different time periods. Figure 4-3 is a 90-m wind speed map for Massachusetts that was recently developed using a mesoscale model. Here, it serves as an example of a state map (Schwartz et al. 2010). Schwartz and colleagues also developed and catalogued individual state maps for most of the other coastal states.



Source: Schwartz et al 2010

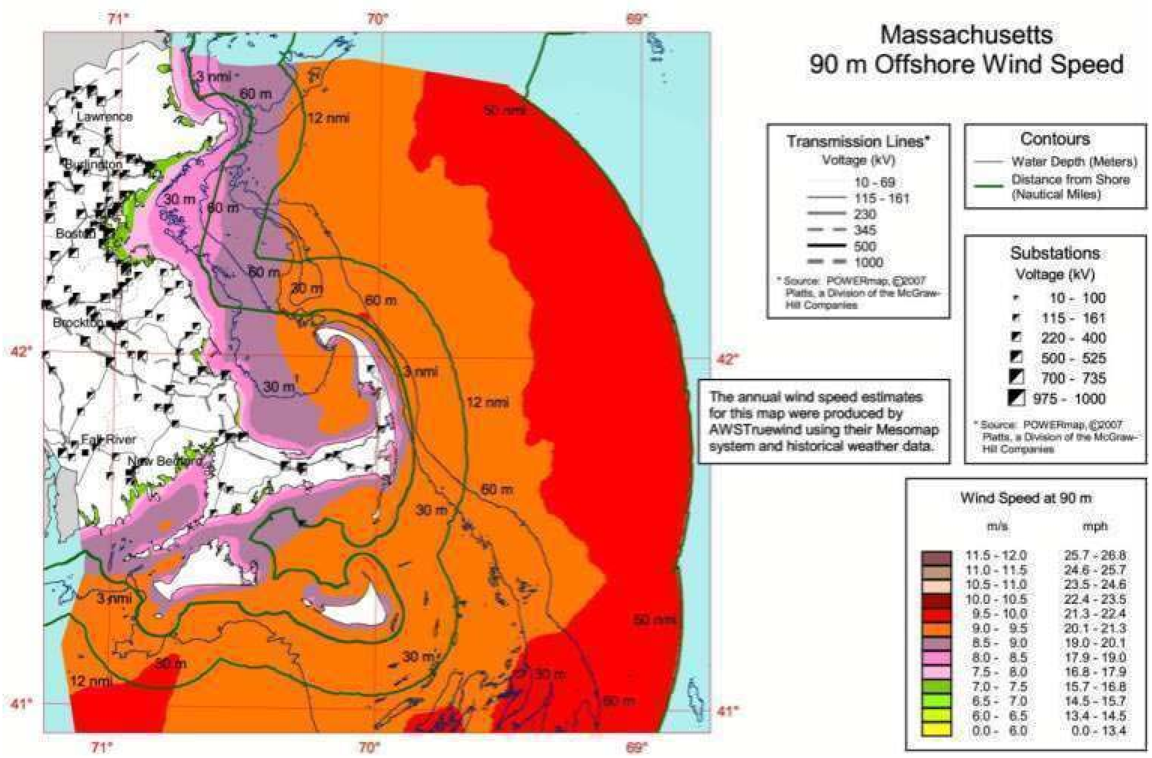
Figure 4-1. U.S. land-based and offshore wind resource estimates at 50-m height (wind classes 3–7)

.



Source: Schwartz et al. 2010.

Figure 4-2. U.S. offshore wind speed estimates at 90-m height



Source: Schwartz et al. 2010.

Figure 4-3. Massachusetts offshore wind speed estimates at 90-m elevation

4.1.2 Wind Turbine Array Density

The wind resource was quantified in 0.5 m/s wind speed intervals at 90 m, starting from an annual average value of 7.0 m/s and moving up. The mesoscale model maps describe the wind characteristics of geographical areas, but expressing these wind areas in terms of wind turbine nameplate potential is often desirable. A uniform factor of 5 MW/km^2 was applied to calculate the total resource potential in terms of installed nameplate wind energy generating capacity. This number corresponds to approximately eight rotor diameter (8D) spacing between turbines, using the 5-MW NREL reference wind turbine (Jonkman et al. 2009). By comparison, spacing for the Horns Rev I wind array is 7D (Horns Rev Offshore Wind Farm 2010), but the research community is still determining the optimal spacing with no consensus yet. Although the modeling is not fully validated for all offshore conditions and new estimates of the U.S. wind resource are still being calculated, the Schwartz et al. study (2010) gives the best available estimates to date of offshore wind resources in the United States. The gross resource does not account for the wind energy that would be extracted by turbines over such a large area and the physical limitations imposed by upper level air on wind replenishment near the sea surface. These array effects, which will diminish the available energy, should be considered to determine the practical spacing for entire wind farms in general. This is discussed briefly in Section 5.3.6.

4.1.3 Wind Speed Gradients

Typically, the models predict steep gradients in annual average wind speed in the coastal regions, extending orthogonally from the shoreline to a few miles offshore. These gradients can represent increases of two or more wind power classes in just a few miles, although their exact nature and exactly how far off the shore they extend adds uncertainty to the estimates. Generally, the wind speed increases with distance from shore. The gradient diminishes with distance from shore and probably levels off from Class 6 to Class 8 depending on the latitude. Ocean surface temperature variations can modify these gradients.

4.2 Offshore Wind Regions

NREL has completed a preliminary offshore study from the wind resource assessments of coastal states in five key geographic regions: the East Coast (including New England, the Mid-Atlantic states, and the South Atlantic Bight); the West Coast (California and the Pacific Northwest); the Great Lakes region; the Gulf of Mexico; and Hawaii. The new resource maps, compiled in Figures 4-1 and 4-2, indicate immense areas of Class 5, Class 6, and some Class 7 wind resources (wind speeds 7.5 m/s and higher) within 50 nm of shore. The physical characteristics of each of the five regions mapped are discussed in the subsections that follow.

4.2.1 East Coast: New England

The northeastern region comprises the Atlantic Ocean offshore areas of Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, and New York. Generally, the winds are Class 6 throughout this region. The largest uncertainties concern the location of the near-shore wind-speed gradients and the areas where the higher wind classes are achieved. Sea ice may be present in some areas but is not a primary design driver. Shallow-water sites are available in many locations, but the waters are generally deeper than those in the Mid- and South Atlantic, especially in Maine. Extreme conditions are driven by lower intensity hurricanes and more frequent and widespread winter “nor’easters,” which are usually within the design envelope prescribed by current wind turbine design standards.

4.2.2 East Coast: Mid-Atlantic States

The resource study of the Mid-Atlantic region comprises the offshore areas of New Jersey south to North Carolina.[10] In the northern part of this region, offshore winds are quite good with classes 5 and 6. To the south, the speeds diminish slightly. The largest uncertainty is still with the location of the near-shore wind-speed gradients and the areas where the higher wind classes are achieved. Thermal changes caused by the Gulf Stream farther out, however, may influence far-shore wind-speed prediction. Sea ice is not likely to be a design problem for wind turbines, but moderate hurricanes will likely dictate the extreme survival conditions.[11] This region has the advantage of large areas of shallow water that are very well suited for near-term technology.

4.2.3 East Coast: The South Atlantic Bight

The South Atlantic Bight comprises the Atlantic Ocean offshore areas of South Carolina, Georgia, and Florida. As the coastline curves westward nearing the Georgia coast, the continental shelf widens, forming a large area of shallow-water resource farther from shore. This area is known as the South Atlantic Bight. Although the offshore winds in this region are thought to be comparatively lower than those of the northern Atlantic coast, the milder climate and shallow water may provide overriding benefits for offshore wind in this region (Stewart, Bulpitt, and Hunt 2006). A full mesoscale modeling assessment of the Georgia coastal area was completed in 2006, and this assessment has improved the accuracy of offshore resource estimates in this region. Hurricanes are a concern in this area, but each site must be evaluated with respect to its unique site-specific conditions because the track and intensity of hurricanes are highly dependent on coastal geography and latitude (Sheets and Williams 2001).

4.2.4 West Coast: California

The winds along the California coast are classes 6 and 7, increasing from the south northward. Some good wind resource areas exist near shore, but a very narrow continental shelf results in a minimal shallow-water resource. Deepwater technology development will be very important if offshore wind is to be developed off the Pacific coast. Sea ice is not an issue, and extreme conditions are storm driven, with little risk from hurricane weather events. The best near-term opportunities may be in shallow coastal regions.

4.2.5 West Coast: The Pacific Northwest

The Pacific Northwest includes the coasts of Washington and Oregon, where solid Class 6 wind resources are found. These resources do diminish slightly off the coast of Washington. As with California, a very narrow continental shelf limits the shallow-water resource. Sea ice is not an issue, and extreme conditions are storm driven, with little risk from catastrophic weather events. High average sea-states may increase fatigue concerns on offshore wind turbine structures.

4.2.6 Great Lakes Region

This region includes the lake offshore areas of Minnesota, Wisconsin, Michigan, Indiana, Ohio, Pennsylvania, and New York. A recent comprehensive mapping project indicates that the Great

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[10] Note that the Mid-Atlantic region as defined by the Energy Information Administration (EIA) and the North American Electric Reliability Council (NAERC) includes only New Jersey to Pennsylvania.

[11] Extreme wind conditions for wind turbines can generally be prescribed by International Electrotechnical Commission (IEC) TC-88 standards in accordance with specified wind classes (NWTC 2002). The overall structural requirements for certification and operation in the ocean will be determined by the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEM; formerly the Minerals Management Service [MMS]).

Lakes have wind resources ranging from Class 4 through Class 6. Each lake has its own unique characteristics in terms of bathymetry, as well as environmental and socioeconomic issues. Local and state governments will largely determine what they will allow in terms of offshore development. The Canadian government has adopted its own approach and Canada, especially Ontario, may offer good synergies for offshore wind development in the United States. The lakes contain freshwater, and surface ice floes will be a major design driver for any offshore turbines (Barker and Timco 2006; Määttänen 2002). Wave heights are substantially lower than ocean areas, so hydrodynamic loading will also be lower.

4.2.7 Gulf of Mexico

This region includes the coastal areas stretching from Florida to Texas. Ninety-meter wind resource data for Alabama, Mississippi and Florida, however, are not available. A study performed at Stanford University suggests that the Gulf states have an excellent wind resource because of better-than-predicted wind shears and higher wind speeds at 80 m (Archer and Jacobson 2003). This has prompted some interest, but claims have not been substantiated by mesoscale models or accurate meteorological measurements. A new comprehensive mesoscale modeling assessment was completed for the wind resource in the Gulf of Mexico for the Texas and Louisiana coastal areas and was incorporated into the larger national assessment (Schwartz et al 2010). The strongest wind potential was found in the western Gulf, from Corpus Christi to the Mexican border. Texas is in a unique position to capitalize on offshore wind resources because its state boundary waters extend 9 nm from shore, whereas other coastal state waters end at 3 nm (*Renewable Energy World* 2005). Any offshore wind development in the Gulf of Mexico will have to be evaluated in the context of extreme hurricanes that frequent the region. Hurricanes will not preclude installing offshore wind turbines in the Gulf, but this additional risk factor must be considered in the structural design of any turbines that are put in place.

4.2.8 Hawaii

The resource study of Hawaii shows many excellent wind resource areas around each island and an abundance of offshore wind resource relative to the total load of the islands. The relatively high electricity rates in Hawaii make wind an attractive alternative. The resource is effectively stranded, however, because of its remoteness from the U.S. mainland.

4.2.9 Alaska

Alaska is not included in the current estimates of the offshore wind resource for the United States. Alaska does, however, have excellent offshore wind resources and high electricity rates. Although Alaska is isolated from the lower 48 states, its offshore wind resources greatly exceed its electricity needs. If these resources were included in the national total, the additional resource capacity would inflate the available resource potential of the United States. Under current energy-use and grid-integration scenarios, exporting electricity generated by offshore wind to the lower 48 states would not be practical, which is why Alaskan wind resources are not included in current estimates. With its vast coastline and extensive regions of Class 7 and 8 winds, Alaska would dwarf any other state's offshore resource. Because the Alaskan coastline is remote and its climate is severe, this study assumes that offshore Alaskan wind potential is stranded and will be unable to contribute to the national electric energy production beyond its own borders.

4.3 Offshore Wind Resource Potential

For this study, the offshore resource has been categorized within each state by average wind speed, bathymetry, and distance from shore. No exclusions (e.g., shipping lanes and environmentally sensitive areas) have been applied to the offshore wind resource estimates in order to arrive at an upper bound of the gross offshore resource potential. Further studies are needed to evaluate the impact of specific exclusions, such as unacceptable human encroachments, shipping lanes, and fisheries, among others. Similar studies produced by other organizations (e.g., in the United Kingdom, Germany, and Delaware) will serve as templates for developing similar exclusions for a U.S. study. Tables 4-1 and 4-2 summarize the estimated regional offshore resource based on bathymetry. Table 4-3 gives additional detail on the breakdown of resource potential by individual state and wind speed. Note that all resource figures are based on the nameplate capacity of the installed wind turbines, which have capacity factors between 0.35 and 0.5, depending on the average wind speed.

Table 4-1. Offshore Wind Resource Potential by Region and Water Depth for Areas with Annual Average Wind Speeds 8.0 m/s or Greater at 90-m Elevation

Region	**GW by Depth** (m)			**Total** (GW)
	0–30	30–60	>60	
New England	73.5	132.2	250.1	455.8
Mid-Atlantic	209.4	179.0	92.5	480.9
South Atlantic Bight	39.1	48.8	7.7	95.6
California	0.9	6.9	521.2	529.0
Pacific Northwest	3.3	18.8	304.1	326.2
Great Lakes	74.6	72.2	388.8	535.6
Gulf of Mexico	55.5	89.3	57.6	202.4
Hawaii	1.2	1.7	328.6	331.5
Total	457.4	548.9	1,950.7	2,957.0

Source: Schwartz et al. 2010.

Table 4-2. Offshore Wind Resource Potential by Region and Water Depth for Areas with Annual Average Wind Speeds 7.0 m/s or Greater at 90-m Elevation

Region	**GW by Depth** (m)			**Total**
	0–30	**30–60**	**>60**	
New England	100.2	136.2	250.4	486.8
Mid-Atlantic	298.1	179.1	92.5	569.7
South Atlantic Bight	134.1	48.8	7.7	190.7
California	4.4	10.5	573.0	587.8
Pacific Northwest	15.1	21.3	305.3	341.7
Great Lakes	176.7	106.4	459.4	742.5
Gulf of Mexico	340.3	120.1	133.3	593.7
Hawaii	2.3	5.5	629.6	637.4
Total	1,071.2	628.0	2,451.1	4,150.3

Source: Schwartz et al. 2010.

Table 4-3. State Offshore Wind Resource Potential (in Gigawatts) by Wind Speed, Water Depth, and Distance from Shore

State	Wind Speed at 90 m (m/s)	Distance from Land									Total
		0–3 nm[a]			3–12 nm			12–50 nm			
		Depth Category (m)			Depth Category (m)			Depth Category (m)			
		0–30	**30–60**	**>60**	**0-30**	**30–60**	**>60**	**0–30**	**30–60**	**>60**	
California	7.0–7.5	1.3	1.2	1.3	0.5	2.3	22.8	0.0	0.1	27.7	57.2
	7.5–8.0	1.2	1.3	0.9	0.4	3.0	19.3	0.0	0.1	98.1	124.3
	8.0–8.5	0.6	0.9	1.4	0.0	0.5	22.7	0.0	0.0	89.1	115.3
	8.5–9.0	0.2	0.7	0.9	0.0	0.1	22.8	0.0	0.0	89.5	114.3
	9.0–9.5	0.0	0.1	0.1	0.0	0.0	4.9	0.0	0.0	60.8	65.9
	9.5–10.0	0.0	0.0	0.1	0.0	0.0	3.3	0.0	0.0	72.8	76.2
	>10.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	33.2	34.6
Connecticut	7.0–7.5	2.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7
	7.5–8.0	3.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5
	8.0–8.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Delaware	7.0–7.5	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
	7.5–8.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6
	8.0–8.5	0.7	0.1	0.0	3.2	0.0	0.0	1.2	0.0	0.0	5.3
	8.5 - 9.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	3.4	0.0	4.7
Georgia	7.0–7.5	2.7	0.0	0.0	10.8	0.0	0.0	5.6	0.0	0.0	19.1
	7.5–8.0	0.4	0.0	0.0	2.6	0.0	0.0	26.0	9.6	0.0	38.7
	8.0–8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.0	2.6
Hawaii	7.0–7.5	0.6	0.5	13.2	0.0	0.2	11.1	0.2	0.6	68.1	94.4
	7.5–8.0	0.3	0.5	12.0	0.0	0.7	25.3	0.0	1.3	171.3	211.5
	8.0–8.5	0.5	0.6	11.8	0.0	0.1	23.8	0.0	0.0	128.5	165.2
	8.5–9.0	0.3	0.3	10.5	0.0	0.0	13.1	0.0	0.0	45.3	69.6
	9.0–9.5	0.1	0.2	5.0	0.0	0.0	9.3	0.0	0.0	24.3	38.9
	9.5–10.0	0.1	0.2	3.3	0.0	0.0	5.3	0.0	0.0	24.6	33.6
	>10.0	0.1	0.4	6.7	0.0	0.0	10.1	0.0	0.0	6.9	24.3
Illinois	7.0–7.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
	7.5–8.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
	8.0–8.5	1.2	0.1	0.0	4.1	2.6	0.7	0.0	2.1	8.4	19.2
	8.5–9.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.4
Indiana	7.0–7.5	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
	7.5–8.0	0.8	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	1.1
	8.0–8.5	0.5	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	1.4
Louisiana	7.0–7.5	39.8	0.1	0.0	39.1	3.2	7.3	55.8	27.4	68.4	240.2
	7.5– 8.0	0.8	0.0	0.0	8.1	0.0	0.0	40.9	11.1	14.3	75.2

Table 4-3 (continued). Offshore Wind Resource Potential (in Gigawatts) by Wind Speed, State, Water Depth, and Distance from Shore

State	Wind Speed at 90 m (m/s)	Distance from Land									Total
		0–3 nm			3–12 nm			12–50 nm			
		Depth Category (m)			Depth Category (m)			Depth Category (m)			
		0–30	**30–60**	**>60**	**0–30**	**30–60**	**>60**	**0–30**	**30–60**	**>60**	
Maine	7.0–7.5	3.9	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	4.5
	7.5–8.0	4.0	1.4	0.1	0.0	0.1	0.1	0.0	0.0	0.0	5.7
	8.0–8.5	3.9	2.2	0.4	0.3	1.9	1.2	0.0	0.0	0.0	9.9
	8.5–9.0	2.6	3.1	0.8	0.1	1.1	7.0	0.0	0.0	2.0	16.7
	9.0–9.5	0.7	2.0	1.5	0.1	2.3	17.5	0.0	0.3	17.7	42.1
	9.5–10.0	0.0	0.1	0.2	0.0	0.2	7.3	0.0	0.0	69.5	77.4
	>10.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.2
Maryland	7.0–7.5	10.9	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.0
	7.5–8.0	9.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.7
	8.0–8.5	0.8	0.0	0.0	4.6	0.0	0.0	2.2	0.1	0.0	7.7
	8.5–9.0	0.0	0.0	0.0	0.0	0.0	0.0	2.7	16.1	6.7	25.4
Massachusetts	7.0– 7.5	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
	7.5–8.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6
	8.0–8.5	4.6	1.6	0.1	0.4	0.8	0.6	0.0	0.0	0.0	8.2
	8.5–9.0	7.5	1.9	0.1	1.6	1.8	4.1	0.1	0.1	1.0	18.0
	9.0–9.5	5.7	1.6	0.1	13.5	7.1	5.0	8.4	25.3	35.0	101.8
	9.5–10.0	0.0	0.0	0.0	0.0	0.6	0.0	2.4	17.3	48.1	68.4
Michigan	7.0–7.5	17.1	1.7	1.2	0.7	0.2	1.3	0.0	0.0	0.1	22.3
	7.5–8.0	23.2	6.3	3.2	15.3	14.6	15.0	0.1	0.5	12.2	90.4
	8.0–8.5	12.9	6.3	3.8	13.9	29.4	47.1	0.2	4.4	37.5	155.4
	8.5–9.0	0.7	0.8	2.0	0.7	2.8	42.9	0.6	6.9	114.2	171.5
	9.0–9.5	0.0	0.0	0.0	0.0	0.0	0.3	0.6	1.2	41.4	43.6
Minnesota	7.0–7.5	0.0	0.2	1.4	0.0	0.1	8.6	0.0	0.0	5.2	15.5
	7.5–8.0	0.0	0.0	0.1	0.0	0.0	0.3	0.0	0.0	4.6	5.0
New Hampshire	7.0–7.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	7.5–8.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	8.0–8.5	0.2	0.1	0.0	0.0	0.4	0.1	0.0	0.0	0.0	0.9
	8.5–9.0	0.0	0.1	0.0	0.0	0.1	1.3	0.0	0.0	0.2	1.7
	9.0– 9.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.5
New Jersey	7.0–7.5	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6
	7.5–8.0	4.8	0.0	0.0	2.6	0.1	0.0	0.0	0.0	0.0	7.5
	8.0–8.5	3.9	0.0	0.0	13.8	0.6	0.0	4.5	1.9	0.1	24.8
	8.5–9.0	0.1	0.0	0.0	1.1	0.0	0.0	10.1	51.9	1.5	64.7

Table 4-3 (continued). Offshore Wind Resource Potential (in Gigawatts) by Wind Speed, State, Water Depth, and Distance from Shore

State	Wind Speed at 90 m (m/s)	Distance from Land									Total
		0–3 nm			3–12 nm			12–50 nm			
		Depth Category (m)			Depth Category (m)			Depth Category (m)			
		0–30	30–60	>60	0–30	30–60	>60	0–30	30–60	>60	
New York	7.0–7.5	5.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.5
	7.5–8.0	9.9	1.8	0.1	2.4	3.0	4.3	0.0	0.0	0.3	21.8
	8.0–8.5	6.6	3.0	1.0	1.9	2.7	15.6	0.2	0.1	10.5	41.6
	8.5–9.0	2.7	0.6	0.0	5.2	0.5	0.0	1.3	3.6	0.5	14.4
	9.0–9.5	0.0	0.0	0.0	2.0	7.0	0.0	0.0	24.6	3.6	37.3
	9.5–10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.1	17.5	26.6
North Carolina	7.0–7.5	9.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.2
	7.5–8.0	15.0	0.0	0.0	5.5	0.0	0.0	0.0	0.0	0.0	20.5
	8.0–8.5	19.6	0.0	0.0	23.3	0.0	0.0	20.2	3.7	1.5	68.3
	8.5–9.0	0.5	0.0	0.0	14.8	1.3	0.0	31.9	72.6	78.2	199.4
Ohio	7.0–7.5	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7
	7.5–8.0	5.5	0.0	0.0	9.8	0.0	0.0	0.0	0.0	0.0	15.3
	8.0–8.5	2.8	0.0	0.0	11.0	0.0	0.0	15.4	0.0	0.0	29.1
Oregon	7.0–7.5	1.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9
	7.5–8.0	2.6	1.6	0.2	0.2	1.2	1.7	0.0	0.0	0.0	7.5
	8.0–8.5	1.0	1.4	0.0	0.1	3.0	12.8	0.0	0.0	24.9	43.2
	8.5–9.0	0.3	0.5	0.0	0.0	0.5	9.8	0.0	0.2	58.2	69.6
	9.0–9.5	0.3	0.3	0.2	0.0	0.2	3.0	0.0	0.0	33.0	36.7
	9.5–10.0	0.2	0.4	0.1	0.0	0.2	3.2	0.0	0.0	26.3	30.3
	>10.0	0.0	0.1	0.2	0.0	0.1	6.8	0.0	0.0	22.7	30.0
Pennsylvania	7.0–7.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
	7.5–8.0	0.6	0.0	0.0	0.3	0.2	0.0	0.0	0.0	0.0	1.1
	8.0–8.5	1.4	0.0	0.0	3.6	1.8	0.0	1.1	0.4	0.0	8.4
Rhode Island	7.0–7.5	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
	7.5–8.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
	8.0–8.5	0.7	0.2	0.0	0.2	0.3	0.0	0.0	0.0	0.0	1.4
	8.5–9.0	0.6	0.5	0.0	0.9	1.4	0.0	0.0	0.0	0.0	3.4
	9.0–9.5	0.3	0.1	0.0	0.9	3.9	0.0	0.0	2.2	0.0	7.3
	9.5–10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8	6.9	11.8
South Carolina	7.0–7.5	4.2	0.0	0.0	3.0	0.0	0.0	0.0	0.0	0.0	7.3
	7.5–8.0	3.0	0.0	0.0	15.3	0.0	0.0	21.4	1.4	0.0	41.0
	8.0–8.5	0.1	0.0	0.0	8.0	0.0	0.0	20.8	19.6	3.4	51.9
	8.5–9.0	0.0	0.0	0.0	0.0	0.0	0.0	10.1	15.5	4.3	30.0

Table 4-3 (concluded). Offshore Wind Resource Potential (in Gigawatts) by Wind Speed, State, Water Depth, and Distance from Shore

State	Wind Speed at 90 m (m/s)	Distance from Land									Total
		0–3 nm			3–12 nm			12–50 nm			
		Depth Category (m)			Depth Category (m)			Depth Category (m)			
		0–30	30–60	>60	0–30	30–60	>60	0–30	30–60	>60	
Texas[a]	7.0–7.5	8.9	0.0	0.0	0.5	0.0	0.0	0.7	0.0	0.0	10.1
	7.5–8.0	45.2	0.0	0.0	5.8	0.0	0.0	40.2	30.9	2.0	124.1
	8.0–8.5	29.6	0.6	0.0	3.7	0.7	0.0	2.9	22.2	23.0	82.8
	8.5–9.0	19.0	3.0	0.0	0.2	4.7	0.0	0.0	16.1	18.4	61.4
Virginia	7.0–7.5	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4
	7.5–8.0	18.0	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0	18.3
	8.0–8.5	5.7	0.0	0.0	14.9	0.0	0.0	11.8	0.3	0.0	32.7
	8.5–9.0	0.0	0.0	0.0	0.1	0.0	0.0	10.2	24.2	4.5	39.0
Washington	7.0–7.5	3.1	0.7	0.3	1.2	1.8	0.9	0.0	0.0	0.0	7.9
	7.5–8.0	1.9	0.0	0.0	1.0	4.2	5.7	0.0	0.0	10.2	23.1
	8.0–8.5	0.3	0.0	0.0	1.1	4.9	2.4	0.0	0.1	82.6	91.3
Wisconsin	7.0–7.5	5.3	1.3	0.7	1.7	3.1	5.4	0.0	0.2	0.8	18.6
	7.5–8.0	7.1	1.2	0.1	1.8	1.1	3.9	0.0	0.0	1.8	17.0
	8.0–8.5	4.2	1.9	0.0	2.3	6.9	12.7	0.0	0.1	10.8	38.8
	8.5–9.0	0.1	0.0	0.0	0.1	1.5	6.7	0.0	0.3	33.3	42.1

Source: Schwartz et al. 2010.

[a] Federal waters begin at 3 nm with the exception of Texas, which begins at 9 nm. For Texas, the area reported is for 0–9 nm; 9–12 nm; and 12–50 nm, respectively.

4.3.1 Coastal State Boundaries and Distance from Shore

The definition of offshore areas is complex, involving the interpretation of the physical characteristics of an area as affected by various treaties and international and domestic law. The BOEM and the National Oceanic and Atmospheric Administration (NOAA) are working to establish this information by defining a baseline of the mean lower low water (MLLW) line. These data can change rapidly, particularly as coastlines are reinterpreted because of storm events. Modifications to the MLLW might also be made to separate inland waters (i.e., bays). From the MLLW, the state and federal administrative zones are derived, extending to the 200-nm U.S. international boundary or another international boundary. These data are still under development, but published interim data—acquired from the BOEM Web portal (http://www.boemre.gov/offshore/mapping/)—were used in this study. These data depict the location of the federally administered offshore regions by state. The federal jurisdiction generally begins 3 nm from the MLLW line, except for Texas and the Gulf Coast of Florida, where federal jurisdiction begins at 9 nm from the baseline.

For purposes of this study, the resource areas are classified into the following: state waters (0–3 nm), nearer shore (3–12 nm), and far shore (12–50 nm). These distances were chosen to separate federal and state management of offshore areas and to delineate some economic separation to depict the varying costs associated with delivering energy produced offshore. In addition, the 12-nm boundary makes an appropriate division between far shore and nearer shore because it is already defined as the boundary for territorial waters. It is also convenient to use this distance as a subjective boundary where visual impacts are estimated to be minimal. Table 4-3 accounts for the additional state waters (0–9 nm) off the coast of Texas.

4.3.2 Wind Resource Information

Although a comprehensive U.S. offshore wind resource assessment is still under way, sufficient information already exists to determine a preliminary wind resource distribution, as shown in Figures 4-1 and 4-2. Where no updated offshore maps are available, the estimates are derived from near-shore resource data created during land-based wind resource assessment activities, supplemental products created by land-based wind mapping projects for areas farther from shore, and resource estimates inferred by examining other modeled and measured wind information. The exceptions to this are the 90-m estimates for Florida, Alabama, and Mississippi. The wind resource information is sorted by average wind speed at 90 m above the water surface (near the turbine hub height). Annual average wind speeds of 7.0 m/s and 8.0 m/s were used to generate Tables 4-1 and 4-2 to allow the resource to be summarized in different ways, with 8.0 m/s and above being a more conservative estimate of the entire resource.

4.3.3 Bathymetry

The assessment of the offshore wind resource with respect to water depth will have a significant effect on the type of technology needed (Musial, Butterfield, and Boone 2003). Most offshore wind turbine technology uses either monopole or gravity-base foundations, employing a class of jack-up installation barges that are limited to a maximum water depth of 25 to 30 m. In general, European installations are in water depths of less than 30 m (EWEA 2010). New technology has already been demonstrated, though, which allows fixed-bottom installations in water depths of up to 45 m (MacAskill 2005). Installations beyond these depths will call for even more innovation, such as floating platforms (see Section 5).

Detailed bathymetry data are available from the NOAA Coastal Relief Model (http://www.ngdc.noaa.gov/mgg/coastal/startcrm.htm) for the majority of the study area, with the exception of Lake Superior. In Hawaii, the NOAA data did not extend the necessary distance from shore, so these data were supplemented by less detailed global bathymetry data. For this study, the bathymetry was classified into ranges corresponding to the technology available: shallow (0–30 m), transitional (30–60 m), and deep (>60 m).

4.4 Wind Resource Research Trends

The scientific understanding of the environment in which offshore wind turbines operate and the characteristics of the wind, ocean waves, currents that affect offshore wind turbine structural safety and energy production is at an immature state. Validation measurements and computational analytical models must be evolved from other disciplines or developed to address this new specific area. The need to improve wind resource assessment capabilities is closely linked to the technology of offshore wind turbines themselves, which is covered in Section 5. The technology trends described in the following subsections relate to the characterization of the wind resource; Section 5 is more focused on the site-specific characteristics that can impinge on a wind turbine installation. Both categories are extremely important and should be addressed in future research initiatives.

4.4.1 Resource Mapping and Quantification

The complete mapping of the entire U.S. coastal boundary has been under way for several years but is not yet complete. Completing this mapping and validating these offshore wind resources for the entire U.S. coastline could reduce many uncertainties in the planning of wind energy projects in their early stages and could assist states and federal governments as they plan long-term energy strategies. Today, much of the data is derived from land-based extrapolations that are incomplete and are patched together with some uncertainty. Mapping and validation efforts could include all remaining unmapped areas including the Atlantic coast from Rhode Island to South Carolina, the West Coast, and the coasts of Alaska, Florida, Hawaii, and the Gulf of Mexico. Updated assessments could be compiled and published regularly in an offshore resource catalogue and report (Schwartz et al. 2010).

The analytical mesoscale models described earlier have improved, but must be validated by accurate long-term measurements. Currently these models are limited to global resource characterization and are not very useful for micrositing or accurately predicting complex weather phenomena such as wind shear profiling, atmospheric stability, or seasonal variations. Models that can estimate these effects at specific offshore wind sites, without the need for the long-term installation of a meteorological (met) mast, are needed to managing risk during the site development of offshore projects, especially in deeper water (Jiminez 2007; Jørgensen 2005;).

4.4.2 Metocean Validation

The existing database of accurate anemometer-based offshore wind-speed measurements consists of a sparsely distributed system of buoys and fixed Coastal-Marine Automated Network (C-MAN) stations maintained and operated by the National Data Buoy Center. Buoy data are generally taken at an elevation of 5 m and are insufficient for confident wind-resource validations or to fully characterize the wind regime at a particular site. The traditional land-based method of taking wind measurements from a met mast is expensive offshore, especially for a large number of sites, and particularly in deeper water.

All modeling estimates must be validated by long-term measurement records. Wind, sea-surface temperature, and other weather data available from numerous databases (NOAA, NASA, the National Weather Service [NWS], and other government agencies) can be compiled to supplement the characterization of coastal and offshore wind regimes (Hasager et al. 2005). The limitations and availability of existing offshore data collected for the purpose of weather observations and forecasting must be reassessed. It may be necessary to increase these measurement efforts to gather real-time data at sea for the purpose of understanding renewable *energy* production potential. In the future, advanced analytical modeling of the atmospheric boundary layer might be able to accurately determine site-specific wind characteristics. If validated, analytical techniques might allow developers to avoid expensive met measurements.

4.4.3 Remote Sensing

For a large number of sites, installing met masts may not be feasible because of cost or water depth. Alternative methods are needed to measure wind speed at multiple locations and to determine wind-shear profiles up to the elevations where wind turbines operate. This will require new systems based on, for example, sodar, lidar, and radar, combined with more stable buoy systems or fixed bases (Antoniou et al. 2006). Some systems are currently being developed, but experience thus far is limited (Zack 2006). To gain enough confidence for these systems to replace the conventional met mast, a large amount of experience with commercial projects at sea will be needed. This will require, in turn, close cooperation among private technology companies, offshore developers and operators, and government R&D programs at the U.S. Department of Energy (DOE) and BOEM, both in terms of taking the data and verifying the results. Once a reliable and proven track record has been established, the improved accuracy for wind and energy production measurements will remove a significant amount of risk from developers. An effective R&D approach might be to engage in international collaborative activities that support the development of these advanced meteorological solutions.

4.5 Findings and Conclusions

To derive state and regional estimates of offshore wind potential for the United States, the wind resource, bathymetry, distance from shore, and administrative jurisdiction information were combined using geographic information system (GIS) technology. Tables 4-1 and 4-2 show the available regional resource for 8.0 m/s annual speeds and greater at 90 m and 7.0 m/s, respectively, by water depth. Table 4-3 categorizes the resource in more detail, by state, depth, and distance from shore.

As shown in Table 4-1, significant quantities of potential resource areas 8.0 m/s or greater at 90 m are available in each region in different depth categories. More than 450 GW of potential occurs in the shallow-depth category (0–30 m) drawn from all of the reported regions for the United States. Expanding this to include 60-m (transitional) depths increases the gross U.S. offshore resource to more than 1,000 GW. Adding deep water brings the gross resource to almost 3,000 GW. Table 4-2 gives these same figures, with the addition of low wind sites (sites with average wind speeds of 7.0 m/s or greater). The gross total resource then exceeds 4,000 GW.

The resource assessment database is based on extensive analysis conducted by NREL and AWS Truepower (formally AWS Truewind) spanning many years (Schwartz et al 2010). The results in some states are preliminary, but enough of the significant regions of the United States have been mapped and included in the database to conclude that the development of offshore wind in the United States is not resource-limited on a national scale. Some individual states fare better than others in terms of their local resource potential. The database contains the necessary information to allow each state to make the decision about whether their resource can make a significant impact on their local energy needs. Regional and physical geographical differences may influence the technology required for each state. Some of these differences include distribution of the resource according to water depth, distribution of the resource with respect to the distance from shore, hurricane risk, and the possibility of ice floe loading (particularly when siting on the Great Lakes).

Research trends show that analytical mesoscale models and atmospheric methods and models could help lower cost and uncertainty by reducing the need for expensive met towers. Similarly, remote sensing techniques that are still under development might someday be able to replace met towers for site characterization.

This assessment of offshore wind resources shows that the United States has an abundance of offshore wind that could make a significant impact on its total energy needs. The resources required to meet the scenario presented in the DOE 20% report (see DOE 2008) are a small fraction of the gross potential offshore wind energy resource of the United States.

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5.0 Offshore Wind Energy Technology—Status and Trends

5.1 Offshore Wind Technology Status

Today's offshore wind turbine design configurations are adapted from standard land-based designs with some significant subsystem upgrades to account for ocean conditions. These modifications include strengthening the tower to handle the added loading from waves, pressurized nacelles and environmental controls to keep corrosive sea spray away from critical drivetrain and electrical components, and personnel access platforms to facilitate maintenance and provide emergency shelter. Offshore turbines require corrosion protection systems at the sea interface and high-grade marine coatings on most exterior components. Turbine arrays can be equipped with aircraft warning lights, bright markers on tower bases, and fog signals to facilitate marine navigational safety. To reduce operational costs and yield better diagnostic information, offshore turbines are often equipped with condition-monitoring systems, automatic bearing-lubrication systems, onboard service cranes, and oil-temperature-regulation systems, all of which go beyond the standard equipment required for land-based turbines. Lightning protection is mandatory for both land-based and offshore systems. The major portion of the turbine's blades, nacelle covers, and towers are painted light gray to minimize visual impacts.

Offshore turbine power capacity is greater than standard land-based turbines, ranging from 2 MW to 5 MW. The current generation of offshore wind turbines typically have three-bladed horizontal-axis, yaw-controlled, active blade-pitch-to-feather controlled, upwind rotors, which are nominally 80 m to 130 m in diameter. Offshore machines are generally larger because there are fewer constraints on component and erection equipment transportation, which limit land-based machine size. Blade-tip speeds of offshore turbines are typically higher (80 m/s or greater) than those of land-based turbines because of lower aerodynamic noise concerns in the near field. The basic drivetrain topology differs very little from land-based systems and is typically designed around a modular, fixed-ratio, three-stage, gearbox speed increaser with planetary stages on the low-speed side and helical stages on the high-speed side. Nominal generator speeds are around 1,800 rpm, but turbine designs usually operate under variable-speed torque control. Offshore towers are shorter than land-based towers for the same output because wind shear (the change in wind velocity resulting from the change in elevation) is lower offshore, which reduces the energy capture potential of increasing tower height.

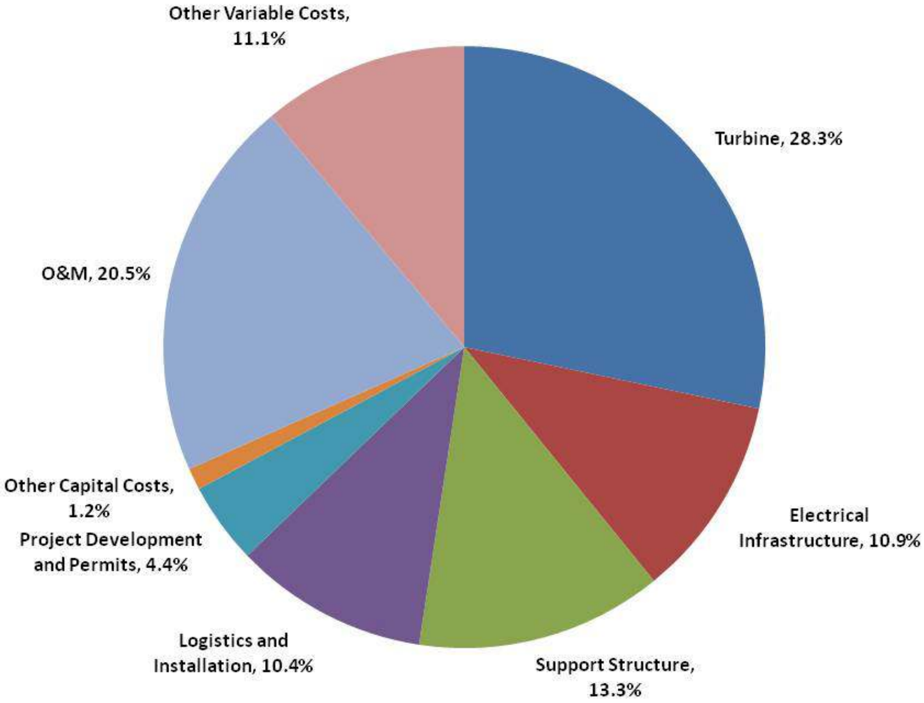
The offshore substructure and foundation systems differ considerably from land-based foundations. The most common substructure type is the monopile—a large steel tube with a wall thickness of up to 60 mm and diameters of up to 6 m. Monopiles have been placed in water depths ranging from 5 m to 30 m. The embedment depth varies with soil type, but typical North Sea installations require pile embedment 25 m to 30 m below the mud line. A transition piece is grouted onto the part of the monopile that protrudes above the waterline, which provides a level flange to fasten to the tower. The monopile foundation requires special installation vessels and equipment for driving the pile into the seabed and lifting the turbine and tower into place. Approximately 20% of offshore wind projects use gravity-base foundations, which avoids the need to use a large pile-driving hammer. Gravity-base systems require a significant amount of bottom preparation before installation and are compatible only with firm soil substrates in relatively shallow waters. Multi-pile substructures such as tripods and jackets have been deployed in some projects, especially when the water depth starts to exceed the practical limit for monopiles.

Infrastructure mobilization and logistical support for constructing a large offshore wind plant are major portions of the total system cost. The wind turbines are arranged in arrays that take advantage of the prevailing wind conditions at the site. Turbine spacing is chosen to minimize array losses and interior array turbulence, while balancing the cost of cabling between turbines, which increases with turbine spacing. Varying water depth presents a siting obstacle that often requires a customized approach to individual substructure design to ensure that each turbine's structural vibration modes are compatible with the turbine operating frequencies (Dolan et al. 2009; Elkinton, Manwell, and McGowan 2008).

The wind plant electric power distribution system consists of the individual turbine's power electronics, the turbine step-up transformer and distribution wires, the electric service platform (ESP), cables to shore, and the shore-based interconnection system. This system, which is counted as part of the overall offshore plant cost, extends beyond the typical costs for a land-based wind farm where the costs are counted only to the substation. Power is delivered from each turbine from the generator and the power electronics at voltages ranging from 480 V to 690 V, and is then increased via the turbine transformers (which can be cooled with dry air or liquid) to a distribution voltage of about 34 kV. The distribution system collects the power from each turbine at the ESP, which serves as a common electrical collection point for all the turbines and as a substation where the turbines outputs are combined and brought into phase. For smaller arrays, or projects closer to shore, the ESP can be eliminated and the power can be aggregated at an onshore substation. For larger projects, the voltage is stepped up at the offshore substation (i.e., the ESP) to about 138 kV for transmission to a land-based substation where it connects to the onshore grid. Power is transmitted from the ESP through a number of buried high-voltage subsea cables that run to the shore-based interconnection point. The voltage may need to be increased again onshore to, nominally, 345 kV for offshore power plants larger than 500 MW (Green et al. 2007).

The ESP can also function as a central service facility for the wind plant, which may include a helicopter landing pad, a wind plant control room and supervisory control and data acquisition (SCADA) monitoring system, a crane, a rescue boat, and a communications station, along with firefighting equipment, emergency diesel backup generators, and staff and service facilities, including emergency temporary living quarters. Note that the exact requirements for offshore safety and service have not yet been established (Sheppard, Puskar, and Waldhart 2010).

Currently, installed capital costs for offshore projects are higher than those for land-based wind turbines. Factors that contribute to these additional costs include the upgrades required for operation at sea, higher reliability components, and particularly, higher balance-of-station (BOS) costs (e.g., expensive installation vessels, logistics of working at sea, longer power cables to shore). In addition, operations and maintenance (O&M) costs are two to three times higher than those for land-based systems. This is partly because turbine accessibility is more complicated, external conditions are more severe and more difficult to measure and characterize, and extreme wind and wave loads add substantial uncertainty to the design methods used on the turbines and substructures. Figure 5-1 breaks down the costs of installing a typical offshore turbine. Capital expenditures for installed and planned projects are examined in greater detail in Section 6.



Source: Ernst & Young 2009; Krohn, Morthorst, and Awerbuch 2009; Fingerish, Hand, and Laxson 2006; Junginger and Faaij 2004; Morgan, Scott, and Snodin 2003)

Figure 5-1. Estimated life-cycle cost breakdown for a typical baseline offshore wind project

The primary point that should be drawn from Figure 5-1 is that offshore project costs are largely determined by a range of elements that extend well beyond the turbine itself. Future efforts to lower cost should place a greater emphasis on other aspects of the system relative to previous land-based R&D efforts.

One element that is not recognized in Figure 5-1 is the initial one-time costs associated with developing the necessary infrastructure to support an offshore industry, including the costs for fabricating numerous vessels, upgrading ports and harbors, establishing manufacturing facilities, and creating and administering workforce training programs. Early projects may have to bear some of these costs of the additional investments needed to get started.

Finally, the baseline shallow-water offshore wind technology described earlier gives the United States a gross technical resource potential of about 457 GW at sites with wind speeds of 8.0 m/s or greater (see Section 4). This gross potential does not take into account numerous siting limitations and exclusions, which will reduce the practical resource potential considerably. It also does not account for some technology solutions that are needed to break down the barriers to offshore wind to allow competitive costs in all shallow-water resource areas, with minimal conflicts with humans and the surrounding ecosystems. Such solutions include turbine designs to withstand hurricanes, especially in the south, and ice designs that would allow turbines to be placed in freshwater, such as the Great Lakes.

5.2 Offshore Wind Technology Barriers

Several barriers to offshore wind development—summarized in this section—are inhibiting the deployment and acceptance of offshore wind technology.

5.2.1 High Cost

Currently, capital costs for offshore projects are nearly double those for land-based wind projects. These higher costs accrue from, for example, the offshore turbine support structures, offshore electrical infrastructure construction, the high cost of building at sea, O&M warranty risk adjustments, turbine cost premiums for marinization, and a decommissioning contingency. These costs can be partially offset by increased energy production. In comparison with land-based wind, however, offshore wind is also immature and its costs are higher because less deployment and experience has not allowed for full realization of the learning curve, by which product costs in new industries are known to decline as a function of production quantity. Further cost uncertainty and upward cost pressure may be introduced because of U.S. dollar/euro exchange rates. High cost is one of the primary deterrents for would-be developers of offshore wind. Current projects in the United States depend on policy incentives to offset some of the high costs, but there are no guarantees that the necessary incentives will be available when a project is approved and permitted. Developing innovative offshore wind technology, accelerating U.S. offshore wind deployment, and implementing regulatory and operational supports to reduce the risks associated with offshore wind investments can all have a downward influence on the future costs of offshore wind. Section 6 covers offshore costs and economics in greater detail.

5.2.2 Technology Immaturity

The near-term technology is still immature, which is an obstacle to offshore wind development. High cost of wind energy can, in part, be addressed directly with technology innovations that increase reliability and energy output and lower system capital expenses. The current technology limits the domain for offshore machines to shallow-water sites at a cost premium that is reflective of the industry's early state. New technology is needed to lower costs, increase reliability and energy production, solve regional deployment issues, expand the resource area, develop infrastructure and manufacturing facilities, and mitigate known environmental impacts. Because of the high up-front investment costs required to explore new technology innovation and the long timeline that is usually required to reap the full benefits of high-risk game-changing innovations, many companies may not be motivated to invest in R&D for offshore wind technology solutions.

5.2.3 Limited Resource Area

The current technology limits offshore development to shallow-water sites in the North and Mid-Atlantic regions with about 457 GW of gross technical potential. This includes sites in the Great Lakes region and the Gulf of Mexico, but risks associated with ice floes and hurricanes, respectively, have not been fully explored and could reduce the gross potential resource even further. Similarly, this resource includes near-shore sites, which might still trigger public engagement issues that could further reduce the offshore wind potential. Public opposition tends to decrease with distance from shore where waters are deeper but the technology is not yet available to deploy in these areas. Technology solutions that would allow for developing further offshore sites could expand the resource area of the United States by a factor of 6, from the 457 GW in shallow water to nearly 2,900 GW (see Section 4 for the wind resource assumptions).

5.2.4 High Risk and Uncertainty

High project risk has contributed to high discount rates for financing offshore wind projects and justifiably, a cautious investment climate. Project risk can be broken down into the uncertainty surrounding regulatory and permitting issues, the risks associated with construction and installation, and the operational risks that are associated with accurate energy production and long-term reliability. Risk and uncertainty may dissipate as the industry matures, but today the process remains immature. Risk reduction can have as big of an impact on the life-cycle cost of an offshore wind project as the reduction in capital expenses. As the project advances through the development process and key milestones are achieved, the overall risk to the project decreases. At the time the project developer seeks the financial backing for the major part of the project's capital expenditure—the capital to procure the wind turbines and the BOS—the largest fraction of risk and uncertainty remaining is primarily associated with the construction, installation, operation, and decommissioning phases. As a result, the biggest opportunity for reducing the costs of offshore wind likely resides in mitigating these technology risk elements.

5.3 Technology Trends

Offshore wind is relatively new in comparison with land-based systems, and there are numerous opportunities to improve on the technology in ways that will lead to lower cost, expanded access to wind resources, and improved performance.

5.3.1 Wind Turbine Technology

Offshore wind turbine technology is significantly different from land-based wind turbine technology, although there are several similarities as well. The pace of technology innovation in offshore wind turbines is also different because the technology is less established and the growth is on an earlier part of the learning curve.

5.3.1.1 Optimized Offshore Wind Turbine Systems

Offshore turbines were originally derived from land-based wind turbines, which have realized a basic level of commercial maturity over the past decade. The evolutionary path taken by land-based designs, though, is not optimum for offshore machines because of the following fundamental differences in the offshore environment, market, and infrastructure:

- Siting farther from human habitations
- Corrosive seawater exposure
- Less constrained shipping size limits
- Higher offshore construction costs
- Poorer accessibility
- Wave loading added to extreme wind and fatigue load combinations
- Lower wind shear and turbulence
- Other external conditions requiring special attention (e.g., ice and hurricanes)
- Contrasting regulatory, construction, and operational risk profiles
- Subsea electrical distribution and land-based interconnections.

Because of these differences, future trends may move toward significant divergences between offshore and land-based designs. Optimized offshore turbine designs may take advantage of innovations and design opportunities that were previously rejected for land-based turbines in order to meet strict noise requirements or to improve aesthetics. Most offshore turbines will be placed far enough from people that some noise sources, such as aerodynamic blade noise, may not propagate an appreciable distance outside the project perimeter. Low-frequency infrasonic noise should be treated separately but has not been an issue for modern upwind turbines, even when in relatively close proximity to residences.

Because of higher BOS and O&M costs, the cost of an offshore wind turbine (the tower plus the rotor nacelle assembly) is estimated to be less than one-half of the capital cost of the wind project (see Section 6). Because transportation and erection size limits are less constrained and BOS costs are higher offshore, the optimum turbine size may be greater than the current sizes that evolved for land, and growth should continue until overall system costs are minimized. The optimized system could even allow for turbines that cost more per megawatt as long as the life-cycle project costs for the offshore system decrease as turbine size increases. Figure 5-2 shows how offshore project economics favor large turbines. As shown, the nonturbine project elements trend toward lower cost on a dollar-per-megawatt basis as turbine size increases. Land-based systems have benefited from turbine growth in a similar way, but offshore systems will probably be larger because of three major factors: (1) greater fraction of cost devoted to the BOS; (2) larger transportation and installation capacity size limits; and (3) the mobilization and logistics of offshore equipment (which favor large structures and larger projects). These factors will enable cost reductions as the turbine and project scale grows. As shown in Figure 5-2, the cost per megawatt of wind turbine capacity decreases with turbine size for the substructure, installation, O&M, and the grid and electrical infrastructure. In addition, larger turbines can extract more total energy for a given project site area than smaller turbines.

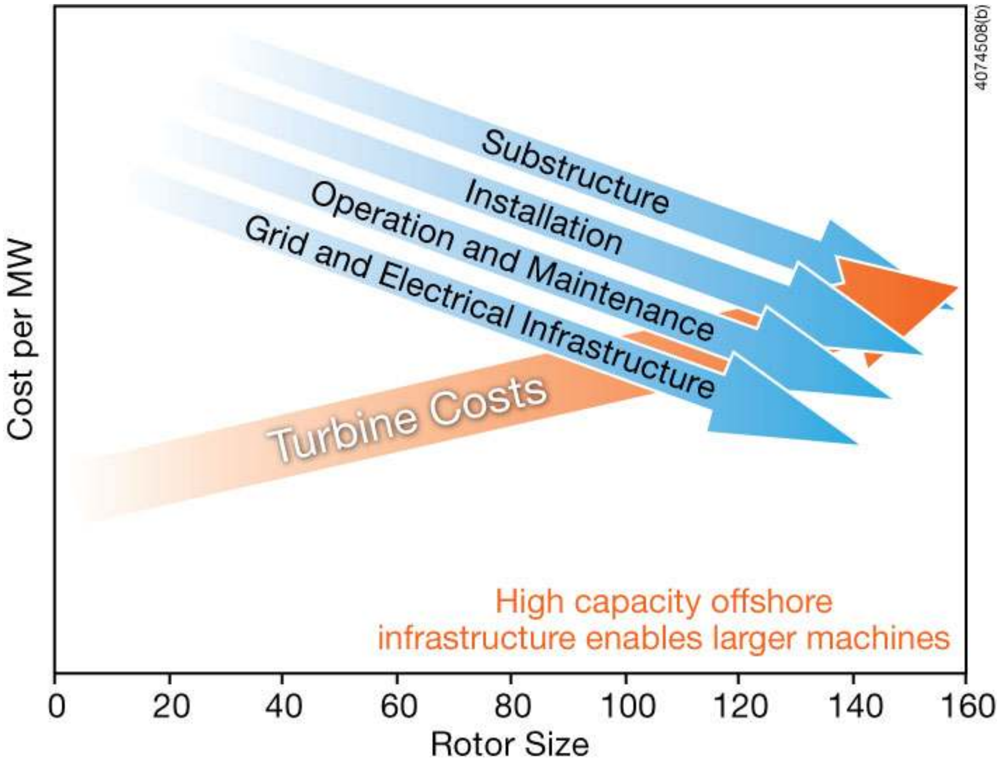


Figure 5-2. Why larger turbines might lower overall cost

There is no consensus on how large offshore wind turbines will become, although most agree that no physical limit prevents building 10-MW or larger turbines. But the technology to develop these ultralarge turbines has not yet been proven and several significant challenges and development risks may exist. Wind turbine growth on land has been an evolutionary process in which wind turbines have grown from 100 kW during the early 1980s to 1,500 kW by 2000. Today, land-based machine size growth may be slowing, and future wind turbine size growth may be paced by offshore development. In Germany, at least three manufacturers have commercial machines on the 5-MW scale, with most targeting the offshore commercial market. According to findings from the UpWind Project (funded by the European Union [EU] and led by the Risø DTU National Laboratory for Sustainable Energy [Risø DTU]), wind turbines will have rotor diameters of more than 150 m and capacities of 8–10 MW in the near future. The UpWind project has been funded at about 110 million Danish krones (DKK) and will develop design tools to optimize large wind turbine components such as rotor blades, gearboxes, and other systems that must perform in large offshore wind farms (Risø DTU 2005). Indeed, manufacturers across Europe and North America are now developing wind turbines of this size (Next Big Future 2010; Renewable Energy Focus 2010; Clipper Windpower 2009; deVries 2009). Table 5-1 lists some of the large wind turbines under development.

Table 5-1. Wind Turbines Rated Above 5 MW, Planned or Under Development

Company	**Rating** (MW)	**Turbine Description**
Clipper Windpower	10	Britannia: design under development
American Superconductor	10	Sea Titan: design under development
Repower	6	6M, based on 5-MW 126-m rotor design: in production
Areva/SWAY (Norway)	10	Floating offshore design: planned
Enercon	6	E126: production; no announced offshore plans

The critical issue in developing ultralarge machines is that the physical scaling laws do not allow some components to be increased in size without a change in the fundamental technology. New size-enabling technologies will be required to extend the design space for offshore wind turbines beyond the current 5-MW size. Some of these technologies may include a variety of stiffer, lightweight composite materials and new composite manufacturing methods; lightweight, low-maintenance drivetrains; lightweight, high-speed downwind rotors; direct-drive generators; and large gearbox and bearing technologies that can tolerate slower rotational speeds and larger scales.

5.3.1.2 Advanced Rotors and Towers

The rotor represents only a small fraction of the total cost of the offshore system, but transfers most of the aerodynamic loads and all of the energy; therefore, this is one of the best places to look for system cost improvements. New high-technology strategies may cause turbine costs to increase to benefit the overall life-cycle economics. Turbine rotors can be enlarged to increase the energy capture in ways that do not increase structural loads, costs, or the requirements of electrical power equipment. A significant amount of R&D has been devoted to this approach for reducing the costs of land-based turbines, and offshore turbines can benefit from the same strategy.

Concepts such as active variable diameter rotors, bend-twist coupled blades, two-bladed rotors, or active control surfaces could have a higher economic value offshore, as long as they can also contribute to higher reliability (Energy Unlimited 2006; TPI Composites 2003a; Griffin 2002). Structural loads caused by turbulence can be reduced using both passive and active controls to allow for longer blades and greater swept area, which can benefit both land-based and offshore turbines. But as offshore blade designs grow beyond the length of current land-based turbines, designers will seek more advanced technologies that offer higher material performance while reducing total blade weight and minimizing tip deflections for the next class of 10-MW turbines fabricated specifically for offshore applications. In addition, blade designers must overcome unique challenges in the offshore environment, considering mitigation strategies for marine moisture, corrosion, and extreme weather. At higher latitudes, ice accretion on the blades and ice floes can add to these concerns.

The wider use of composites and concrete may also penetrate the machine material mix. Blades, hubs, towers, foundations, and drivetrains could all benefit from lightweight, low-cost solutions. Lightweight carbon hybrids and advanced manufacturing techniques employed in blade fabrication may differ significantly from those of traditional land-based blades, which rely mostly on fiberglass-reinforced polymers. The effects of the marine environment on many wind turbine blade materials, especially with respect to fatigue and corrosion, are not well known. These must be determined, though, before designing and fabricating durable offshore wind structures (Rasmussen 2005). Because blades for offshore turbines are not subject to onshore transportation constraints, larger blades are simply more practical, and will challenge researchers to improve material properties, manufacturing processes, and testing methods, and to develop large-blade test facilities (Griffin and Ashwill 2003).

Finally, the heaviest component above the water is the tower, which is fabricated almost exclusively from low-cost steel. Alternative, lightweight materials (like composites that could also help resist corrosion) could lower tower weight. Concrete has also been proposed as a possible low-cost tower material for large offshore towers.

5.3.1.3 Drivetrains

Higher rotational speeds could allow for smaller blade planform areas and lighter blades for the same energy output. Increasing the maximum design blade tip speed, which is normally constrained to about 75 m/s, could result in significantly lower nacelle weights because of lower input torque, lower gear ratios, and hence, smaller drive shafts and gearboxes (DUWind 2001). Some trends in offshore drivetrain designs favor direct-drive generators, which could be smaller, lighter, and less expensive with higher rotational speeds. Some engineers believe that direct-drive generators could be more reliable than modular gear-driven systems, but some of today's direct-drive generators use wire wound-rotor generators that are heavier than the modular systems. Permanent-magnet generator designs promise weight reductions and improved efficiency (Poore and Lettenmaier 2002). Larger capacity turbines may allow the industry to move into technologies such as lightweight, superconducting generators that become more cost effective with size and show promise for substantial weight reductions that could be advantageous in large floating wind turbines (Jamieson 2003).

5.3.1.4 Reliability

One lesson learned from offshore oil and gas is that work at sea takes longer because it is more difficult to plan and predict and the conditions are harsher. Even simple tasks take more time. Complex logistics can add extra steps that are necessary to maintain safety but do not contribute to the end goal and require a more skilled, more highly paid local labor pool. Work at sea, however, is inherently more expensive. Reassessing current practices for an offshore wind project could reveal many opportunities to lower project costs by redistributing the balance between work done at quayside and that done at sea. For offshore systems, the current land-based turbine service and reliability records are unacceptable and have contributed to some notable operational misfortunes (Modern Power Systems 2005). In the long term, a new balance between initial capital investment and long-term operating costs could be established that might have a broad impact on the cost of energy. Because new offshore strategies must minimize work done at sea, a paradigm shift that accounts for all aspects of the project is needed. If the offshore wind industry is to be successful, new turbine designs must place a higher premium on reliable designs and low-cost in situ repair methods, from the preliminary concepts to the finished product. Likewise, new materials must be selected for durability and environmental tolerance. The design basis could be refined to minimize uncertainty and ensure that actual offshore loads will not exceed the design envelope. Emphasis should be placed on avoiding large maintenance events that require deploying expensive and specialized equipment. This could be done through integrated system designs and design tools, appropriate design redundancy, improved quality control and inspection, and a substantial increase in the level of validation testing at all stages of development.

Offshore prototype wind turbines should be proven on land or on sites close to shore before they are deployed offshore in large numbers. The industry could establish guidelines to determine when a new machine is ready for deployment at sea. This process of improving reliability begins by identifying the root causes of component failures and understanding the frequency and cost of each event. Reliability is then determined, and finally, appropriate design improvements are implemented (Stiesdal and Madsen 2005; Rademakers et al. 2003).

5.3.1.5 Controls and Condition Monitoring

One trend is to equip operators remotely with intelligent turbine-condition monitoring and self-diagnostic systems to manage O&M, predict weather windows, minimize downtime, and reduce the equipment needed for up-tower repairs. Systems that monitor turbine operating conditions can be used to inform smart controllers of needed operational changes or parameter adjustments. They also alert operators to schedule maintenance at the most opportune times. A warning about an incipient failure can alert the operators to replace or repair a component before it causes significant damage to the system or leaves the machine inoperable for an extended period of time (WindRisk 2010). More accurate weather forecasting could also become a major contributor in optimizing service for low cost, and this research area has strong synergies with land-based systems (Ougaard 2005).

Because offshore turbines are larger, they offer new opportunities that are not as practical at smaller sizes. The cost of the control system and health-monitoring sensors that diagnose turbine status will not increase substantially as turbine size increases because the hardware is independent of size. For the same cost fraction, larger offshore turbines will enable a much higher level of control, maintenance management, and condition-monitoring intelligence. The value of such condition-monitoring information is multiplied in offshore applications because their remote and relatively inaccessible siting makes service and status information more critical. Much of the controls research for land-based systems can also apply to offshore machines, including new algorithms to increase power production and decrease blade loading. Some unique offshore applications may offer opportunities for enhancing these solutions, especially for floating systems that can use the rotor to help manage overall system displacements and loads (Neville 2009).

5.3.2 Offshore Wind Substructure Technology

Substructures are one of the most critical aspects in the development and expansion of offshore wind energy. The following section is devoted to a discussion of the state of this technology and some of the opportunities for technology advancement.

5.3.2.1 Substructure Technology Overview

The substructure of the offshore wind turbine is defined as the supporting system that begins at the lower flange of the tower and extends to the structural elements that attach it to the seabed. Offshore wind substructure technology can be divided into three major technology classes based on water depth, such as those shown in Figure 5-3.

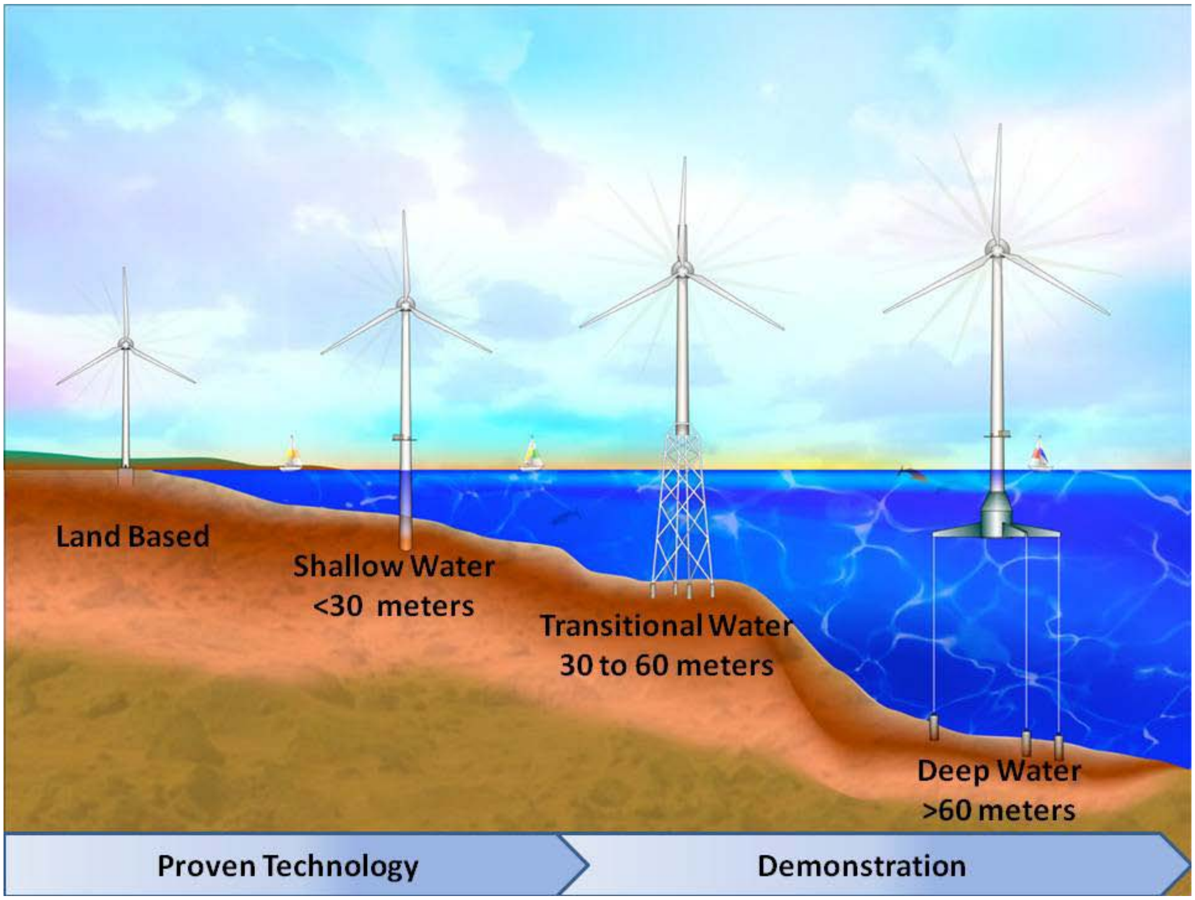


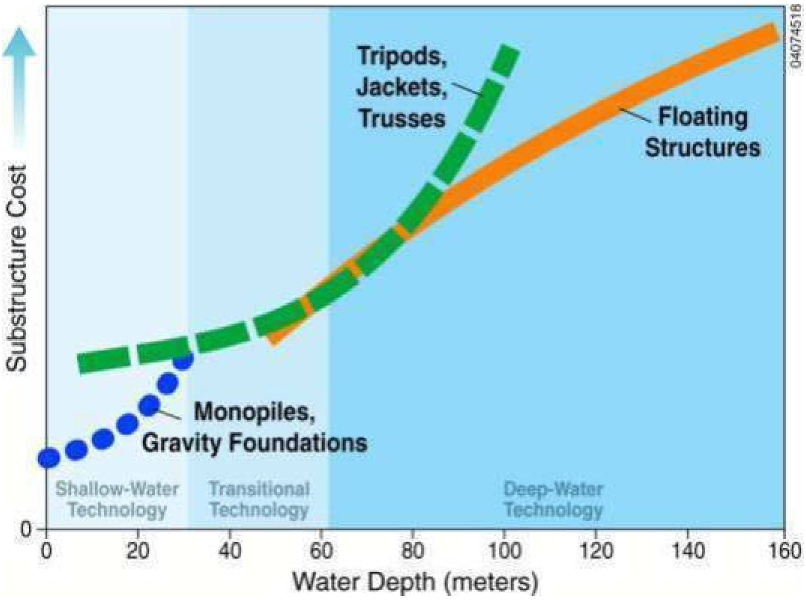
Figure 5-3. Substructure technology classes for offshore wind turbines

Shallow water is defined in this study as between 0 m and 30 m. This definition captures the water depth of most of the projects installed today, as well as the bulk of industry experience (refer back to Figure 3-3). Transitional depths range between 30 m and 60 m. Beyond 60 m in depth, several floating concepts derived from the oil and gas industry have been developed.

As a caution, note that the above-water depth bands for shallow, transitional, and deep water are specific to offshore wind turbines and are not derived from the oil and gas vocabulary, where deep water can mean 2,000 m or more. In addition, these depth bands only approximate the break points for the three technologies, but not enough experience exists to know if they are chosen accurately. They serve as good guides, though, for estimating the resource and the need to develop new solutions.

As water depth increases, the cost of offshore substructures is likely to increase because of the added complexity of design, fabrication, and installation, as well as the additional materials needed below the waterline.[12] Rising costs resulting from water depth may appear in stages as technology limits are reached. Industry trends indicate that technology solutions might be able to mitigate these jumps for the specific site characteristics as the industry gains experience.

Figure 5-4 gives a conceptual view of how the costs of different substructure technologies change with respect to water depth. The figure also illustrates the need for different designs to suit the exact site depth conditions. The actual trajectories of these foundation cost curves will vary depending on the detailed design, site-specific metocean characteristics, soil conditions, visual impact requirements, environmental constraints on seabed disturbance, and various other external conditions. The objective, however, is to develop designs that are the most economical and that meet the requirements for a given set of site conditions and water depths.



Source: Adapted from Dolan 2004.

Figure 5-4. Cost of offshore wind turbine substructures with water depth

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[12] In some cases very shallow waters can increase the cost of offshore wind because of the added difficulty in finding heavy-lift vessels that can navigate at these depths.

In shallow water, the necessary substructures and installation vessels are more basic, and to a large degree, design and implementation methods have been extrapolated from current land-based experience. Although monopiles and gravity-base foundations are the most commonly used substructures, they tend to increase in size nonlinearly with depth. At transitional or intermediate water depths, tripods, jackets, and other multi-pile systems may become more cost-effective than monopiles and gravity bases. Multi-pile offshore wind substructures are modified versions of proven oil and gas offshore designs. Because wind turbines have inherently lower environmental and safety risks and can expect higher production volumes demanded by offshore large modular wind power facilities, however, costs can be expected to be lower for wind energy. For transitional depths, the main challenge will be to minimize cost escalation with water depth.

The development of floating technology will require substantial additional investment, validation, and verification not just in the substructure, but in the integrated turbine/system, with the payoff being a tripling of the usable U.S. resource area. Note that even though the cost of the substructure may increase with depth for floating substructures, the system cost has the potential to be lower or the same for floating systems. Floating wind turbines and substructures are treated together in Section 5.3.3 because an integrated approach is required for these technologies to succeed.

5.3.2.2 Shallow-Water Substructures

Figure 5-5 shows the most common shallow-water foundations being deployed today. They include monopiles, gravity-base, and suction-bucket substructures, with the latter in the experimental stage. There is no technical reason why some of the transitional substructures (discussed later) would not also perform well in shallow water, but a full analysis of all conditions has not yet been performed.

Monopiles are used in shallow depths because they are simple and the design developments required to transition from land to sea are minimal. In addition, their footprint on the seabed is minimal. Monopiles are used in most offshore installations, including the 160-MW wind farm at Horns Rev I off the western coast of Denmark (DONG Energy 2010). Monopile designs are limited by resonance avoidance issues because they are slender and flexible. For the same pile diameter, the natural frequency of the turbine/support structure system decreases with water depth until it coalesces with rotor excitation sources that are typically focused on the one-per-revolution rotor speed and the blade-pass frequencies. To maintain adequate monopile stiffness, the monopile diameter and thickness must grow to accommodate greater depths. This requires a volumetric (cubic) increase in mass, and a concomitant increase in material costs. At the same time, installation equipment such as pile hammers and jack-up vessels also become more specialized and expensive to drive these increasingly large diameter piles. Eventually the required hammer capacities and jack-up water depths will not be practical and the monopile becomes much larger than required for structural strength. The practical depth limit is thought to be somewhere near 30 m (Ali 2004), but it is technically feasible to design a monopile to work at 40 m. The tradeoff is that to meet the resonance avoidance criteria, the monopile will be larger and more expensive than necessary to meet its strength requirements at depths beyond 25 m to 30 m. Other considerations include soil characteristics—relatively hard bottom conditions with no significant rock to obstruct the pile penetration are required. Monopiles generally have a larger projected area toward the wave front, which can increase the loading from waves in general. In some shallow-water sites (between 10 m and 15 m deep), where waves may only break when they reach extreme wave heights, the load contribution from extreme breaking waves can become a design driver for monopiles and must be given full attention in the design (Dolan et al. 2009). In shallower sites, the waves may break more frequently under storm conditions but the wave attenuation is significant enough to reduce the overall impact on the design. Because these conditions may still drive certain fatigue cases, they must be considered.

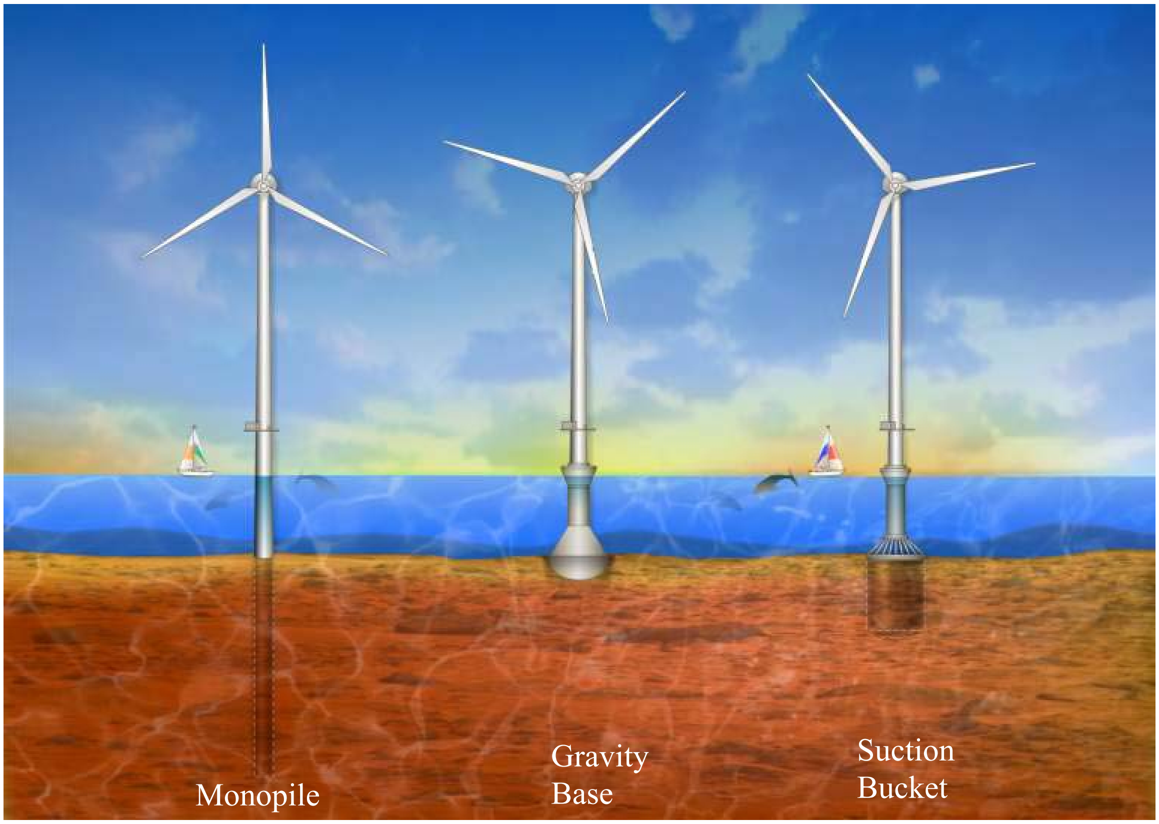

Figure 5-5. Shallow-water foundation technology

The gravity-base substructure (also shown in Figure 5-5) is the most common alternative to the monopile. Gravity-base substructures have been deployed successfully at sites such as the 165.6-MW Nysted project in southeastern Zeeland and at the 23-MW Samsø project in northeastern Jutland, both in Denmark, and more recently at the Thornton Bank project in Belgium. These substructures overcome the structural flexibility and pile-driving issues of monopiles, but are very sensitive to soil conditions at the surface. The cost of gravity-base foundations generally increases rapidly as the water deepens. Under some site conditions where rocky substrates exist or where pile-driving vessels are not available or are excluded for ecological reasons, gravity-base substructures can be the best alternative (Volund 2005). Extensive site-specific soil analysis is required for each gravity base to ensure homogeneous soil properties and compaction to minimize uneven settling. When bottom conditions are thoroughly understood, the seabed must be prepared so that foundations can be accurately leveled to within 20 mm in some cases (Aarsleff July/August 2003). Heavy-lift cranes are used to set the unballasted gravity-base structure in the proper position and thousands of tons of dead weight (ballast) are added to the structure to stabilize it from high overturning moments.

The suction-bucket foundation has not yet been used commercially as a shallow-water foundation, but significant development research has been done. This new technology could show promise for some shallow-water sites, especially in avoiding the limitation of the large pile drivers needed to install monopile-type foundations (Ibsen 2005). Suction buckets provide a wide base and are driven into the seabed by drawing a vacuum inside to allow the bucket to be seated by hydrostatic pressure.

In shallow water with soft soils or extreme breaking waves (see Section 5.3.11), it could be necessary to use technology now being considered for transitional water depths. Under these unique conditions, technologies that depend on a central column at the mud line to resist overturning might not be the optimum substructure. A concept for a shallow-water multi-pile substructure is being proposed for a project off Galveston Bay in Texas (Coastal Point Energy 2010).

5.3.2.3 Transitional Technology

Transitional substructure technologies are used to support offshore wind turbines in waters deeper than 30 m but shallower than 60 m. Transitional depths are often referred to as intermediate depths but are thought of in this report as "transitioning" from the current technology into deeper waters but still fixed to the bottom. This means that projects installed in transitional water depths will be deeper and farther from shore than projects in the current experience base. For water depths greater than 30 m, or at sites with softer soil compositions, a wider substructure base is needed to counteract overturning forces and to conform to turbine design requirements for stiffness. In most cases, transitional substructures will result in higher costs and add incremental technology challenges. Transitional substructures use multiple anchor points, using jackets or tripods. Deeper water means more structure placed below the waterline, and logistically, a more difficult installation process. A fleet of installation vessels will need to be adapted to perform the needed functions at these greater depths. New installation methods and quayside infrastructure would need to be developed to make this technology competitive with shallow-water wind. Figure 5-6 gives a range of conceptual transitional substructures.

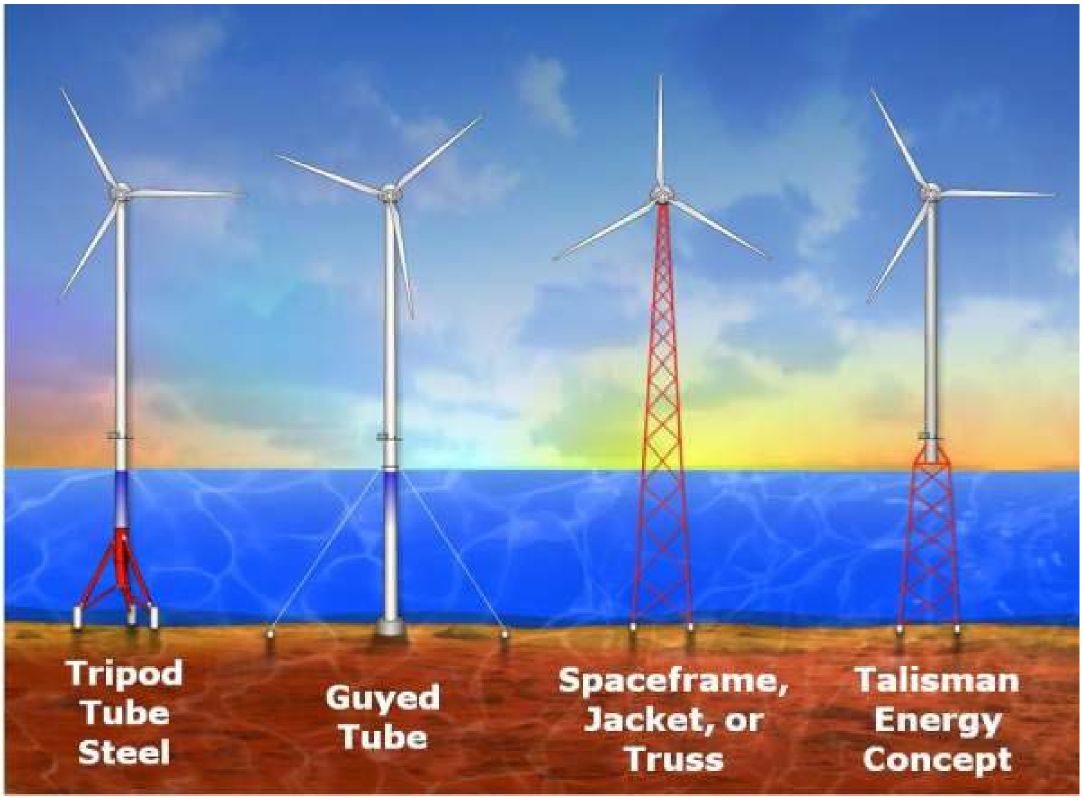

Figure 5-6. Transitional substructure technology

Not all of the concepts shown in Figure 5-6 have been developed yet, but the figure shows some possibilities. The tripod shown on the left and the Talisman energy project concept are discussed later in this report. The guyed steel tube concept provides a wider base in deeper water but has not yet been deployed in the field. The full height jacket or spaceframe design (third from the left) is a variation of designs that have been tried on land but were eliminated because they cost more and tended to attract birds.

Transitional-depth technology is an important step in the development of offshore wind. Resource assessments at 90-m elevation for the United States show that the transitional-depth wind energy resource exceeds 552.9 GW for 8.0 m/s or greater (see Section 4). In general, one advantage of this resource area is its location farther from shore where visual impacts are lessened. In many cases, the wind farms would be entirely beyond the horizon. Another advantage is that breaking waves are not as likely to occur at transitional water depths as they are in some shallow-water sites, significantly reducing extreme wave loading.

Talisman Energy deployed the first offshore wind turbines with a transitional substructure in a demonstration project of two 5-MW wind turbines at 45-m depths in the North Sea (MacAskill 2005). Figure 5-7 shows the load-out and lattice type substructure—known more commonly as a “jacket” substructure—for the Talisman wind turbine project.

Figure 5-7. Repower 5-MW turbine installed on jacket substructure (left, Talisman Energy, NREL/PIX 17883) and load-out to Beatrice Field (right, Talisman Energy, NREL/PIX 17884)

The Alpha Ventus project in Germany, which was completed in November 2009, also uses a transitional substructure. Although the water depths are just above 30 m, the project comprises six 5-MW Repower turbines on jackets and six 5-MW Multibrid turbines on tripods, and is the largest project installed in transitional depths so far. In the United States, Deepwater Wind has adopted this four-pile jacket design and has proposed a long-term marketing strategy that focuses on transitional technology. Deepwater Wind is now in the process of planning its first project sites in Rhode Island, New Jersey, and New York (Deepwater Wind 2010).

Figure 5-8 shows actual examples of transitional technology multi-pile foundation types. On the left is the Bard substructure concept (BARD GmbH 2010), which uses three vertical piles and a transition piece to a tube tower. This is still in the demonstration phase of development. The photo on the right in Figure 5-8 shows the jacket substructure with a transition to a tube tower. This concept was first deployed on the Talisman project using a Repower 5-MW turbine and has been replicated at the Alpha Ventus project on six units.

Figure 5-8. Transitional substructure technology under development: BARD 1 foundation structures awaiting loadout with 5-MW AREVA and REpower test turbines in background (Gary Norton, DOE NREL/PIX 17889); submerged four-pile jacket with transition to tube tower on Talisman Energy project with Repower 5-MW turbine (right, Talisman Energy, NREL/PIX 17885) (MacAskill 2005)

5.3.3 Floating Wind Turbine Technology

At deeper water sites, it might be more economical to use floating substructures, but the technology is at a nascent stage of development. The development of floating wind technology will dictate a new set of wind turbine design specifications to handle the coupled hydrodynamic/aerodynamic forcing, as well as the added weight and buoyancy stability requirements. These new requirements will initially add a higher degree of technical risk but with a potentially high payoff in the long term. The major incentives to develop floating systems include the following:

- Potential for reducing costs through system design site independence and greater opportunities for mass production
- Greater potential for full-system assembly at quayside and reduced load-out cost
- Higher wind speeds and energy capture over deeper waters
- Reduced impacts on human activities and environmental ecosystems
- Tripling the U.S. resource potential past 60 m in depth.

In this study, the total deep water wind energy resource potential for the United States at a 90-m elevation was calculated to be 1,978 GW for annual average wind speeds greater than 8 m/s and inside 50 nm from shore (see Section 4). This represents about two-thirds of the total offshore wind resource in the United States.

For floating systems, the benefits derived from turbine weight reduction will increase and could spur a new class of novel, lightweight wind turbine technologies that might be economical only in the context of floating substructures. The marine industry has demonstrated that a large portion of the buoyancy structure is needed to support the mass above the waterline. In the case of wind energy, this is the tower and rotor-nacelle assembly. Further studies are needed to quantify the benefit of pursuing lighter weight wind turbine subsystems on integrated floating platform architectures that could support such turbines (Butterfield et al. 2007). Some examples of novel concepts that have been previously rejected for land-based and fixed-bottom offshore substructures for economic reasons include lightweight composite towers, concrete aggregates that weigh 30% less than standard mixtures but can deliver the same strength (Holm and Ries 2006); multi-rotor concepts (Heronemus and Stoddard 2003; Jamieson 2003); high tip-speed rotors, downwind rotors, two-bladed designs, superconducting generators, and vertical axis rotors (Vita et al 2009). Cost-saving opportunities with the mooring and anchor systems could also be significant (Liu 2004; Ruinen 2004).

As a caution to manage expectations, note that revolutionary innovations often promise lower costs and optimized system performance, but the benefits may take longer to realize if the concept is a significant departure from conventional practice.

In June 2009, Statoil Hywind teamed with Siemens Wind Energy to install the world's first full-scale floating wind turbine (Statoil 2009). Statoil will test the 2.3-MW Siemens wind turbine over a 2-year period. The project is a demonstration of the Hywind concept, which uses a ballasted spar type substructure. Statoil is investing around 400 million Norwegian krones (NOK) in the construction, testing, and R&D related to this wind turbine concept. This cost, which translates to approximately US$70 million 2009$, appears to make this technology look unreasonably expensive, but this project is the first of its kind and most of the costs are one-time investments associated with R&D and infrastructure to design the system, deploy it at sea, and monitor its behavior. Future cost projections by Statoil suggest that the mature commercial costs can be competitive with fixed-bottom offshore wind. Figure 5-9 shows two photos of the Hywind turbine project as it appeared during load-out and after installation.

Figure 5-9. First operating deepwater floating wind turbine: Statoil Hywind 2.3-MW prototype during load-out (left) and installed on station (right) (Photos courtesy of Statoil)

Many of the issues governing the current knowledge about floating platforms for wind turbines can be described in terms of platform stability and system dynamics because it is logical that successful turbine platform systems will minimize the external loading introduced by the two equally important, simultaneously acting spectrums resulting from wind and waves, respectively.

This design space is a considerable departure from standard oil and gas platform designs, which are driven primarily by wave loading and static vertical payload capacity. Many of the same issues that govern oil and gas platforms will also influence the design of wind platforms, but the importance of each variable will be weighted differently.

A vast number of permutations of offshore wind turbine platform configurations are possible, considering the variety of available anchors, moorings, floater geometry, and ballast options. To help simplify the design process, the National Renewable Energy Laboratory (NREL) has developed a framework for generically plotting the design space for most floating platform designs. The method is referred to as the “stability triangle,” which classifies floating wind turbine platforms according to their method of achieving static stability (see Figure 5-10).

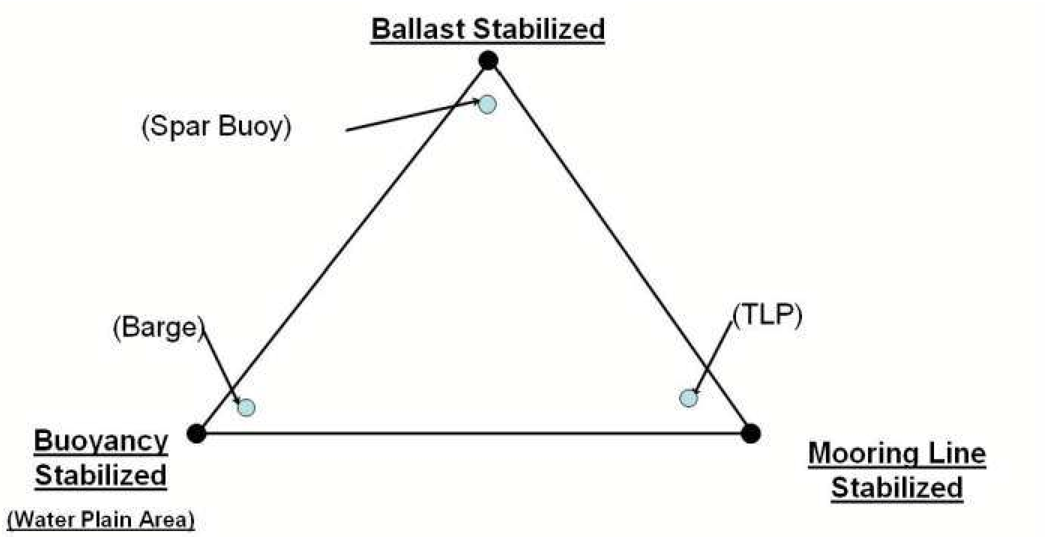

Figure 5-10. Stability triangle for classifying floating substructures according to method of achieving static stability

Three idealized structures were defined to plot the design space that corresponds to three methods for achieving static stability (Butterfield et al. 2007):

1. Buoyancy at the water plane (ideal barges)
2. Ballast (spars)
3. Mooring line tension (tension-leg platforms).

The optimum platform will probably be a balance between a platform that can deliver dynamic behavior to minimize loads and deflections while also minimizing the complexities of installation, load-out, logistics, maintenance, and overall work at sea. Some of the variables to be considered are identified in the following list (Butterfield et al. 2007):

- Additional control requirements to limit motion
- Buoyancy tank cost and complexity
- Tank material and fabrication options
- Manufacturing automation and assembly options for mass production
- Mooring system cost and deployment complexity

- Load-out cost and complexity
- On-site installation requirements
- Decommissioning cost
- Maintainability and personnel access
- Corrosion resistance and exposure
- Degree of water depth independence
- Sensitivity to bottom conditions
- Required footprint (varies as a function of depth and mooring strategy)
- System weight and weight distribution (especially above the waterline)
- Degree of induced tower-top motions
- Wave loading and exposure at the waterline
- Allowable heel angle.

Figure 5-11 shows some examples of floating offshore platform architectures that are being considered.

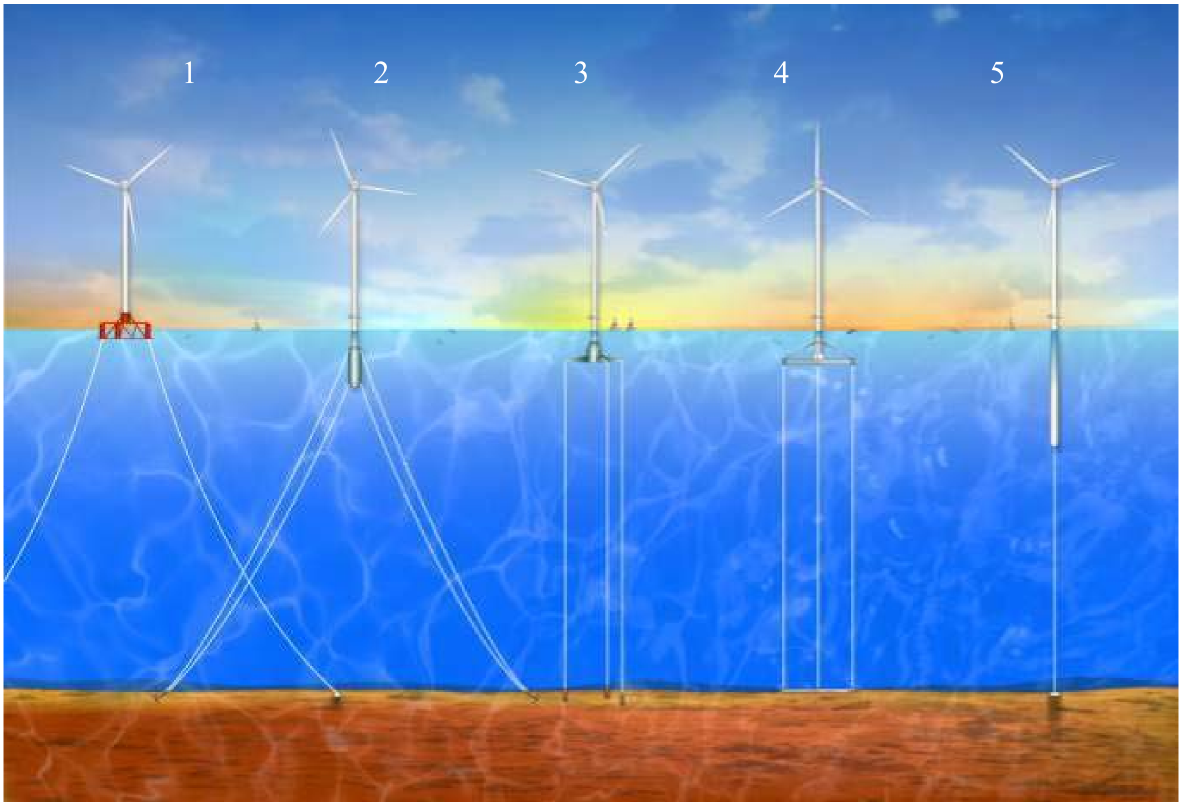

Figure 5-11. Floating deepwater platform concepts: (1) semisubmersible Dutch tri-floater (Bulder et al. 2002); (2) spar buoy with two tiers of guy wires (Lee 2005); (3) three-arm mono-hull tension-leg platform (TLP) by Glosten Associates (2010); (4) concrete TLP with gravity anchor (Fulton, Malcolm, and Moroz 2006); (5) deepwater spar (Sway 2010)

Most of the concepts shown in Figure 5-11 have not yet been demonstrated. The Dutch tri-floater concept (1) was developed in a design study in the Netherlands and uses buoyancy to achieve static stability, although mooring lines and heave plates add significant pitch and roll damping for dynamic motion control. The spar shown in (2) was analyzed under an independent study at the Massachusetts Institute of Technology (MIT) and features a two-tiered guy-wire system using both mooring lines and ballast. The concept in (3) features a conventional TLP design with a single center buoyancy tank stabilized by mooring lines similar to the concept proposed by Glosten Associates (2010). Studies at NREL indicate that TLPs can be very stable but the expensive vertical load anchors used by the oil and gas industry may limit their cost-effectiveness. Alternative TLP concepts like the one shown in (4) may reduce the cost of these expensive vertical load anchors. Fulton and colleagues (2006) performed this analysis under a U.S. Department of Energy (DOE) study in 2005. The classical deep-draft spar buoy, much like the Hywind concept described earlier, is shown in (5). This concept was developed by another Norwegian company, SWAY, which is partially owned by Statoil.

Floating platforms, mooring line systems, and anchor installation and deployment are all significant cost drivers. A new generation of drag embedment-type anchors or vertical-load anchors (VLA) should be developed to lower installation and deployment costs (Liu 2004; Ruinen 2004). Deployable gravity anchors show promise for all platform types because they can be manufactured from low-cost materials and can be incorporated into simple float-out installation systems. Concept Marine Associates analyzed a gravity-anchor concept for a TLP using concrete buoyancy tanks and deployable anchors (Fulton, Malcolm, and Moroz 2006). Because offshore wind farms could consist of hundreds of turbines, developers can take advantage of economies of scale to streamline repetitive installation procedures and look for innovative tooling that cannot be justified in single-unit installations such as offshore oil rigs.

All floating designs should be fully evaluated in terms of the key variables that will determine survivability under extreme conditions, fatigue loading, and life-cycle costs. This comparison would allow the key issues that limit each platform type to be identified, guiding future study in this area. A floating substructure must have enough buoyancy to support the weight of the turbine and to restrain pitch, roll, and heave motions within acceptable limits. Although these limits have not yet been fully established, modeling results to date indicate that turbine loads and tower-top motions will probably be higher than those of conventional fixed-bottom turbines because of system-wide interactions. As one example, coupled turbine/platform dynamics add inertial loading, requiring turbines that are more dynamically tolerant.

Floating wind turbines in deeper water would be naturally located farther from shore with increased technical risk and development that would tend to drive costs upward, so the cost-competitiveness of floating systems depends on other factors. Floating wind systems enable major departures from fixed-bottom systems in their ability to partially decouple from the seabed. This offers a new degree of site independence that fixed foundations do not have, along with the ability to mass produce the platform and automate the system assembly at quayside. Fabrication facilities could be strategically located near harbor facilities for mass production, onshore assembly, and rapid deployment with minimal dependence on large vessels and land-based transportation. Offshore floating systems could be loaded out fully assembled and installed with a reduced burden for large vessels and time spent at sea, which could significantly reduce project costs. Turbine/platform systems and offshore infrastructure could be designed to take advantage of this strategy. These new strategies could be integrated into the turbine design process at an early stage (Fulton, Malcolm, and Moroz 2006; Hansen 2005; Lindvig 2005; Poulsen and Skjærbæk 2005).

The development of floating wind turbines comprises multiple technology challenges that will require more time, rigorous engineering discipline, broader skill sets, and more complex infrastructure. As such, the commercial development of this technology will take longer than shallow-water and transitional-water technology, but with the benefits of mass production and site independence, could open up a large new resource area at costs similar to those of shallow-water offshore wind.

5.3.4 Dynamic Computer Simulation Modeling

Researchers have used an integrated hydrodynamic/aerodynamic approach to understand the system loads and design requirements to develop offshore wind energy system concepts, especially floating systems. Following such an approach is strongly recommended before hardware is constructed (Jonkman 2009; Nichols et al. 2009; Jonkman 2007; Jonkman and Buhl 2007; Jonkman et al. 2007; Passen et al. 2007; Jonkman and Sclavounos 2006; Nielsen, Hanson, and Skaare 2006; Tarp-Johansen 2005). Creating computer codes capable of accurately predicting the dynamic forces and motions acting on offshore turbines is considered essential before floating turbines can be reliably evaluated, designed, and tested at sea. To a lesser degree of complexity, the same challenge exists for fixed offshore wind structures, which are also subjected to significant wave loading. These design codes need to address not just structural design, but also controls to enhance stability, energy production, and certification verification issues. The work to develop these codes is underway, but they are not complete and have not yet been verified to deliver results with the necessary accuracy. Land-based wind experience indicates that validating the codes will require substantial measured field data from demonstration projects such as the ongoing DOE-funded project at the University of Maine (Dagher 2010a; 2010b).

The complexity of the task to develop accurate offshore modeling tools increases with the degree of flexibility, movement, and coupling of the turbine and substructure system. Structural analysis must also account for the dynamic coupling between the translational (i.e., surge, sway, and heave) and rotational (i.e., roll, pitch, and yaw) platform motions and turbine motions, as well as the dynamic characterization of mooring lines. NREL is conducting some of this work and the European wind industry is performing other parts of the work in collaboration with the International Energy Agency (IEA; see Jonkman and Musial 2010). Usually, greater substructure flexibility results in greater responses and motions to wave and wind loading. As a result, predicting wave loads and dynamics for turbines on monopiles is less difficult than for turbines on floating platforms. A primary challenge for floating systems is to predict loads and resulting dynamic responses of the coupled wind turbine and support structure when subjected to combined stochastic wave and wind loading. The existing codes are becoming mature with respect to wind load modeling. In the new coupled models, though, a broad complement of hydrodynamic effects must be incorporated, including a representative combination of wave-loading models in regular and irregular waves for the design envelope defined in the stability triangle. These results will yield better insights about optimization. Time-domain wave-loading theories, including free-surface memory effects, should be used to relate simulated ambient wave-elevation records to loads on the platform.

5.3.5 Grid and Electrical Distribution Systems

The rate of offshore wind deployment in the United States could be paced, as it is on land, by the available grid infrastructure. With 54 GW of new wind capacity expected according to the DOE

20% report (DOE 2008), the availability of suitable transmission injection points for offshore wind is one of the factors that might limit the nation's ability to meet the target set in the study. Comprehensive grid integration analysis should be conducted to identify weaknesses in the current grid infrastructure and opportunities for future expansion that facilitates the growth of the offshore industry. DOE has begun conducting some of these studies, including the *Eastern Wind Integration and Transmission Study,* which was published in January 2010 (EnerNex Corporation 2010). Other studies have focused on regional offshore solutions to the problems states would face in bringing offshore wind onto the main grid system. Several concepts are being explored, such as constructing a large-capacity offshore transmission backbone that multiple offshore projects could share. This would eliminate the need to bring the power from each project to shore individually (Tierney, Okie, and Carpenter 2010; Ackermann et al. 2005; Tambke et al. 2005).

The offshore grid will have unique characteristics that warrant more in-depth studies and modeling, including grid-fault and stability analysis. As wind farms grow in size and move farther from shore, the behavior and modeling of offshore electrical transmission systems should be analyzed with respect to grid-system reliability, grid losses, and grid-architecture options (Tambke et al. 2005). Offshore wind meteorology and its impact on power fluctuations and wind forecasting will also be critical (Kempton et al. 2010). Offshore winds may correlate differently with load than typical land-based sites, but more information is needed to quantify these effects over multiple regions (Barthelmie et al. 2005a; Sørensen et al. 2005). New grid code and security standards should also be established. Control and communication systems for large offshore farms will also be needed for aggregating the behavior of hundreds of large turbines onto the grid under transient or high-penetration scenarios (Barthelmie et al. 2005b).

5.3.6 Arrays and Array Effects

If offshore wind capacity expansion follows the scenarios predicted by the Regional Energy Deployment System (ReEDS; formerly known as the Wind Deployment System or WinDS; see Section 6), dozens of large arrays spanning large areas will be required. The offshore wind regime introduces a unique set of atmospheric and turbine-to-turbine interactions that developers will have to take into account. The configuration and spacing of wind turbines within an array has a marked effect on power production from the aggregate wind plant, as well as for each turbine. Consequently, these uncertainties in power production could create a large economic risk factor for offshore development. Computer codes are needed to model regional project development to monitor and predict the impacts of future fleet expansion and to help ensure that thousands of offshore wind turbines are introduced in an orderly way, which minimizes conflict on the Outer Continental Shelf (OCS) and maximizes the benefits to the public.

Experience has established that the performance of turbines operating within an array is negatively affected because adjacent turbines reduce the kinetic energy in the flow and generate additional turbulence that is difficult to predict. Empirical data show that computer models attempting to predict turbine array performance are inadequate in representing individual turbine output. Some codes have been successful in predicting aggregate array performance for rectangular arrays (Jensen and Høgedal 2005). These codes, however, cannot be relied on for detailed array layouts, nor do they capture the turbine-specific physical conditions that relate to specific energy production and reliability. Array losses of more than 10% for offshore wind farms have been documented, but improvements in array layout and optimization models could enable more efficient array designs that could reduce these losses and make better use of the available submerged land.

Offshore wind array performance is very sensitive to the stability of the atmospheric boundary layer, which influences the degree of mixing in the wind. The stability tends to vary significantly at a given site as well as by region. This characteristic determines the degree of stratification as the wind moves over the water and the amount of mixing among the horizontal layers because of thermal density differences. A stable, stratified boundary layer is less able to dissipate mechanically generated turbulence created by upstream turbines and cannot regenerate the kinetic energy in the wind as fast as an unstable boundary layer that is naturally mixing with the outer, more energetic layers. This mixing is necessary to regenerate the kinetic energy of the inflow for downstream turbines. Current array models represent these stability effects poorly. In addition, they lack the ability to accurately predict the impact of turbulence inside the wind plant, which increases greatly when stable boundary layers are present. Accurately characterizing the behavior of the atmospheric boundary layer, and developing more accurate wake models, will be essential for designing turbines that can withstand offshore wind plant turbulence (Mróz, Holnicki-Szulc, and Kärnä 2008; Noppenau 2005). Because turbulence causes wear and tear on the turbines, maximizing turbine reliability will require careful characterization of the degree of turbine-generated turbulence under a wide range of conditions. This can be done by developing tools to optimize the layout of an array to balance low turbulence with high energy production. The degree to which stable boundary layer conditions occur could be studied using climate models and empirical data taken in situ.

Offshore, the impact of one wind plant on another is likely to be a larger problem than for land-based systems because the open ocean contains continuous tracks of unobstructed windy territory. Wind plants introduce downstream turbulence that regenerates over some distance depending on the atmospheric stability and other variables, but analytical models to predict optimum spacing between arrays are immature. Nevertheless, wind plants installed upstream must be assessed in terms of their effect on downstream wind plants and the resulting impacts on energy capture and structural loads. Understanding and managing “wind rights” and setback requirements could require accurate flow models, new satellite measurement techniques, broader satellite data domains, and better weather prediction tools and methods (Gravesen et al. 2005). In Europe, some researchers have begun using satellite images to determine the extent of the wake behind operating offshore wind plants. Understanding this issue in the near term may prove essential because minimum spacing requirements could limit the total extractable resource potential.

5.3.7 Regional Issues

Several potentially significant regional barriers to the development of offshore wind may limit its deployment in the United States. They include floating ice, water depth (already covered), and hurricanes.

5.3.7.1 Ice Load Resistance

Additional offshore foundation loads arise from the impact of floating debris and ice. In the United States, this is most likely to be an issue in the freshwater of the Great Lakes but could present a problem in other specific areas (e.g., northern latitudes). Turbines designed for and placed in the Baltic Sea have already managed ice issues successfully but salt content there may decrease the impact. The issue of ice loading requires more in-depth study, which could be done in collaboration with cold-climate countries—such as Canada and Sweden—that are pursuing offshore wind (Online Lawyer Source 2010; AWEA 2009).

5.3.7.2 Hurricane Resiliency

In some cases and in certain locations in the United States, the current generation of wind turbines that are type-certified to the IEC 61400-03 code for offshore turbines may not be able to withstand the extreme loading caused by hurricanes (IEC 2005). Although the IEC standards require the designer to determine the extreme loads imposed by hurricane conditions and design the appropriate strength into the structure, most wind turbines are designed and type-certified long before the site location is known. In many locations in U. S. waters, the extreme wind conditions will exceed the IEC Class 1 specifications—the most stringent class—which assumes gusts no greater than 70 m/s. In many sites, the 50-year storms will be category 4 and 5 hurricanes that can have gusts greater than 80 m/s. Even though it is possible to develop structurally adequate designs using the existing standards, the process may require a more integrated design approach in cooperation with the turbine manufacturers or a Class S turbine (hurricane resilient) that exceeds the Class 1 requirements. It is possible to implement turbine design modifications for existing turbine designs that would resist or reduce the extreme loads resulting from these conditions. Such modifications could involve changes to blades and towers. Some of these changes may require compromises that might diminish the energy capture potential for a wind turbine installed at those sites to ensure survivability. For example, although the extreme winds are higher, hurricane sites have typically lower annual average wind speeds that would normally warrant a larger rotor. At hurricane sites, larger rotors may be prohibitive due to requirements for resisting extreme hurricane gusts. This may dictate a new design strategy. Work on the next edition of 61400-3 is scheduled to begin in 2010 and will incorporate explicit guidance for hurricanes (IEC 2010).

Understanding of extreme loads on wind turbines generated by hurricanes is important for reducing the uncertainty about survivability of the primary structure. The methodology for determining the probability of a hurricane at a particular site and the magnitude of its winds is not fully established. Some methods do exist but further validation is needed (FPLPM 2010).

In shallow water, hurricane-generated breaking waves may also create an extreme load case that has not yet been properly evaluated, especially in the Atlantic (Dolan et al. 2009).

Hurricanes present unique external conditions that could require turbine design modifications. The turbine's protection system may need specific upgrades to withstand hurricane conditions. This could include not only extreme winds that could impose high instantaneous loads, but also sustained wind speeds, high wind/wave frequency, rapid direction changes, impulsive gust loading, breaking and slamming wave loads, and multidirectional wind/wave spectra.

5.3.8 Logistics and Infrastructure

Impeding the onset of the offshore wind industry in the United States are the one-time costs associated with establishing the necessary infrastructure, such as upgrades to ports, harbors, manufacturing facilities, and vessels. Small projects will have a difficult time absorbing these costs and as mentioned earlier, these costs may not show up on the balance sheet but are necessary for project development.

According to the American Wind Energy Association (AWEA), not a single specialized vessel for constructing offshore wind energy projects has been built in the United States to date. U.S.-

built vessels currently serving the oil and gas industry are not available for offshore wind because they are in high demand in the oil and gas industry (TPI Composites 2003b). Even if they were available, they would need modifications to perform wind turbine installations. New special-use vessels are needed, as well as upgraded ports and harbors from which to build and deploy them. Strategies that are consistent with the Jones Act (see Section 3.6.4) should be developed (Snodin, Hassan, and Partners Ltd. 2004). A survey of other potential port facilities might be needed to look for regional synergies, taking into account the siting and resource needs for vessel work, manufacturing, and deployment.

Large-scale development of offshore wind farms would require a significant stream of resources (EWEA 2009; Tegen, Goldberg, and Milligan 2006, Ancona 2010). Unlike land-based installations, which are typically in remote areas far from production and assembly operations, offshore turbines and components could be constructed and assembled in or near seaport facilities. This could allow easier transportation from the production location to the installation site and eliminate the need to ship large components over inland roadways (GWEC 2008). Under the 20% wind scenario (DOE 2008), assuming that reasonable cost reductions can be realized over the next 20 years, the offshore wind industry may invest more than $150 billion in constructing offshore projects. Offshore wind production facilities could deliver economic benefits to local communities by creating high-paying industrial jobs in regions aiming to expand the manufacturing sector. This was discussed in the SeaWind Europe Report and the EWEA report *Wind at Work: Wind Energy and Job Creation in the EU,* and similar outcomes for job creation could apply in the U.S. economy (Garrad Hassan 2004, EWEA 2009). Port staging areas could be upgraded to handle the logistics of the turbine assembly, substructure assembly, and load-out, allowing work at sea to be minimized.

5.3.9 Research Facilities for Field Testing

Offshore turbines will also require significant new test facilities and upgrades to accommodate larger component sizes and higher reliability requirements. In 2009, DOE directed $25 million in funding to support the Massachusetts Clean Energy Center (MASSCEC) in a partnership with NREL to build a large-blade testing facility capable of testing blades up to 80 m (Cotrell, Musial, and Hughes 2006). In addition, DOE awarded $45 million in matching funds to a South Carolina consortium that will develop a new large-scale drivetrain test facility for wind turbines up to 10 MW in size (Hull 2010).

These same needs exist for open-ocean test facilities. Shallow-water testing will be essential to verify standards, validate design tools, and test design assumptions. The first phase of offshore wind deployments could be used to establish offshore design requirements and to verify design assumptions through measurements made on actual wind turbines at sea (Palo 2003). It might be necessary to conduct multiple tests or deploy several test beds to examine technology at various depths and external conditions. These types of projects could validate the fundamental baseline turbine and foundation technology assumptions, allow the actual meteorological ocean environment to be measured, and verify assumptions relating to permitting and potential environmental impacts. The field data output could yield critical design methods and codes; uniform standards for structural reliability; design specification guidelines; industry-accepted safety margins; and valuable data to validate design models, codes, and assumptions (Sclavounos 2004). As transitional and deepwater technologies are deployed and tested, more specialized testing facilities may be warranted. In 2009, the University of Maine was awarded more than $12 million in DOE grants to begin developing a deepwater wind energy test facility (University of Maine 2010), and in June 2010, voters approved a bond for $11 million of additional funding.

5.3.10 Certification and Standards

The Bureau of Ocean Energy Management Regulation and Enforcement (BOEM; formerly the Mineral Management Service [MMS]) has been authorized to define the structural safety standards for offshore wind turbines on the OCS (see Section 7) (IEC 2010; MMS 2009). Technical research, analysis, and testing are needed to build confidence that safety is adequate and to prevent an excess of caution resulting from a lack of information. This will require a complete review of the existing offshore wind standards as well as the applicable offshore oil and gas standards (e.g., American Petroleum Institute [API]). A joint industry project, partially funded by DOE and BOEM, revealed that, as written, the existing IEC and API standards will deliver comparable levels of safety. Nevertheless, BOEM has not yet adopted any standards for use in the United States for wind turbines on the OCS (Dolan et al. 2009). The AWEA Standards Coordinating Committee has formed an expert industry-based working group that is tasked with developing a roadmap or guide that identifies the appropriate existing standards to use in the design, fabrication, installation, testing, operation, and inspection of offshore wind projects. Developers, turbine designers, manufacturers, regulators, and certification verification agents, among others, may use this guide. This joint project, supported by DOE and AWEA, is underway. Further development is also continuing to make sure that the existing IEC TC-88 61400-03 standard for offshore wind is maintained and upgraded to account for innovations in the industry (IEC 2005). These innovations will include deepwater floating platforms, new offshore load cases, turbines larger than 5 MW, and hurricane survival criteria.

5.3.11 Metocean Characterization

The metocean characteristics at offshore sites, which include a range of wind, ocean waves, water current, and ice floe conditions, as well as their various combinations, are much more difficult to assess than the winds over land.

Manwell and colleagues (2007) discuss external design conditions related to offshore wind and the topic is also covered in IEC 61400-03 where the external conditions and load cases are defined for wind turbines. One of the primary challenges is to assess and evaluate the statistical nature of wind and wave combinations as they affect the turbine substructures under a wide range of design conditions. The evaluation of extreme events that are determined through statistical analysis comprising the probabilistic occurrence of the 50-year extreme wind/wave conditions is the subject of substantial research. Assessments of fatigue conditions are also extremely important and can have a hand in driving the design. Directionality of waves and wind and their combinations may influence the assessment significantly. Experimental validation is required to verify design load assumptions and to assess stochastic turbine responses over a wider range of metocean conditions where the analysis might miss significant load cases. The response of the system is highly dependent on the type of substructure, the water depth, and the characteristics of the waves. Breaking waves can impart loads that have more than twice the magnitude of regular more sinusoidal wave structures, and can be a unique design driver that has not yet been fully validated (Dolan et al. 2009). The research done so far indicates that the impact of breaking waves can be much more severe on a monopile substructure than on a jacket-type substructure because of the monopile's larger profile. This impact has not yet been fully explored but may have significant economic consequences at some sites.

Ice loading will be a factor in the Great Lakes where freshwater ice loading must be taken into account during the design. Ice loading can result in significant horizontal loading to the substructure during ice floes and through expansion cycles. Ice floes can also cause harmonic excitations to the tower base under certain conditions and ice fracture modes that can in turn result in possible resonance conditions that need to be assessed. Ice can also build up around the base at the water surface and change the dynamic characteristics of the turbine system by effectively stiffening the structure. This condition also needs thorough evaluation. Most field work on ice loading has been conducted in the Baltic Sea and in the Great Lakes on bridge structures. Freshwater test facilities are needed to explore ice loading on wind turbine substructures in the Great Lakes.

5.4 Synergies with Other Offshore Industries

The development of offshore wind technology in the United States could take advantage of vast experience already obtained in both the oil and gas industry and the European wind energy industry. The oil and gas experience dates back over 50 years when the first oil wells were drilled in shallow water offshore. In Europe, more than 2 GW of offshore wind has already been installed with a track record approaching 20 years. These existing industries can be valuable alliances in the development of offshore wind in the United States, using experts already trained in the various offshore fields (see Figure 5-12).

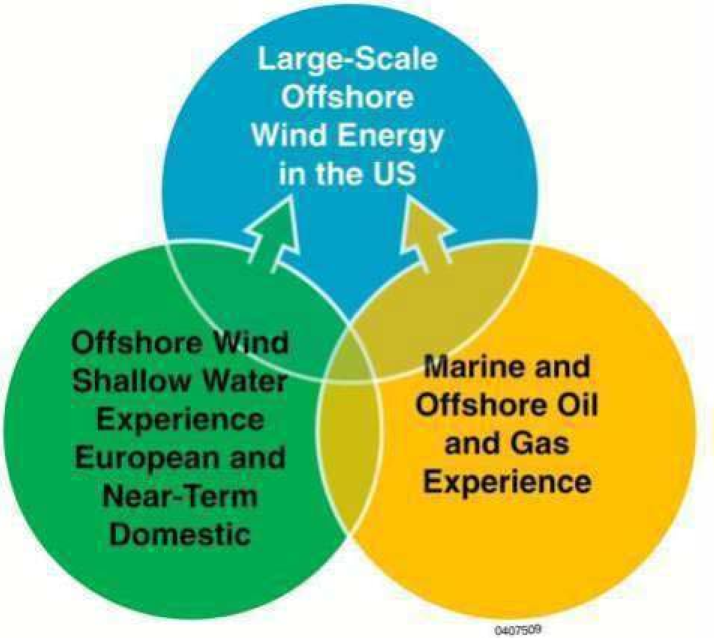

Figure 5-12. Expertise and experience for offshore wind development

Many of the technologies for offshore wind development have already been proven in the oil and gas industry. Applying this experience to offshore wind, however, will require technology innovations and new methods for manufacturing, logistics, and maintenance that will be critical to lowering costs and expanding the resource areas where offshore wind is viable.

The increased complexity of offshore construction, operation, and maintenance relative to land-based wind will require adaptations of technologies, methods, and experience derived from the marine and offshore oil and gas industry. The portion of the offshore turbine system below the waterline will largely be designed and implemented using experience developed over the past 4 decades by the oil and gas industry but with several modifications to adapt to the offshore wind situation. Primarily, the installation of an offshore wind farm is a mass production event that requires repetitive steps not common to oil and gas. Most oil platforms, for example, are single-unit installations. The installation of a wind farm is a continuous operation that takes place over several months rather than several days.

The design and installation of the electrical grid system, from placing interturbine cabling to running the cable to shore, will be performed by the existing submarine cable industry. Offshore wind projects will employ the established offshore industry to perform site assessments and geotechnical engineering. Turbines could be installed and maintained using existing, modified, or new offshore vessels and equipment, with designs based on the established practices of the offshore industry. Personnel access and service for turbines will use experienced offshore labor or new labor forces trained by the established marine industry. In the United States, where land-based wind development has been largely unregulated, offshore turbines will have to undergo extensive structural evaluation and certification with a BOEM approval process (MMS 2009). This transfer of knowledge between offshore wind and offshore oil is already well underway in Europe, where dozens of oil and gas and marine engineering and construction contractors are engaged in offshore wind energy. In addition, other technological advancements in computers, controls, materials, corrosion prevention, energy storage, and generation, among others, continue to increase the capabilities for offshore oil and gas development and will synergistically strengthen the technical viability of offshore wind. Ultimately the dependence of wind energy on offshore oil and gas experience will help to facilitate the transition from a fossil-based energy economy to a more sustainable energy economy based on renewable sources.

5.5 Findings and Conclusions

So far, offshore wind energy has used technology similar to land-based wind energy but the opportunities for offshore technology improvement are significantly different. For offshore wind technologies, a much higher fraction of the capital cost must go toward BOS and construction. In addition, there is a greater need for high reliability because the inherent lack of turbine access at sea makes O&M more difficult. Offshore wind turbines are generally larger because many of the land-based transportation and erection constraints can be avoided. They also rotate faster than land-based machines because there are fewer near-field noise issues. Offshore turbines need to be strengthened to accommodate waves and storms, weatherized to guard against corrosion and the sea environment, and designed to accommodate unique offshore personnel facilities. Consequently, offshore wind energy tends to cost more per unit of energy capacity than land-based wind energy. Also, one-time costs are associated with developing the infrastructure to support the offshore industry, including vessels for installation, ports and harbor upgrades, manufacturing facility construction, and workforce training program development.

The biggest design difference in offshore wind energy technology is in the substructure and foundation as it pertains to water depth. This presents a major barrier that could prevent the development of the largest resource areas located in waters with depths greater than 60 m, which in turn would prevent offshore wind energy from reaching its full potential as an energy supply.

Offshore wind turbine substructure designs are mainly based on water depth, soil conditions, and vessel constraints. The technology break points fall into three depth categories: shallow (30 m or less), transitional (>30 m to 60 m), and deep water (>60 m). In shallow water, the substructure extends to the sea floor and includes monopoles, gravity bases, and suction buckets. In the transitional depth, new fixed-bottom technologies are being created or adapted from oil and gas, including jacket substructures and multi-pile foundations. At some depth, it is no longer economically feasible to affix a rigid structure to the sea floor, and floating platforms may be justified.

Three idealized concepts have arisen for floating platform designs, including the semisubmersible, the spar-buoy, and the tension-leg platform. Each design uses a different method for achieving static stability. Although it is not yet known which configuration will deliver the optimum system performance, designers choose platforms that are easy to install and that minimize the increase in the overall turbine loads when compared to loads from a land-based reference turbine.

Shallow-water projects dominate the current market. Work on transitional technologies is just beginning and only two have been installed to date. Transitional foundations may cost more because greater depths usually mean higher costs for fixed-bottom systems. There is currently one floating deepwater demonstration project, the Hywind, which was launched in 2009. One of the key conclusions is that future floating deepwater technology may not necessarily cost more than fixed-bottom systems because full wind turbine/substructure systems can be mass produced and fully assembled on land, avoiding expensive ocean-based construction costs. More research is needed to verify this supposition for low-cost floating wind turbines. New technology will be needed to address low-cost, easily deployable mooring systems for floating wind systems. In addition, there is more wind and therefore more energy over the deeper waters. The development of this technology is more complex and higher risk, but has a potential for high payoff.

To minimize cost, new turbine designs must be optimized for the offshore environment. Some manufacturers are leaning toward designing larger offshore turbines, as evidenced by the current research being conducted on turbines in the 10-MW class. Improved efficiency may be obtained by employing new rotor and drivetrain designs, using new materials, developing better codes to analyze arrays and their effects, improving design standards, and gaining a better understanding of the external metocean conditions.

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6.0 Offshore Wind Economics

In the last 20 years, more than 2,000 MW of offshore wind capacity have been installed in Europe (EWEA 2010; Fichaux and Wilkes 2009). Several industry and academic publications cite actual capital costs and projected levelized costs of energy (LCOE) for these installations. These sources, which are generally based on the actual experiences of developers, are the best publically available information on project costs.

This section looks at offshore wind cost data in two ways: the capital cost to install the wind plant and the life-cycle cost, or LCOE. The LCOE is the cost of energy produced over the life of the project, generally considered to be 20 years. LCOE calculations are more uncertain than capital cost estimates because they include future projections of energy production, operational costs, decommissioning costs, and long-term reliability, in addition to the initial capital cost. This section begins by examining the observed capital cost trends of offshore wind projects and then discusses the levelized cost of offshore wind energy. Finally, it describes two capacity expansion scenarios that investigate plausible market conditions under which offshore wind could flourish in the U.S. energy market.

Numerous economic and technology-specific factors can affect the capital cost of offshore wind projects—fluctuations in exchange rates, commodity prices, credit availability, manufacturing capacity, labor costs, and risk premiums. These variables are liable to change drastically from year to year, which makes it difficult to accurately predict future project costs. Uncertainty increases when attempting to forecast U.S. project costs by extrapolating European data because the two markets differ substantially:

- The infrastructure or logistical support required for offshore wind projects is not yet developed in many areas of the United States.
- Policy and regulatory environments are distinctly different.
- Risk perceptions associated with initial offshore wind projects differ because of contrasting policies and market motivation.
- The U.S. metocean and physical environment is different because of water depth and tropical storms.

Some of these differences could mean higher initial costs for U.S. offshore wind projects, but these costs should come down as the U.S. market matures.

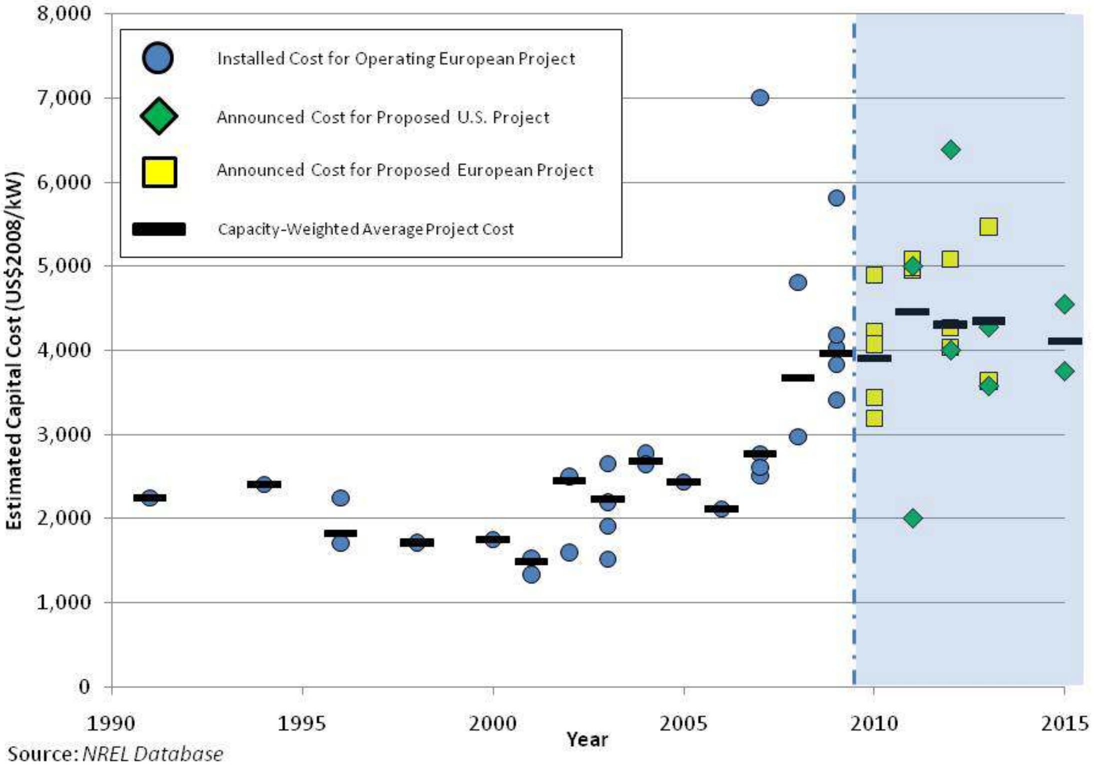
National Renewable Energy Laboratory (NREL) projections of U.S. offshore wind deployment scenarios show tremendous sensitivity to assumptions about the regulatory, policy, and market conditions. Scenarios examined under the 20% report (DOE 2008)—which are based on assumptions that reflect plausible conditions of the current U.S. economic and political environment—postulate substantial deployments of offshore wind in the United States in the coming years.

6.1 Offshore Wind Capital Cost

Offshore wind project cost cannot be fully evaluated by looking at the upfront capital investments, but because the industry is very new, life-cycle cost assessments are more uncertain. Therefore capital cost can provide a useful metric for evaluating the state of the industry.

6.1.1 Market Studies

Capital cost data for offshore projects are available for 2,263 MW of the total global installed offshore wind capacity of 2,387 MW (Alpha Ventus 2010; Offshore Wind Energy 2010a, 2010b, 2010c, 2010d, 2010e, 2010f, 2010g, 2010h, 2010i; PowerTechnology.com 2010a, 2010b; RWE npower renewables 2010; Vattenfall 2010; EWEA 2009; Ministry of Foreign Affairs of Denmark 2009; National Wind Watch 2009; reNews 2009; Snyder and Kaiser 2009). Data for proposed projects in the United States and Europe were gathered from news articles and developer web sites (AWS Truewind 2010; Garden State Offshore Energy 2010; reNews 2009; Sokolic 2008; Williams 2008; Geoghegan 2007). Usually the project developer reported the data, which could be not be verified independently. Estimates of reported capital cost were converted to 2008 dollars and then averaged to arrive at a normalized capital cost number for each project. Figure 6-1 shows capital cost per kilowatt for the wind farms where data are available.



Source: *NREL Database*

Figure 6-1. Offshore wind plant capital cost per kilowatt

Figure 6-1 shows that capital costs of offshore wind plants commissioned between 1991 and 2006 ranged between $1,300/kW and $2,800/kW (a capacity-weighted average of $2,273/kW). Beginning in 2007, installed project costs were considerably higher. Capital costs of projects commissioned between 2007 and 2009 ranged between $2,500/kW and $5,800/kW[13] (a capacity-weighted average of $3,544/kW). The 56% rise in capacity-weighted average project cost can be attributed to a number of factors:

- Fluctuations in exchange rates[14]
- Increased demand for turbines
- Increased supply-chain bottlenecks
- Higher profit margins for turbine original equipment manufacturers (OEMs) and wind project developers
- Increased knowledge of technical risks gained from developing and operating offshore wind projects (e.g., logistics, reliability)
- Increased complexity in siting, engineering, and building offshore wind projects (larger capacity, increasing depth, increasing distance from shore)
- Higher raw material and commodity prices.

Analysis of the estimated cost of proposed projects shows increasing variability, and based on projections from developers, this wide range of capital cost is expected to persist at least in the near term (projected future project costs range from $2,000/kW to $6,390/kW with a capacity-weighted average of $4,260/kW). Table 6-1 lists future project costs for several different subgroups.

Table 6-1. Estimation Methodologies for Future Offshore Wind Project Costs (US$2008)

Metric for Calculation of Future Offshore Wind Project Cost	Arithmetic Mean (US$/kW)	Capacity-Weighted Average (US$/kW)
Installed 2009 projects	4,252	3,964
Proposed 2010 projects	3,965	3,905
Proposed U.S. project 2010–2015	4,191	3,921
Proposed European projects 2010–2015	4,411	4,431
Proposed projects 2010–2015	4,327	4,259

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[13] The installed capital cost of $7,000/kW in 2007 represents the Talisman Energy demonstration project, which is installed in deeper waters than any commercial offshore wind project.

[14] The variability of currency exchange rates has the potential to obscure cost trends when projects that are denominated in English pounds or euros are compared to projects denominated in U.S. dollars. This possibility was investigated by plotting data that had been converted to 2008 euros using official European Union (EU) inflation data. This study found that the data exhibit the same basic trend of increasing capital costs with time, which confirms that this is a real trend and not simply an artifact of exchange rate fluctuations.

Table 6-1 gives a range of estimates of future offshore project capacity-weighted costs from $3,921/kW for near-term U.S. projects to $4,431/kW for near-term European projects. This range of estimates is consistent with the stated opinions of developers, who expect costs to stabilize or rise slightly from 2009 levels. Note that the cost projections of U.S. developers are about 13% lower than the cost projections of European developers for 2010 to 2015.

The capital costs of offshore wind can vary widely depending on technical aspects of the specific project. Figures 6-2 through 6-4 show the influence of water depth, distance from shore, and project size on the capital costs of offshore wind development thus far. Data from plants in operation are divided into two groups: plants brought online before 2007 and projects commissioned between 2007 and 2009. These data points are compared to data for proposed U.S. and European projects.

Figure 6-2 plots the average water depth of each project site against capital cost per kilowatt. Engineering and economic modeling suggests that fixed-bottom projects sited in deeper water should have higher costs because they require increasingly heavier and more complex foundations and specialized installation vessels. This expected trend is not readily apparent, however, in either the data for commissioned projects or those for proposed projects. Of the 50 installed and proposed projects in the data set, 48 are in shallow water (depths of 30 m or less) and the average depth is 12.9 m. The two projects installed in deeper water, Talisman Energy and Alpha Ventus, have significantly higher capital costs, but both are relatively small demonstration projects and may not adequately represent large-scale future projects.

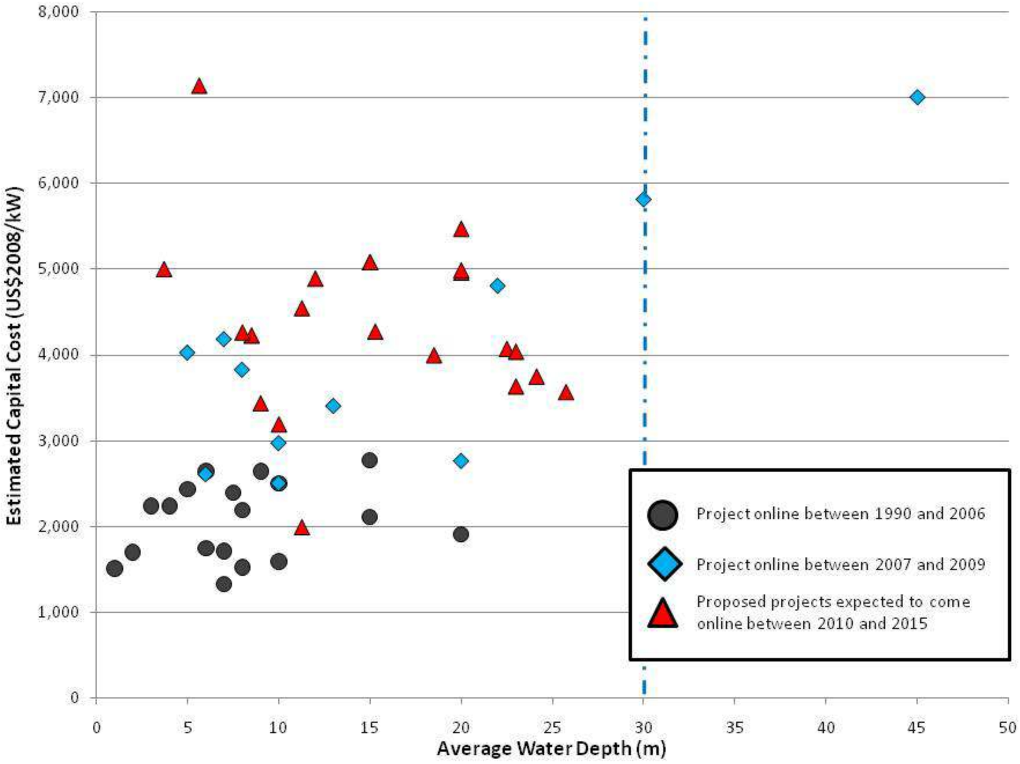

Figure 6-2. Effect of water depth on capital cost per kilowatt

Capital costs are also expected to increase when projects are sited farther from shore because of longer power cables and increasingly complex project logistics. Figure 6-3 shows distance from shore plotted against capital costs. The expected relationship between distance from shore and capital costs is not apparent for either installed projects or proposed projects. Of the 50 projects examined in this study, 49 are sited within 30 km of shore and the average distance is 13.5 km. Alpha Ventus is the only project sited outside this range, at 45 km from shore.

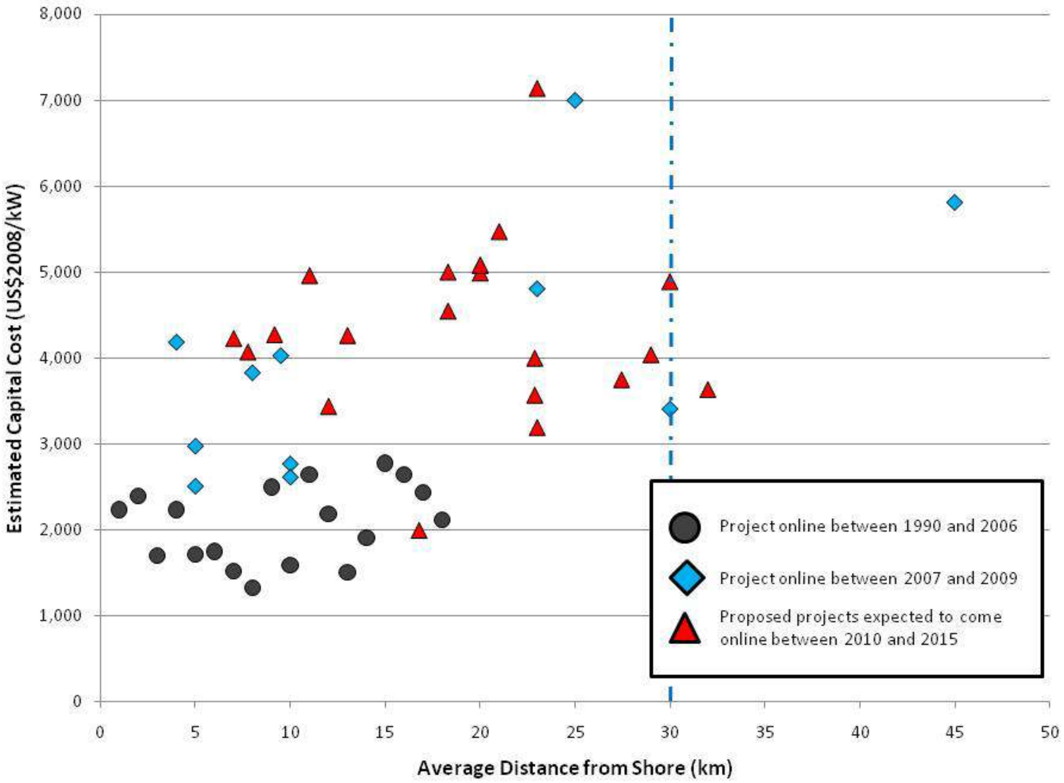

Figure 6-3. Effect of distance from shore on capital cost per kilowatt

Another factor that influences capital cost per installed kilowatt is the overall project size. It is generally expected that large offshore wind projects will benefit from economies of scale. Larger projects are expected to have lower capital costs per kilowatt because they can spread the fixed costs of project development (e.g., permitting, vessels, and grid connection) over a greater amount of total generating capacity. The data in Figure 6-4 demonstrate that project size does not yet show a clear effect on capital cost per kilowatt, but this could be caused by the lack of consistent data. If one looks at only the most recent project installations (2007 to 2009—blue diamond symbols), project size and cost appear to be correlated, but further analysis is needed.

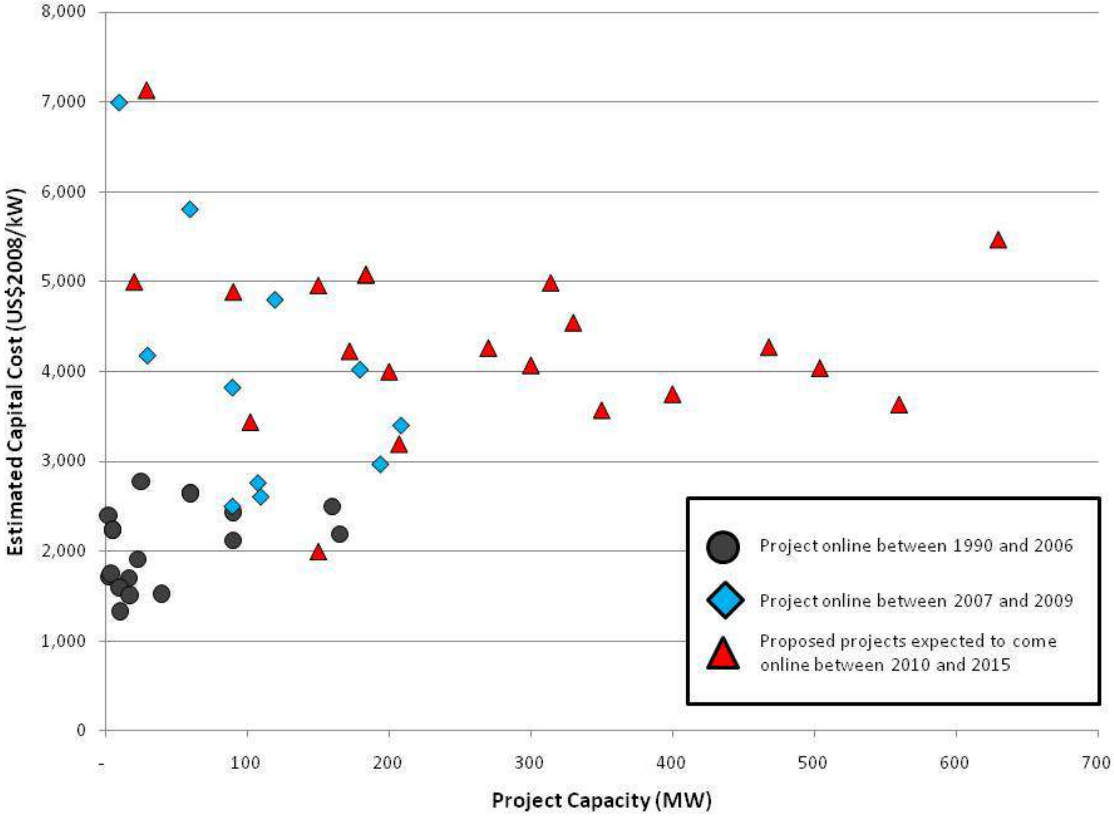

Figure 6-4. Effect of project size on capital cost per kilowatt

Projects in the data set range in size from 2 MW at the Lely Windpark in the Netherlands to 209 MW at the Horns Rev II project in Denmark (installed in 2009). The average size for installed projects is 69 MW. Projects scheduled to come online between 2010 and 2015 will be significantly larger than existing offshore projects. Proposed projects range from the 10-MW North Carolina Coastal Wind demonstration project[15] in the United States to the 630-MW London Array in the United Kingdom. The average capacity of the proposed projects in the data set is 267 MW.

Possible reasons why the offshore wind project cost data do not reveal some of the expected trends associated with depth, distance from shore, and size/scale are related to the relative immaturity of the industry and differing market and policy environments that project developers face. These reasons include the following:

- The few offshore wind projects built makes it difficult to extract statistically significant trends.

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[15] Duke Energy has not released an estimate of the North Carolina Coastal Wind demonstration project's capital cost. As a result, the project cannot be included in NREL's capital cost database, although these demonstration turbines could be among the first installed in U.S. coastal waters (Duke Energy 2010).

- The broad jump in project costs after 2006 appears to be market-related and overwhelms more subtle trends in recent and projected costs.
- Companies are still standardizing their approaches to project financing, transport, logistics, and installation.
- Project costs vary depending on the extent to which the electrical grid and the interconnection are considered part of the overall project. In countries like Germany and Denmark, the government-managed utility is responsible for the grid infrastructure out to and including the offshore substation—this is not the case for the United States or the United Kingdom (EWEA 2009).

6.1.2 Capital Cost Breakdown

A literature survey was conducted to determine the installed capital cost breakdown for a typical offshore wind project. Several studies estimated the breakdown of capital costs for offshore turbines installed in shallow water by component. Generally, the authors segmented capital costs into the categories described in Table 6-2. The operational categories (operation and maintenance [O&M] and other variable costs [OVC]) do not contribute to capital cost, but are used here in the subsequent discussion of LCOE.

Table 6-2. Descriptions of Cost Breakdown Categories

Cost Category	Description
Turbine	• Rotor and blades • Drivetrain nacelle • Tower • Control, safety system, condition monitoring • System marinization • Commissioning • Surety bond (to cover decommissioning) • Warranty (typically 5 years)
Electrical Infrastructure	Internal grid between turbines Export cables to shore Substation • Transformers • Grid connection/upgrades
Support Structure	Turbine base (e.g., monopile, gravity base) • Transition piece connecting base and tower • Personnel access infrastructure • Scour protection
Logistics and Installation	Note: Some reports separate logistics and installation costs from the costs of the turbine, electrical infrastructure, and the support structure. This category includes costs for one or more of the following: Port and staging equipment Component transportation Turbine Installation • Electrical infrastructure installation • Support structure installation
Project Development and Permitting	Project development Project engineering Environmental studies Permitting
Other Capital Costs	Miscellaneous capital costs not included in categories listed
O&M	Regularly scheduled maintenance

	Unscheduled maintenance Service and spare parts • Logistics and installation
OVC	Lease payments • Taxes Insurance premiums Transmission charges • Operational administration

Figure 6-5 shows the capital cost breakdown results (Blanco 2009; Duke Energy 2009; Ernst & Young 2009; Krohn, Morthorst, and Awerbuch 2009; Carbon Trust 2008; Fingerish, Hand, and Laxson 2006; Junginger and Faajj 2004; Morgan, Scott, and Snodin 2003; DUWind 2001). The estimates for the turbine's contribution to total capital cost range from 36% to 59%, with a mean of 44%. This is a lower percentage of the capital cost than for land-based turbines, where the turbine can comprise nearly 70% of total project costs (Blanco 2009). Some studies do not specifically treat logistics and installation as a separate category.

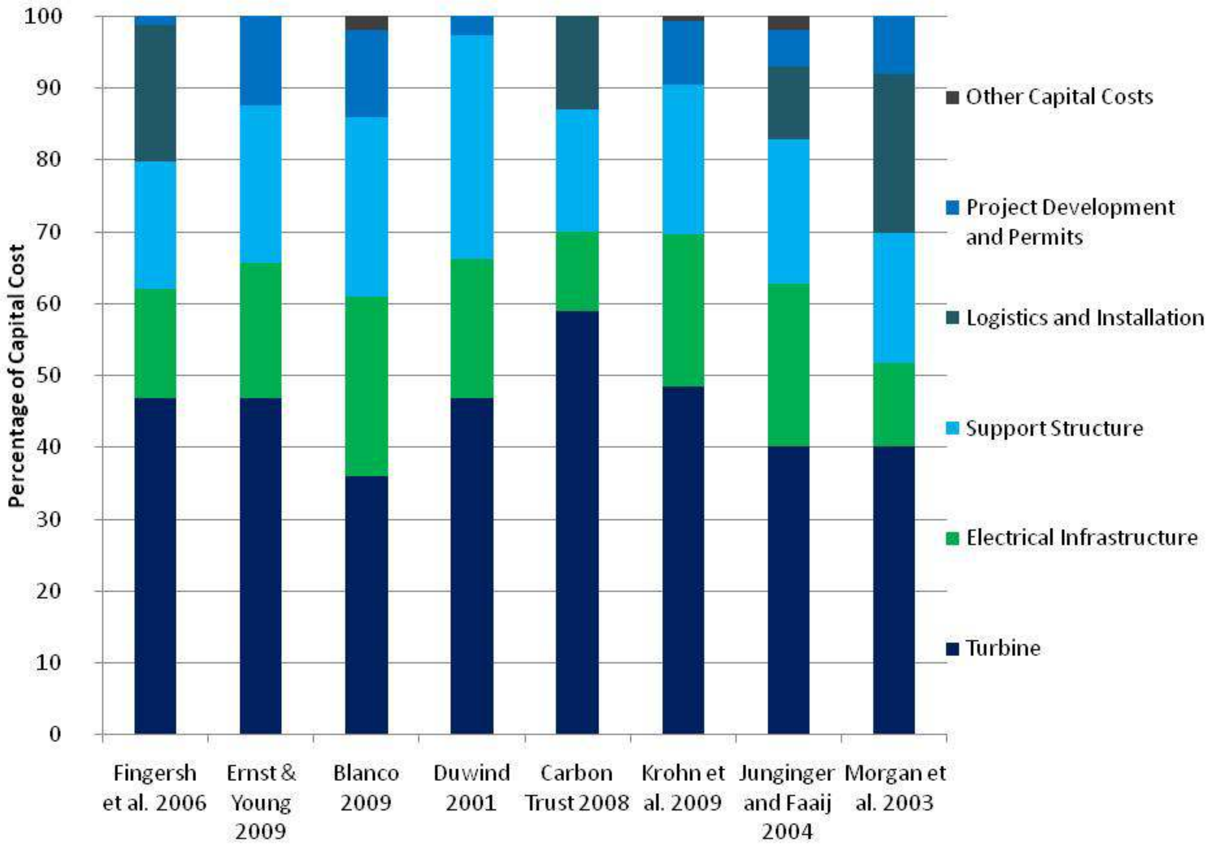


Figure 6-5. Capital cost breakdowns for offshore wind plants in shallow water

6.2 Offshore Wind Cost of Energy

The overall economics of offshore turbines depend on project life-cycle costs, including the capital investment, O&M costs, cost of fuel (zero for wind projects), and cost of capital. Total project life-cycle costs are divided by total lifetime energy production to obtain an LCOE, which is the cost of generating power from a particular project (Fingerish, Hand, and Laxson 2006). Offshore wind energy is roughly twice as expensive as land-based wind, which currently costs about 5–8¢/kWh. Significant cost reductions are possible, however, because offshore wind is a relatively new technology and has not yet realized many of the technology optimization and learning opportunities. The future cost of offshore wind energy will be closely tied to the state of the technology, the maturity of the industry, the level of deployment, and the experience gained through implementation.

Differences in the energy markets of the United States and Europe, especially how risk is allocated during project development and financing, could affect the cost of offshore wind in the United States. Different government policies and project support mechanisms between EU countries and the United States might influence both the required up-front capital investment and the cost of capital. Germany, for example, requires utilities cover the cost of grid connection out to and including the substation, which is located several kilometers out to sea for offshore wind, reducing the required investment cost to developers. Germany also offers feed-in tariffs that guarantee a price of 15 euro cents for every kilowatt-hour of electricity generated by an offshore wind project for the first 12 years of operation. By guaranteeing revenue, the German government reduces the risk of investing in projects, effectively reducing the cost of capital (GWEC 2010). The effects of different policies and support mechanisms are not fully analyzed in this report but contribute to some cost uncertainty in projecting the LCOE of initial offshore projects in the United States.

Breakdowns of the elements of LCOE are given in the studies cited in Figure 6-5, and Figure 6-6 summarizes those data. Because of differences in the way that each author cited life-cycle project costs, some assumptions were made to allow reasonable comparisons across the various datasets (see the footnotes to Figure 6-6).

Although the exact proportions of each cost category will vary with the specifics of each project, life-cycle cost of offshore wind energy is dominated by balance of station (BOS) and O&M. The electrical and grid infrastructure, foundations and support structures, offshore logistics and installation, and O&M represent the highest percentage of the total project cost, ranging from 57% to 71%. Because project economics are dominated by BOS and operating costs, adopting larger capacity turbines should result in significantly lower overall costs of energy for offshore projects. O&M costs are two to three times higher than those of land-based systems (Rademakers et al. 2003) and can reach 20% to 30% of the LCOE.

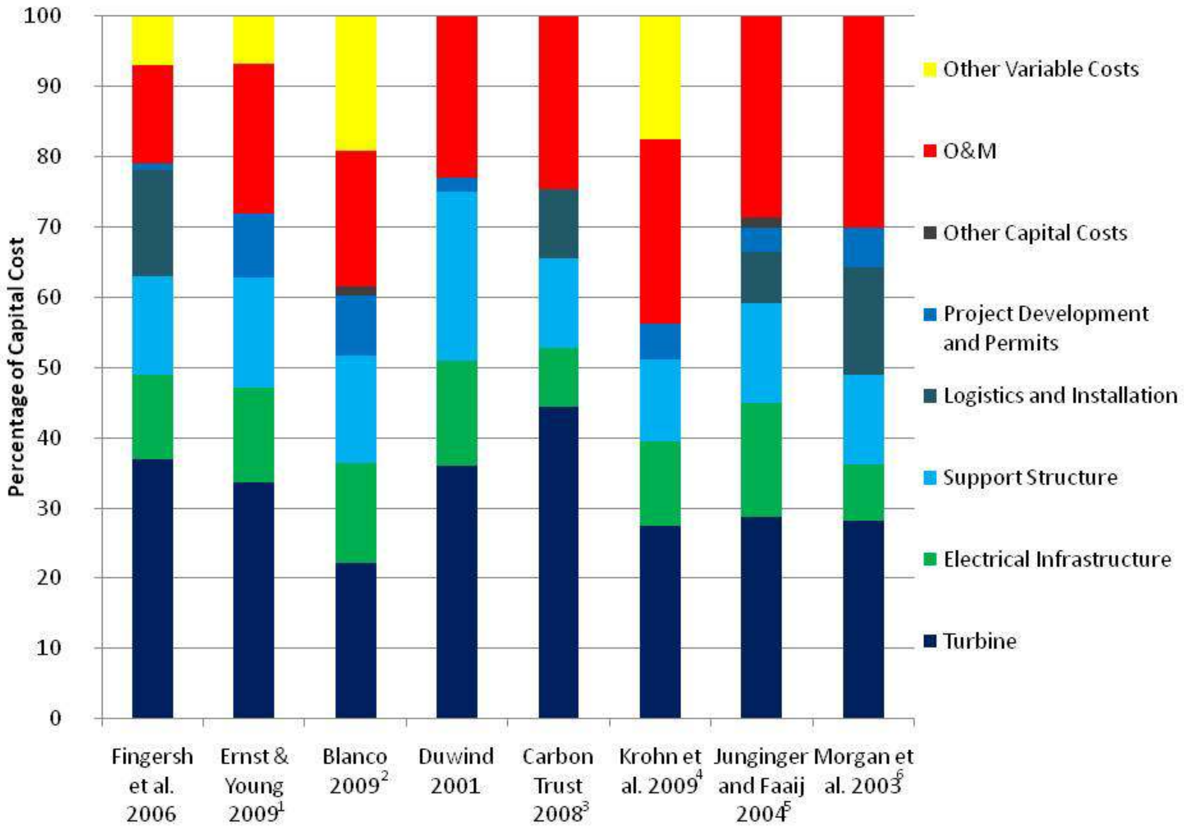


Figure 6-6. Life-cycle cost breakdowns for offshore wind plants in shallow water

[1] Ernst and Young [6-33] estimate that total operational costs for projects closing in 2009 ran to £79,000/MW/yr. This amount is divided into £60,000/MW/yr for O&M and £19,000/MW/yr for other operating costs (lease payments, transmission charges, grid maintenance costs, insurance premiums, and decommissioning provisions). With a 3% rate of escalation over 20 years of operation, life-cycle O&M was ~£950,000/MW, and other operating costs ran to ~£300,000/MW.

[2] Blanco (2009) estimates that O&M costs are 50% of the variable costs of a turbine over a project's lifetime, meaning that other operational costs (management, administration, land rental, insurance premiums) make up the other 50%.

[3] The Carbon Trust (2008) does not estimate O&M costs or of other variable costs for offshore wind projects. Based on industry standards, an O&M cost assumption of £16/MWh was used to estimate the life-cycle cost of O&M. Assuming a 35% capacity factor, a 3% rate of escalation and a 20-year operational life, the total life-cycle O&M cost was £780,000/MW.

[4] Khron, Morthorst, and Awerbuch (2009) state that offshore O&M costs typically run €16/MWh over the lifetime of the project. Assuming a 35% capacity factor, a 3% rate of escalation, and a 20-year operational life, the total life-cycle O&M cost was approximately €780,000/MW. Khron and colleagues (2009) estimate that O&M costs are 60% of the variable costs over a project's lifetime, meaning that other operational costs (split equally between land, insurance, and overhead) make up the remaining 40%.

[5] Junginger and Faaij's article (2004) gives a range of estimates for cost components based on the literature. An average of the range for each component was normalized to create a usable cost breakdown estimate.

[6] Morgan, Scott, and Snodin (2003) state that estimated variable costs are £70,000/year per turbine (includes O&M, overhead, and insurance) but do not define the size of the turbine. The turbine was assumed to have a rated capacity of 2 MW, based on the size of a typical offshore wind turbine available in 2003. Using Morgan and colleagues' cost assumption (2003), O&M costs were assumed to be £35,000/yr/MW. With a 3% rate of escalation over 20 years of operation, total life-cycle O&M spending was approximately £556,000/MW.

The LCOE of offshore wind projects is highly sensitive to project-specific economic factors. To illustrate this, NREL developed a set of baseline assumptions for the current cost of energy and calculated the capital and operating costs for a hypothetical project using its cost and scaling model (Fingerish, Hand, and Laxson 2006). Researchers then calculated the LCOE of the project and its sensitivity to changes in the three key variables—capital costs, discount rates, and wind speeds. A financial model developed by Sam Baldwin of the DOE's Office of Energy Efficiency and Renewable Energy was used to conduct the analysis (Baldwin 2010). Figure 6-7 illustrates how LCOE varies with wind speed and discount rate for two different capital cost scenarios; it also gives detailed explanations of the rationale for choosing capital cost and discount rate parameters in the figure's footnotes.

Figure 6-7 shows estimates of LCOE for a project with a capital cost of $4,259/kW varying from $0.14/kWh with a low discount rate and high wind speed to $0.40/kWh with a high discount rate and low wind speed. The LCOE for a project with a capital cost of $3,194/kW (25% reduction from baseline) ranges from $0.11/kWh to $0.30/kWh.

A reduction in the cost of capital from 16% to 8% for a project with a capital cost of $4,259/kW and wind speed of 9 m/s will reduce LCOE from $0.23/kWh to $0.16/kWh ($0.07/kWh). For a project with the same characteristics but a 25% lower capital cost, LCOE is reduced from $0.23/kWh to $0.18/kWh ($0.05/kWh). This suggests that even with the higher capital costs expected to persist in the near future, offshore wind energy production costs could be reduced substantially if developers can obtain favorable financing terms for their projects.

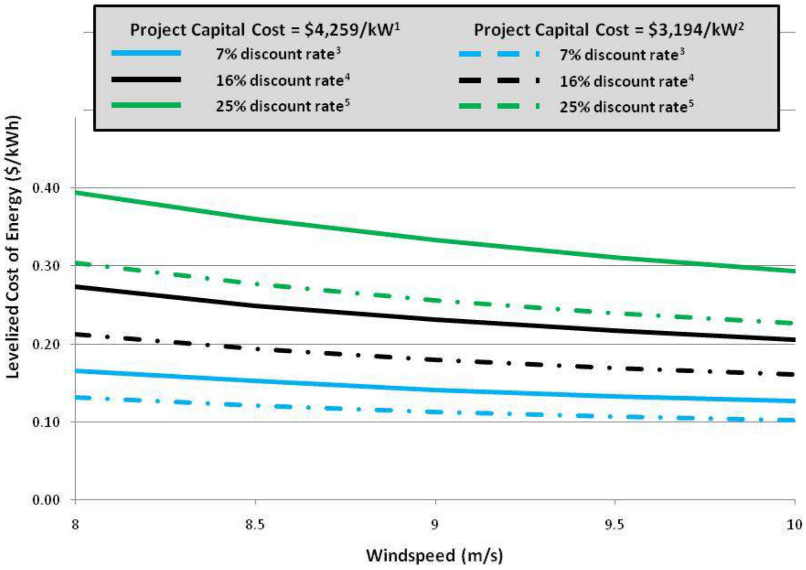


Figure 6-7. LCOE sensitivity with respect to capital cost, discount rate, and wind speed

[1] A capital cost of $4,259/kW is the baseline capital cost assumption. The value is the capacity-weighted average cost of all projects proposed for installation between 2010 and 2015 for which data are available (AWS Truewind 2010; Duke Energy 2010; Garden State Offshore Energy 2010; Blanco 2009; reNews 2009; Sokolic 2008; Williams 2008; Geoghegan 2007).

[2] A capital cost of $3,194/kW is a 25% reduction in cost from the baseline capacity cost assumption of $4,259/kW. This value is tested to illustrate how capital cost improvements affect LCOE.

[3] A 7% discount rate is commonly used by the U.S. Department of Energy (DOE) as reference for the comparison of renewable energy generation technologies.

[4] The California Energy Commission (2003) uses a 16% discount rate as a standard assumption for merchant (nonutility) project developers.

[5] According to NREL conversations with private equity financiers, a 100% equity investment in renewable energy technologies with no operational history in the United States requires a return on equity between 25% and 35% (P. Schwabe, personal communication). A discount rate greater than 25% is likely to be cost-prohibitive.

To date, three U.S. offshore wind projects under development have signed power purchase agreements (PPAs) with utilities. Table 6-3 shows the prices and terms of these PPAs (National Grid 2010, 2009; Delmarva Power & Light 2008). The price of an individual PPA is very different from the cost of generation (LCOE) for an offshore wind project. Renewable energy projects receive subsidies from the federal government and include attributes such as renewable energy credits (RECs) and the value of capacity credits. These attributes produce additional revenue streams and allow project owners to sell output below the actual cost of generation. As an example, the PPA price for the Delaware Offshore Wind project is 9.99¢/kWh and depends on the assumption that the Delaware legislature would pass Senate Bill 328. This amendment increases the value of RECs generated by the wind project to 350% of the value of RECs from other renewable projects and allows Delmarva to pass the incurred costs of off-taking power from the project onto its entire ratepayer base. This measure was passed in June 2010 (Delaware State Senate 2010).

Table 6-3. Announced PPA Prices for U.S. Projects under Development

Project Name	Developer	Power Purchaser	Capacity Contracted (MW)	PPA Price (¢/kWh)	PPA Base Year	Escalator (%)	**Term** (years)
Cape Wind	Cape Wind Associates	National Grid	264	18.70	2013	3.5	15
Delaware Offshore Wind	NRG Bluewater Wind	Delmarva Power & Light	200	9.99	2007	2.5	25
Block Island Wind Farm	Deepwater Wind	National Grid	29	23.75	2007	3.5	20

The prices of these offshore wind PPAs range from 10¢/kWh to 24¢/kWh. It is important to be cautious when comparing the prices and terms of PPAs. These contracts are immensely complicated, and the purchase price depends on several factors other than the simple generating cost of the project, including differences in state policy, regulation, and the structure of the regional electric market.

6.3 Projected U.S. Offshore Wind Deployment

Today, offshore wind in the United States might be able to compete in coastal markets, assuming the availability of economic incentives. These could include a federal production energy tax credit, state renewable portfolio standards (RPSs), state-sponsored system benefits funds, high local energy prices, pollution-control incentives (e.g., a price on carbon emissions or stricter air quality controls), or certain state-sponsored incentives. This competitiveness is evidenced by the more than 2,000 MW of offshore wind projects currently proposed under varying economic schemes. It is not clear how many of these projects will actually be completed because they would need significant long-term cost reductions. Costs might be lowered, however, through the initiation and success of a few early projects to first develop experience and intuition with the technical and regulatory issues.

The key question examined in this section is whether offshore wind has the potential to make a significant, long-term impact in the energy mix. Part of the answer was given in Section 4, which showed ample wind resource near large load centers for offshore wind to become a major contributor. The critical question remaining is whether technology-driven cost reductions combined with reasonable state and federal government incentives could create sufficiently favorable market conditions for offshore wind to be competitive with conventional generation. The answer will require a significant amount of analysis, along with some assumptions about current costs, engineering innovations, and future energy market trends.

6.3.1 Regional Energy Deployment System

To conduct these analyses, NREL developed an economic computer model that examines the entire U.S. electric grid. The primary tool was the Wind Deployment Systems (WinDS) model (now called the ReEDS [Regional Energy Deployment System] model), developed by Short et al. (2003). ReEDS is a multiregional, multi-time-period, geographic information system (GIS) and linear-programming model of capacity expansion in the electric sector of the continental United States that can forecast out to 2050. ReEDS is designed to examine the principal market issues related to the penetration of wind energy technologies into the electric sector. These issues include access to and cost of transmission, along with the variability of wind power. As a linear-optimization model, ReEDS resembles the Electric Market Module of the National Energy Modeling System (NEMS) model maintained and developed by the Energy Information Administration (EIA). It varies significantly from NEMS as a whole—most obviously because it features greater geographic diversity and deals only with the electric generation sector (NREL 2006).

Although the model does account for the cost of adding new transmission and the intermittency impacts at high penetration levels, it does not explore potential barriers related to transmission construction lead time or wind-farm permitting and site selection other than via typical resource exclusions. If the economics dictate, the model will build new electrical transmission links that become available at the time the capacity is needed. Also, it does not look beyond the geographical borders at Canada or Mexico to evaluate the effect of exporting or importing wind energy.

ReEDS models aggregate land-based and distributed wind technologies into one category because tools do not yet exist for handling distributed wind. It treats offshore wind separately, and specific cost models were developed to model these installations. Generally, the characteristics of the model's offshore wind penetration predictions depend highly on system interactions with land-based wind energy as well as on interactions with other forms of electric energy conversion.

The model considers an average capital cost of installed wind, an average O&M cost, varying capacity factors for different wind-speed classes, estimated transmission-line availability, estimated cost of new transmission construction, and estimated future improvements in performance or reductions in cost, out to a target year of 2030. Finally, the model does not differentiate wind turbine size, even though offshore turbines are generally larger than land-based turbines and thus will have different economics.

6.3.2 Offshore Generation Capacity Expansion Modeling

The assessments made in this section are preliminary and are not a comprehensive study of the cost reduction potential for offshore wind. Instead, they attempt to build a reasonable case for offshore wind that demonstrates economic feasibility within a rational set of market assumptions. They also supply suitable justification to pursue offshore wind as part of a broader national energy agenda, which would include a more detailed study of the market potential.

Two assessments are presented here. The first is the study titled *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply,* which was conducted by the American Wind Energy Association (AWEA), DOE, NREL, and Black & Veatch. The 20% report, as it is commonly known, demonstrated a plausible scenario in which it is technically feasible to generate 20% of the nation's electricity from wind energy by 2030, with a significant portion coming from offshore wind (DOE 2008).

The second assessment looks at specific input assumptions that correlate with high expansion rates of offshore wind energy generation (Short and Sullivan 2007).

6.3.3 Offshore Penetration for the 20% Wind by 2030 Scenario

The 20% wind study relied on the WinDS model (Short and Sullivan 2007) to simulate electricity generation capacity expansion through 2030. The wind energy contribution in each year was specified to approximate industry growth that expands rapidly in the next 8–10 years and reaches a relatively constant level of annual installations that could theoretically be maintained (including replacing retiring wind turbines) beyond 2030. Assumptions about the cost and performance of wind technology today through 2030 include capital cost reductions of 12.5% for offshore wind technology (from $2,400/kW in 2006 U.S. dollars excluding construction financing, 10% for land-based wind technology from $1,650/kW in 2006 U.S. dollars excluding construction financing) and an average of 15% improvement in performance over all wind classes for both land-based and offshore wind technology. Conventional generation technology cost and performance projections were also assumed (Short and Sullivan 2007). These costs are low according to today's market data but were accurate at the time the study was conducted. The marked increase in offshore wind costs in 2006 (see Figure 6-1) demonstrates the dynamic market for offshore wind and for wind power in general. Indeed, these upward cost trends are indicative of the entire energy marketplace.

The study estimated regional variations in the cost of generation technology and new transmission lines. Wind technology capital costs were increased as a function of population density, with an additional 20% of the capital cost added for plants sited in the Northeast. These cost variations reflect the regional costs of actual wind projects installed in 2006 (Wiser and Bolinger 2006). Variations in regional transmission cost, developed by an AWEA expert panel, include an additional 40% in New England and New York; 30% in PJM East (New Jersey and Delaware); 20% in PJM West (Maryland, West Virginia, Pennsylvania, Ohio, part of Illinois, Indiana, and Virginia); and 20% in California. These regional costs were intended to reflect real effects resulting from population and the experience of public resistance to siting generation technology or transmission lines.

The scenario defined in the 20% report requires more than 300 GW of wind generation capacity by 2030 to produce more than 1,200 TWh/yr, which is 20% of the projected U.S. electricity demand (DOE 2008; Figure 6-8).

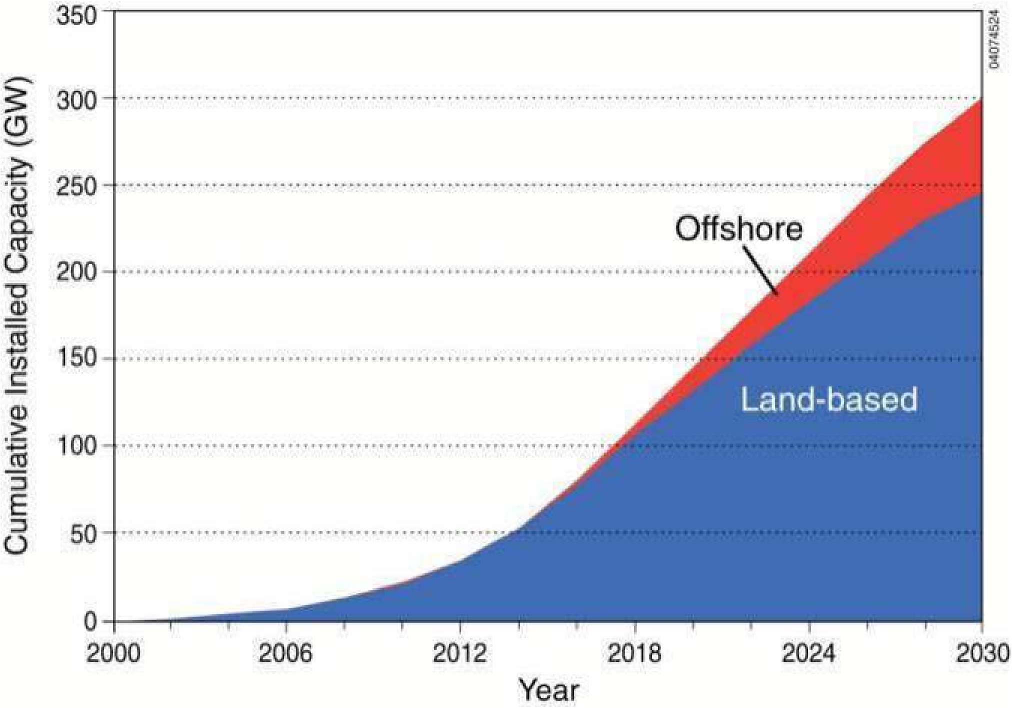


Figure 6-8. Cumulative wind generation capacity associated with 20% wind by 2030

Of this capacity, 54 GW, or 18%, would be from offshore wind resources, primarily off the coast of the states in the Northeast. In the latter years of the 20% wind scenario, though, offshore technology is installed off West Coast states and southeastern states. Because the energy generation from wind technology is prescribed in each simulation period to create this scenario, the cost-optimization features of the WinDS model have the land-based wind technology competing against the offshore wind technology to meet the specified target for annual energy generation.

Much of this analysis depends on significant declines in offshore wind capital costs, which have not been demonstrated through rigorous study of the elements of a typical project because of the relative infancy of offshore installations. Nevertheless, significant cost declines are plausible based on the historical behavior of other new industries, including land-based wind. New industries typically show significant cost decreases simply by increased production volume (i.e., learning curve effects) and technology improvements (Short and Sullivan 2007). Using the learning curve theory, offshore capital costs can expect greater reductions in the future than the costs of more mature land-based wind energy systems, which have realized an 11% cost decline per doubling of installed capacity over the past three decades (Wiser and Bolinger 2009). Although learning curve effects may be more conservative because some maturation has been passed over from land-based wind, the effect could be very important in stimulating cost reductions in offshore wind, especially if European markets meet their targets of 150 GW by 2030.

6.3.4 Restricted Coastal Grid and High Gas Pricing

To assess the potential penetration of offshore wind in the United States, the WinDS model was run outside the 20% wind scenario under different technology development, cost, and policy scenarios (Short and Sullivan 2007). The method was to define a business-as-usual case, which is considered conservative with respect to the market conditions that may stimulate wind energy growth, and then adjust the scenario via three parameters:

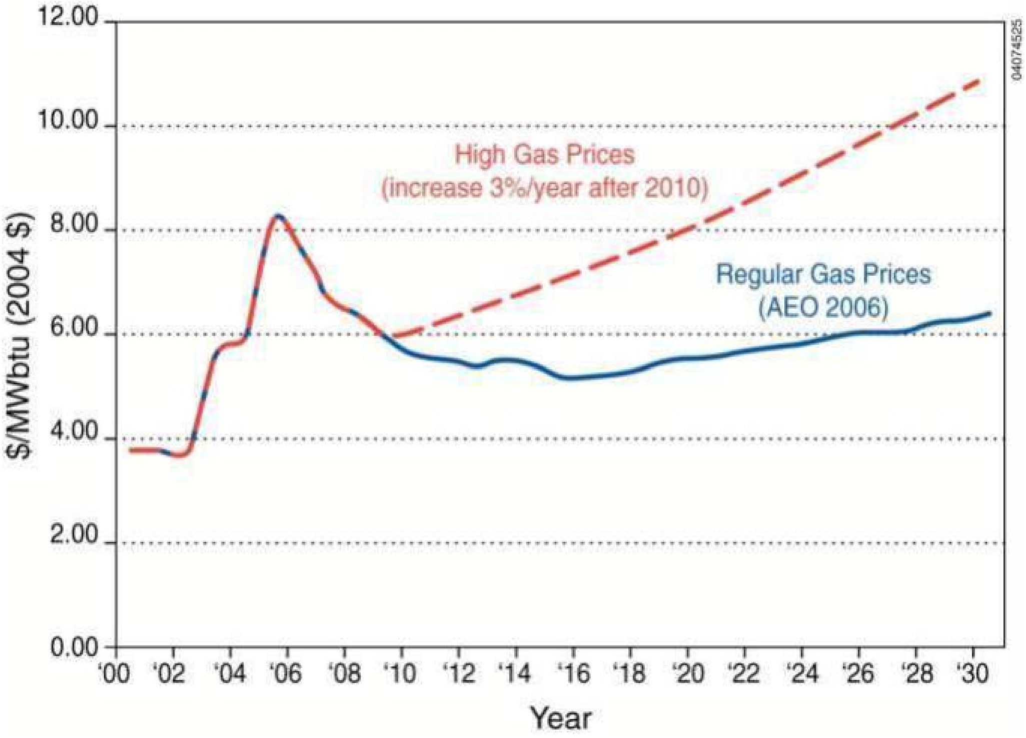
1. Allow the fuel price of natural gas to rise 3% annually.
2. Restrict technologies that can be built to meet electric demand along highly populated coastal areas of the country.
3. Set a national requirement that 20% of generation must come from renewable sources by 2030.

The WinDS model was run for eight scenarios (created by combinations of these three conditions) to determine the effect of each condition, or set of conditions, on the penetration of offshore wind. Because this analysis was performed in 2007, the scenario definitions and assumptions may not reflect recent changes in the energy market, which could be significant. Clearly, further analysis is needed. It also does not consider the large amount of land-based capacity installed in recent years (~18,000 MW installed in 2008 and 2009, bringing the total to ~35,000 MW). The trends identified in this assessment are, however, expected to remain relevant—under the right policy and market conditions offshore, wind has the potential to generate a significant portion of our nation's electricity.

The business-as-usual case for this offshore comparison uses fuel prices and load forecasts from the reference case of the EIA's *Annual Energy Outlook 2006* (DOE and EIA 2006). Conventional generation technology costs and wind data inputs came from the 20% wind scenario. Other parameters are input according to current conditions: no national RPS, but state RPSs are enforced if currently enacted (as of August 2005); the sulfur dioxide (SO_2) cap follows current regulations; and no carbon cap or tax is applied. Corporate financing and the consequent debt-service coverage requirements are accounted for explicitly, as are federal tax credits and income tax deductions. An inflation-adjusted production tax credit of $18.50/MWh for wind power is assumed to expire in 2008 (DOE and EIA 2006).

In the business-as-usual scenario, WinDS projects that by 2030, wind will deliver 74 GW of electric capacity to the grid, with only 0.07 GW coming from offshore wind—and all of it in shallow water off the coasts of California and Massachusetts. Because the scenario does not penalize or restrict carbon or fossil fuels, the build-out of wind power is in large part attributable to the ability of land-based wind power to cost-effectively meet state RPS requirements as well as the increasing economic competitiveness of wind farms with conventional power plants. Natural gas costs do increase slightly with time (*Annual Energy Outlook 2006* projections, shown as a solid line in Figure 6-9), and SO_2 emissions caps restrict using older coal technologies. Offshore wind, as evidenced by the lack of installed capacity, simply remains too expensive to compete.

In the first scenario, natural gas prices are allowed to increase at a flat rate of 3% per year after 2010 (shown as a dashed line in Figure 6-9).



Source: DOE-EIA (Annual Energy Outlook) 2006.

Figure 6-9. Comparison of U.S. average natural gas price increase from *Annual Energy Outlook 2006* with 3% annual increase

This increases the relative cost of all natural gas technologies compared to alternative options such as coal, wind, or nuclear (no carbon emission penalties). This increased gas price trajectory does not, however, have a large near-term effect. The present value of gas costs over a 20-year analysis period for a gas plant investment does not exceed that of a plant built in 2006 until after 2020. All other parameters remain consistent with the base case in this scenario.

As expected, with higher natural gas prices the installed capacity of both combined-cycle and combustion-turbine natural gas technologies decreases markedly. The bulk of the lost capacity is replaced by new coal plants (almost all modern plants use pulverized coal; integrated gasification combined-cycle plants are still not built in significant numbers), although over the last few time periods in the model, some nuclear plants are built as coal-plant construction lags. Wind experiences modest increases to 114 GW total capacity, with 5 GW coming from shallow-water offshore plants. In this scenario, the bulk of the offshore capacity is shared between New York and Massachusetts, with Maine, New Jersey, Rhode Island, and California claiming the rest.

In the second scenario, a constraint is placed on the technologies that can be built in populated coastal regions to meet the regions' load growth. The new restriction requires that all new demand in heavily populated coastal regions be met either by combined-cycle gas power plants or by offshore wind farms, and that there can be no new transmission into the designated regions. The rationale for this constraint is that congestion in these regions makes new major transmission capacity prohibitively expensive and that the populace would resist new construction of dirtier generation technologies (e.g., coal or nuclear facilities).

The selected regions include the entire Pacific Coast and the northern Atlantic Coast. The southern Atlantic Coast and the Gulf of Mexico are unrestricted, except for Houston. Similarly, only Chicago is restricted around the Great Lakes. Arguments could be made to include some Great Lakes or southern coastal cities, such as Milwaukee, Cleveland, Detroit, Savannah, or Miami, or to leave out some of the more sparsely populated Pacific Coast regions. The decisions were not made by any specific metric, but instead by a first-pass estimation of where population density was sufficiently high over a large portion of the WinDS region. Also taken into account were nonscientific considerations for the environmental tolerance of the region's inhabitants, the quantity and quality of the available wind resource, and current regional electric prices.

Siting-restricted scenarios were run with both regular and high natural gas prices so that the two conditions could be cross compared. Figure 6-10 compares the 2030 capacity for selected technologies among the four scenarios. In the scenario with both high gas prices and the siting restriction in place, offshore wind exhibits a sharp increase over the other three scenarios. In this scenario, offshore wind needs to compete only with combined-cycle gas—when gas prices get too high, offshore wind becomes the more economical of the two. In this case, 78 GW of offshore wind is built in exactly the regions where the coastal restrictions, shown in Figure 6-11, were imposed. If the siting-restricted scenario were extended over the high-population regions of the Great Lakes region and Gulf of Mexico, the amount of offshore wind nationally would most likely increase. Future studies should be done to show these effects.

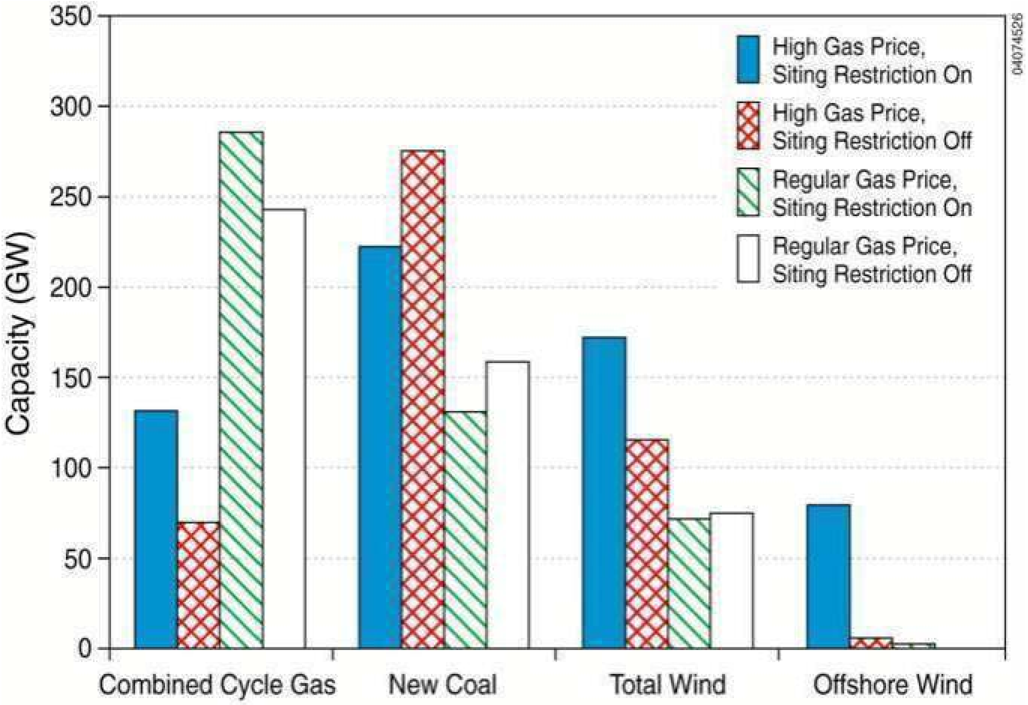


Figure 6-10. 2030 capacity in a gas price and siting restriction comparison

Figure 6-11. 2030 offshore wind capacity under a high gas price, siting-restricted scenario

The third parameter is the institution of a 20% national RPS for wind, which would require at least 20% of U.S. electrical load to be met by wind power by 2030. The requirement ramps linearly from zero in 2007 to 20% in 2030. The four previous scenarios (high and regular gas prices, with and without the coastal restriction) are evaluated again, but this time with the 20% RPS.

In all the RPS scenarios, WinDS predicts much more wind capacity than before—both land based and offshore. In all the RPS cases, more offshore wind is installed than in the non-RPS cases simply because some offshore sites are more cost-effective than the remaining land-based wind options at these high levels of penetration. For example, with regular gas prices and without the siting restriction, 32 GW of offshore wind is built by 2030, which is a significant amount—especially when compared to the 0.07 GW constructed in the RPS-free counterpart. On the other hand, the difference between the two cases with and without the 20% RPS (with high gas prices and siting restrictions) increases only from 78 to 89 GW, which is a much less substantial difference.

6.4 Findings and Conclusions

Capital costs for offshore wind plants are analyzed using data from European deployments and projected costs for potential U.S. projects. The costs have been trending up over time, as have the costs for land-based installations. Although water depth is expected to have a significant effect on capital cost, and larger wind plant sizes should lead to lower overall capital costs, these effects have been overshadowed in the data by recent jumps in the cost of energy from all sources and other energy market dynamics. The wind turbine itself contributes approximately 44% of the total capital cost. Capital cost trends are presented for year of installation, water depth, distance from shore, and project size. Year of installation is the most significant variable in the capital cost, with a sharp rise in price (56%) indicated between 2006 and 2008. Other trends such as decreasing cost with project size may show some correlation, but consistent data are not yet available to quantify this trend.

The LCOE of offshore wind plants is about double that of comparable land-based plants using 2009 market prices. This increase in the cost of energy can be attributed to higher O&M costs as well as the previously described higher capital costs. O&M costs can account for as much as 30% of the total life-cycle cost for an offshore wind plant. Three offshore wind projects in the United States have now signed PPAs (see Table 6-3). The reader is cautioned about making direct comparisons between these PPAs because the terms are complicated and several factors may not be obvious under a casual analysis.

The two studies using WinDS (ReEDS) give solid evidence that offshore wind could supply a substantial and economically viable electric energy source in the future, although a comprehensive assessment has not yet been completed. The 20% report showed that offshore wind could contribute 54 GW, or 18%, of the nation's total wind energy (DOE 2008). Short and Sullivan (2007) supported this magnitude of offshore wind growth, with up to 89 GW coming from offshore wind. Recent economic and political developments increase the likelihood that the "transmission-constrained" scenario may evolve as a baseline case in the eastern United States, leading to large deployments of offshore wind.

These scenarios testify that offshore wind could be used to meet new loads in locations where siting restrictions on new land-based power plants and transmission are severe, such as coastal metropolitan areas. In these locations, offshore wind could be competitive with combined-cycle natural gas plants if gas prices increase significantly from EIA projections. If a 20% RPS is implemented, some offshore wind will be built simply because it is more cost-effective than the remaining land-based resource at these high levels of penetration.

Several other scenarios that might affect the deployment of offshore wind installations have yet to be investigated. Primary among these would be a climate change policy scenario with either carbon taxes or caps. NREL is modifying the ReEDS model to be able to address such scenarios. In addition, NREL is planning and making general improvements to the ReEDS model that will allow it to better capture the potential of offshore wind. These improvements are expected to include an updated regional structure, an improved representation of transmission, siting considerations for fossil-fired power plants, and recent state restrictions on the siting of both new generating plants and transmission.

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7.0 Federal and State Regulatory Pathways for Siting and Permitting Offshore Wind Facilities

7.1 Introduction

The United States is still establishing the regulatory pathways for offshore wind. Although the country has a long history of managing energy-related industries such as oil and gas on federal lands and in federal waters, no such institutional knowledge exists regarding offshore alternative energy facilities. Wind turbine technology and electric power distribution offshore have siting characteristics that significantly differ from the more mature extractive industries. Moreover, 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 in Danish waters. Because of the absence of wind energy land management agency experience in the United States and the nascent state of the offshore wind industry, the regulatory and institutional pathways for offshore wind energy are just now emerging. The learning curve faced by the federal and state agencies when balancing the risks and benefits of using energy generated from offshore wind farms has been steep. Consideration of the myriad competing and complementary ocean uses has been complex and still lacks cohesion across many U.S. coastal regions. Accordingly, federal regulatory and technology development agencies working are working together to develop a regulatory pathway with due regard for scientifically credible data needs and standards of environmental quality that have been established historically under National Environmental Policy Act (NEPA) and other federal laws.

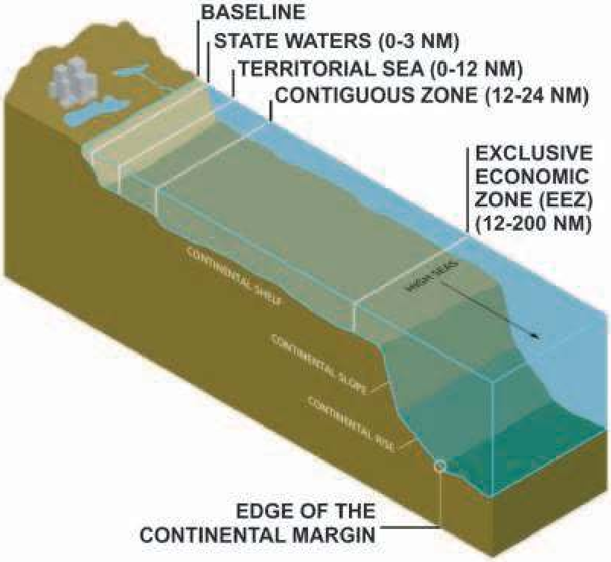
This section is an overview of the regulatory pathway for offshore wind development in federal waters with respect to ocean policies and jurisdictions, regulatory roles of federal agencies, and compliance with key regulatory legislation such as NEPA. This section also describes the changing codes, standards, and certification processes for the regulation of the offshore wind industry.

7.2 Ocean Policies and Jurisdictions

Rights, restrictions, and responsibilities in the marine environment are contingent on designated ocean jurisdictions and administrative boundaries (MMS 2010a) as well as on multiple and overlapping use rights. This complex regulatory environment determines whether a state or federal agency is the lead for the approval process. Section 7.2.1 below outlines the laws regulating ocean jurisdictions and Section 7.2.2 discusses the emerging ocean policy of coastal and marine spatial planning. This policy could further define ocean space boundaries, but is currently in its infancy.

7.2.1 Jurisdiction

The federal government retains the power to regulate commerce, navigation, power generation, national defense, and international affairs throughout state waters. States, however, are given the authority to manage, develop, and lease resources throughout the water column and on and under the seafloor (MMS 2006). As explained in Figure 7-1, for most states, jurisdiction extends to 3 nm from the shoreline, in accordance with the Submerged Lands Act (2002), and federal jurisdiction extends the breadth of the territorial sea (out to 12 nm) and then out to at least 200 nm on the Outer Continental Shelf (OCS) or to the outer edge of the continental margin. The jurisdictions of the Great Lakes, on the other hand, fall under state agencies until they meet the international borders with Canadian provinces. Bays and sounds are likewise under state jurisdiction (see Section 7.5 for more details).



Baseline

The U.S. baseline is the mean lower low-water line along the coast. A key factor determining the jurisdictions for wind energy projects in the ocean is the project boundary line dividing the land from the ocean or the baseline. However, the baseline is not static and may shift and/or be contested because of natural erosion or seabed changes.

State Waters (0 to 3 nm)

Enacted in 1953, the Submerged Lands Act gave coastal states jurisdiction over a region of the ocean extending 3 nm seaward from the baseline, commonly referred to as state waters. The seaward boundary of the eight states bordering the Great Lakes is the U.S.-Canada International boundary. Generally, projects located within 3 nm of the ocean coast are designated to be in state waters. Because of legal histories, Texas and Florida are two states with exceptions, with their state boundaries in the Gulf Coast extending to 9 nm.

Territorial Sea (0 to 12 nm)

Under international law, every coastal nation has sovereignty over the air space, water column, seabed, and subsoil of its territorial sea, subject to certain rights of passage for foreign vessels and, in more limited circumstances, foreign aircraft. In 1988, President Reagan proclaimed a 12-nm (22-km) territorial sea for the United States, consistent with provisions in the LOS Convention. The proclamation extended the territorial sea only for purposes of international law, explicitly stating that there was no intention to alter domestic law.

Contiguous Zone (12 to 24 nm)

International law recognizes a contiguous zone outside the territorial sea of each coastal nation. Within its contiguous zone, a nation can assert limited authority related to customs, fiscal, immigration, and sanitary laws. In 1999, President Clinton proclaimed a U.S. contiguous zone from 12 to 24 miles (19–39 km) offshore, enhancing the U.S. Coast Guard's authority to take enforcement actions against foreign-flag vessels throughout this larger area.

Exclusive Economic Zone (12 to 200 nm)

The LOS Convention allows each coastal nation to establish an EEZ adjacent to its territorial sea, extending a maximum of 200 nm (370 km) seaward from the baseline. Within its EEZ, the coastal nation has sovereign rights for the purposes of exploring, exploiting, conserving, and managing living and nonliving resources, whether found in ocean waters, the seabed, or subsoil. Specifically pertaining to the topic of energy, these national rights include the commercial recovery of minerals and the production of energy from water, currents, and wind. These rights also grant nations jurisdiction to establish artificial islands, installations, and structures within their EEZ. In 1983, President Reagan proclaimed the U.S. EEZ, which occupies the area between 12 nm (22 km, the seaward limit of the territorial sea) and 200 nm (370 km) offshore, for international purposes. The United States does not generally assert control over ship transportation, air space, the laying of cables and pipelines on the ocean floor, or marine scientific research in the U.S. EEZ to the same extent that most coastal nations do.

Continental Shelf (12 to 200 nm or outer edge of continental margin)

The legal concept of the continental shelf has evolved over the past 60 years. The LOS Convention generally defines the continental shelf for purposes of international law as "the seafloor and subsoil that extend beyond the territorial sea throughout the natural prolongation of a coastal nation's land mass to the outer edge of the continental margin or to 200 nm (370 km) from the baseline if the continental margin does not extend that far." Thus, the legal definition of the continental shelf overlaps geographically with the EEZ. The term "deep seabed" is used to describe the seabed beyond these national jurisdictions.

High Seas (areas beyond national jurisdictions)

International law has long considered areas of the ocean beyond national jurisdiction to be the high seas.

Source: Energetics, adapted from U.S. Commission on Ocean Policy 2003.

Figure 7-1. Schematic of state, federal, and international ocean jurisdictions

The Outer Continental Shelf Lands Act (OCSLA) was enacted in 1953 to manage federal offshore areas for the exploration of mineral resources. The OCS refers to submerged lands lying seaward and outside of the area of lands beneath navigable waters of each of the respective states subject to federal jurisdiction and control (MMS 2010a). Over the past 20 years, U.S. presidents have issued a series of proclamations changing the extent and nature of U.S. authority over the oceans and reflecting aspects of the United Nations Convention on the Law of the Sea (LOS Convention; 2010). The LOS Convention, in effect since 1994, has been ratified by 158 nations as of December 2009. Absent the determination by the Continental Shelf Commission that the U.S. Continental Shelf extends beyond 200 nm, rights beyond 200 nm are governed by international law and regulatory bodies. Although a signatory of LOS, the United States has not ratified the treaty because of several objections to specific provisions. The United States generally accepts, however, most provisions of the LOS Convention as binding under customary international law. Given current and foreseeable technology options for powering offshore wind generation plants, currently planned and future projects will most likely be located within the 200-nm (370-km) exclusive economic zone (EEZ) boundaries.

Changes to U.S. maritime law have created a territorial sea to 12 nm (22 km), a contiguous zone to 24 nm (44 km), and an EEZ (between 12 and 200 nm or 370 km), although they have not been comprehensively reflected in domestic laws. Many laws also use imprecise or inconsistent terms to refer to ocean areas, such as "navigable waters," "coastal waters," "ocean waters," "territory and waters," "waters of the United States," and "waters subject to the jurisdiction of the United States." These terms can mean different things in different statutes and are sometimes not defined at all. Figure 7-1 depicts the maritime "zones" based on domestic and international laws. The important boundaries regarding offshore wind energy projects relate to the baseline, state waters, and the OCS. Ownership of the seabed resource raises political and socioeconomic issues relating to who is paying for and who is receiving project royalties and profits (Firestone et al. 2004).

7.2.2 Ocean Policies

Our oceans, coasts, and Great Lakes are already heavily industrialized and used for tourism, commercial and recreational fishing, and aquaculture as well as extraction of nonrenewable resources. Coastal ecosystems are critical habitat for migratory birds and mammals as well as fish species. Despite the critical importance of these areas, wide range of stresses and competing demands threaten these resources and communities (see Section 8). The challenges lie not only in ecosystems management but also in the hundreds of policies, laws, authorities, and governance structures intended to manage our use and conservation of ecosystems (White House Council on Environmental Quality [CEQ] 2010a).

Various administrations have attempted to streamline and strengthen ocean policies and governance—the most recent initiative was on June 12, 2009, when President Obama issued a memorandum establishing an Interagency Ocean Policy Task Force, led by the CEQ. Two major interim policy reports have suggested a national ocean policy to strengthen stewardship, a framework for better coordination, and an implementation strategy (CEQ, 2009a, CEQ 2009b).The second report, *Interim Framework for Effective Coastal and Marine Spatial Planning,* offers a comprehensive, ecosystem-based approach to planning and managing uses and activities offshore that addresses conservation, economic activity, conflicts of interest, and sustainable use (CEQ 2009c). About a year later, President Obama signed an Executive Order establishing a National Policy for the Stewardship of the Ocean, Coasts, and Great Lakes, adopting the *Final Recommendations of the Interagency Ocean Policy Task Force*, and creating a National Ocean Council to strengthen ocean governance and coordination across the federal government (The White House 2010).

Because offshore wind farms will potentially compete with or complement existing uses of state and federal waters, interagency coordination could assist a region in more efficient siting of offshore wind. Because potential risks of wind projects are very site specific, marine spatial planning should be assessed in concert with stakeholder engagement to anticipate potential conflicts and compatibilities in the marine environment. It is important to note that state governments are also moving toward marine spatial planning and "zoning" developments within state waters (see sections 3 and 7.5 for details on the state permitting and planning process).

The CEQ initiatives will most likely affect the siting and management of the offshore renewable energy projects along our coasts and in the Great Lakes as the guiding principles for coastal and marine spatial planning (CMSP) get tested and developed. CMSP can be defined several ways: according to the United Nations Educational, Scientific, and Cultural Organization (UNESCO), marine spatial planning is a public process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to achieve ecological, economic, and social objectives that usually have been specified through a political process (UNESCO 2010).

The two guiding principles outlined by CEQ include:

- Ecosystem-based management (which integrates ecological, social, economic , commerce, health, and security goals and recognizes both that humans are key components of ecosystems and that ecosystems are essential to human welfare).
- Adaptive management (which calls for routine reassessment of management actions to better inform and improve future decisions).

Both principles are central to sustainable renewable energy deployments on the OCS, and some states are moving in this direction (see Section 7.5). CMSP could support siting of offshore wind deployments by instituting both science-based and robust stakeholder processes for selecting and vetting candidate sites or zones for developments.

The CEQ process involved holding 38 expert roundtable meetings, including one on renewable energy in September 2009 (CEQ 2010a). Some of the concerns of the offshore wind energy interests focused on whether a perceived cumbersome federal process would slow down the urgent need to deploy clean energy supplies. The reality is that CMSP is a cumbersome and often lengthy process because of the variety of stakeholders, "users," and agencies involved in management. Under the framework proposed, CMSP would be regional in scope and would be developed cooperatively among federal, state, tribal, and local authorities with stakeholder input. It is still uncertain how these frameworks would affect the deployment of offshore renewable energy, but CMSP is an essential building block of sustainable offshore wind energy deployments. There is clear evidence for this approach as several states have instituted marine spatial planning along their coasts (see Section 3 for more details).

Another aspect of CMSP is to support data collection that is based on science and relies on a risk framework so decision makers can identify deployment sites that are more compatible with habitats, species, and human activities as well as those that would present conflicts (see Section 8 for risk framework). Per the Energy Policy Act of 2005 (EPAct 2005) direction, the National Oceanic and Atmospheric Administration (NOAA) and the Bureau of Ocean Energy

Management, Regulation, and Enforcement (BOEM; formerly the Minerals Management Service ([MMS]; see Section 7.3.1) are working on developing marine spatial planning tools and collecting data that will populate a Multipurpose Marine Cadastre, a mapping and permitting tool that identifies applicable jurisdictional boundaries, restricted areas, laws, critical habitat locations, and other important features (Digital Coast 2010, MMS 2006).

7.3 Current Regulatory Situation

On August 8, 2005, President Bush signed EPAct 2005 into law (PL 109-58) (42 USC 15801), granting the then-MMS new responsibilities over renewable energy and alternate uses of offshore federal lands. There are regulatory parallels between the compliance mechanisms and NEPA documentation already in place for the offshore oil and gas industry and the new requirements for a renewable energy program.

7.3.1 MMS Regulatory Paradigm

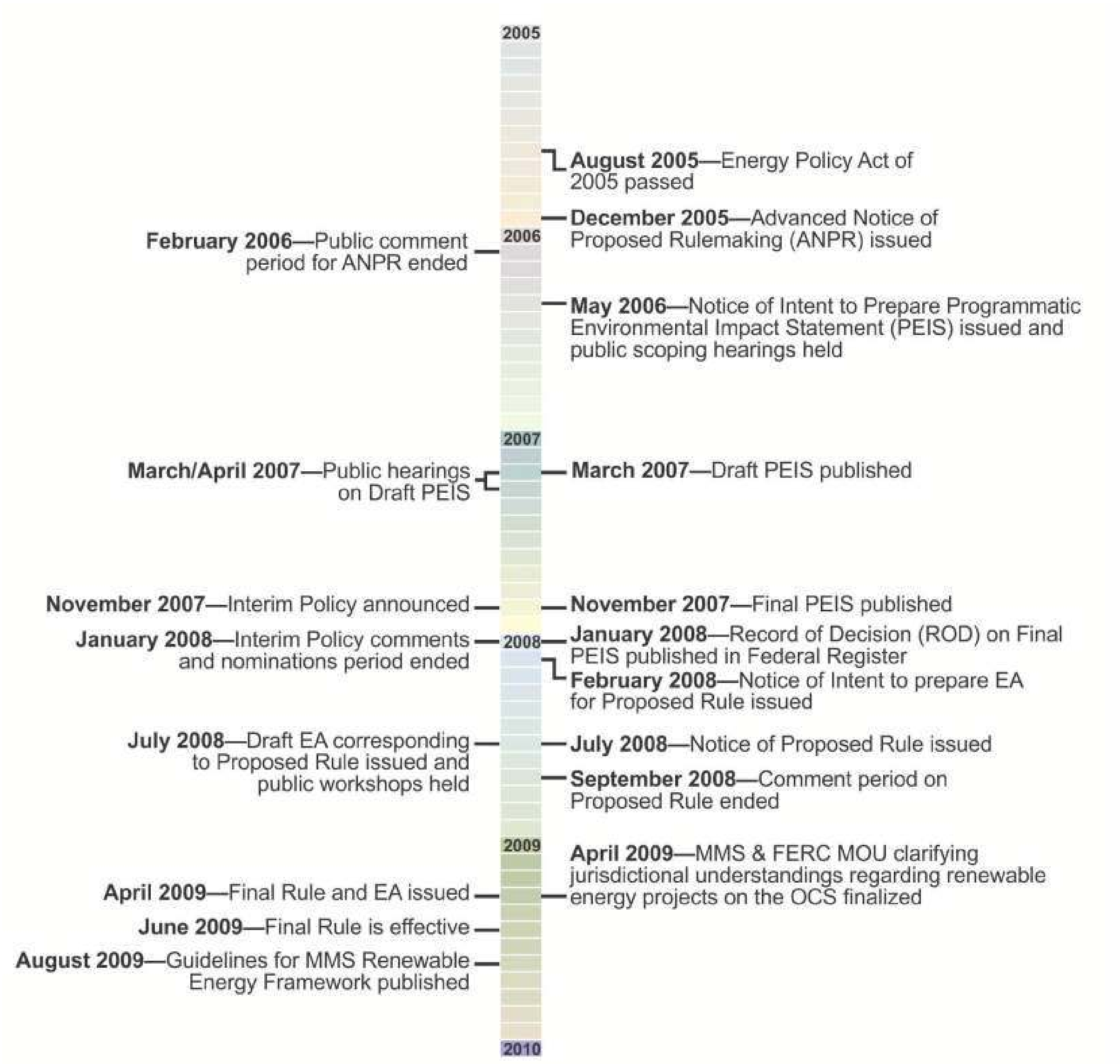
As stated in the *Federal Register* announcing the new regulatory program, “Section 388 of the Energy Policy Act of 2005 (EPAct) amended the OCSLA to grant the Secretary of the U.S. Department of the Interior (Secretary) the discretionary authority to issue leases, easements, or rights of way for activities on the OCS that produce or support production, transportation, or transmission of energy from sources other than oil and gas” (MMS 2008a). This authority covers renewable energy developments, including, but not limited to, commercial-scale and demonstration wind, wave, current, and solar power pilot projects. The authority does not supersede or modify existing authority of any other federal agency (Burton 2002). In July 2010, the MMS was reorganized under a new name; the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEM). The bureau will remain in the U.S. Department of the Interior (DOI) and will retain responsibility for managing the nation's natural gas, oil and other mineral resources on the OCS, including offshore wind. The BOEM was developed with greater provisions for oversight of managing the resources, collecting revenues, and guarding the public safety.

Congress directed the Secretary of the Interior through EPAct 2005 to establish a regulatory paradigm for siting and managing offshore wind facilities within 270 days and made specific requirements for inclusion in the regulations. Key provisions mandated that the Secretary:

- Act as the lead agency for permitting offshore renewable energy projects
- Grant easements, leases, or rights-of-way for uses of the OCS on a competitive basis (unless it is determined that there is no competitive interest)
- Ensure consultation with affected states and other stakeholders
- Coordinate with relevant federal agencies
- Ensure safety and environmental protection
- Prevent interference with other reasonable uses of the sea and seabed
- Protect national security interests
- Perform oversight, inspection, research, monitoring, and enforcement

- Require financial surety to ensure that facilities constructed are properly removed at the end of their economic life (decommissioning)
- Ensure a fair return to the nation.

MMS finalized the regulatory rules when they were announced by President Obama on Earth Day in April 2009 and published in the *Federal Register* on April 29, 2009. The rules went into effect on June 29, 2009, and detailed guidelines were issued on August 3, 2009. Figure 7-2 charts significant milestones in the rule development process, including public hearings to support the rulemaking, publication of a Programmatic Environmental Impact Statement (PEIS; see Section 7.4.1), and the issuance of an interim policy allowing the installation of met towers at a limited number of sites (see Section 7.3.2.2).



Source: MMS 2009a, 2009b, 2009c 2009d, , 2008b, 2007a.

Figure 7-2. MMS timeline of rule development activities

The framework establishes a "cradle to grave" approach to regulate offshore renewable energy activity from the prelease stage through leasing, site assessment, construction and operations, and decommissioning. Key elements support safety, environmental protection, state and local coordination with affected agencies, financial assurance, fair return for use of submerged public lands, and equitable revenue sharing with the states (Cushing 2009; Bornholdt 2009). Table 7-1 outlines the major provisions in the program.

Table 7-1. Major Provisions in the Final Renewable Energy Framework

Major Sections of the Rule	**Subpart in Rule**
General provisions and definitions	(Subpart A)
Leasing process and issuance • Commercial and limited • Competitive and Noncompetitive • Research activities	(Subpart B)
Rights-of-way grants and rights-of-use and easement grants for renewable energy activities	(Subpart C)
Lease and grant administration	(Subpart D)
Payments and revenue sharing	(Subpart E)
Plans • Site assessment and construction and operations • General activities	(Subpart F)
Facility design, fabrication, and installation	(Subpart G)
Conduct of approved plan activities; environmental and safety monitoring and inspections	(Subpart H)

Source: MMS 2009b, 2009f.

Before EPAct 2005, no regulatory mechanism for authorization of offshore renewable energy activity existed except through Section 10 of the Rivers and Harbors Act, which is administered by the U.S. Army Corps of Engineers (USACE) and covers construction activities in navigable waters (the USACE is still the lead federal agency for the Great Lakes region; see Section 7.5.1 for more details). Wind developers of two proposed projects, Cape Wind and Long Island Offshore Wind Park (the Long Island proposal was ultimately put on indefinite hold), had applications that were proceeding under the Rivers and Harbors Act when EPAct 2005 was enacted. These two initiatives were given special status by Section 388(d) of EPAct 2005 and were exempted from the site competition requirements. During the lengthy rulemaking process under EPAct 2005, MMS recognized that potential offshore wind developers needed to pursue site characterization and technology testing activities to support future leasing and development. In November 2007, MMS announced an interim policy authorizing such activities on the OCS under limited leases (see Section 7.3.2.2 on the interim policy) (MMS 2008b). A centerpiece of the new MMS regulations was the establishment of a leasing process for prospective developers. The next section outlines the provisions of the leasing process, including the competitive and noncompetitive options as outlined in the Final Rule (MMS 2009b).

7.3.2 Leasing Process

In developing a regulatory paradigm for the issuance of renewable energy leases, easements, and rights of way on the OCS, MMS had to consider how to ensure a fair return to the public for use of the sea and seabed while not putting an undue financial burden on new renewable energy companies. As noted in Subpart E of the rule, the regulatory framework prescribes a base rent of $3.00 per acre for leases and $5.00 per acre and $70 per statute mile for easements (right of use and easement) and right-of-way grants (see Subpart C). Leases that generate electricity also are subject to an annual operating fee based on a formula that includes nameplate capacity, hours per year, capacity factor, power price, and a fee rate. Limited leases pay the rental fee only because they may authorize only de minimus generation of energy for commercial sale (see Section 7.3.2.2.). In addition to these lease payments, a revenue-sharing provision through Section 388 amended OSCLA 8 (p. 2). Coastal states are entitled to 27% of the revenue from offshore leases in federal waters within 3 miles of the state's seaward jurisdictional boundary. These revenues can start with bids for a competitive lease or acquisition fees for a noncompetitive lease. Where multiple states are involved, the revenues are calculated assuming states are within 15 nm (28 km) of the geographic center of a project (for more details, see Subpart E of the MMS rule).

As explained in Subpart B, the framework establishes two leasing options—a commercial or a limited lease:

- A commercial lease allows full-scale project development and sale of power to the grid for 30 years.
- A limited lease allows resource assessment and technology testing for 5 years.

According to Snyder and Kaiser (2009), such a lease term is consistent with European policies that aim to limit speculation but allow enough time for fluctuations in the economic climate.

The first OCS renewable energy leases issued by MMS came under the interim policy. Five limited leases for authorizing construction of meteorological towers or buoys were offered in June 2009, and four were executed and went into effect in November 2009. The first commercial wind lease was offered to Cape Wind Associates in July 2010, and the first commercial wind leasing process under the regulatory framework was initiated with the issuance of a Request for Interest for an area off Delaware in April 2010 (MMS 2008b, 2007a, and 2010c).

7.3.2.1 Commercial Lease

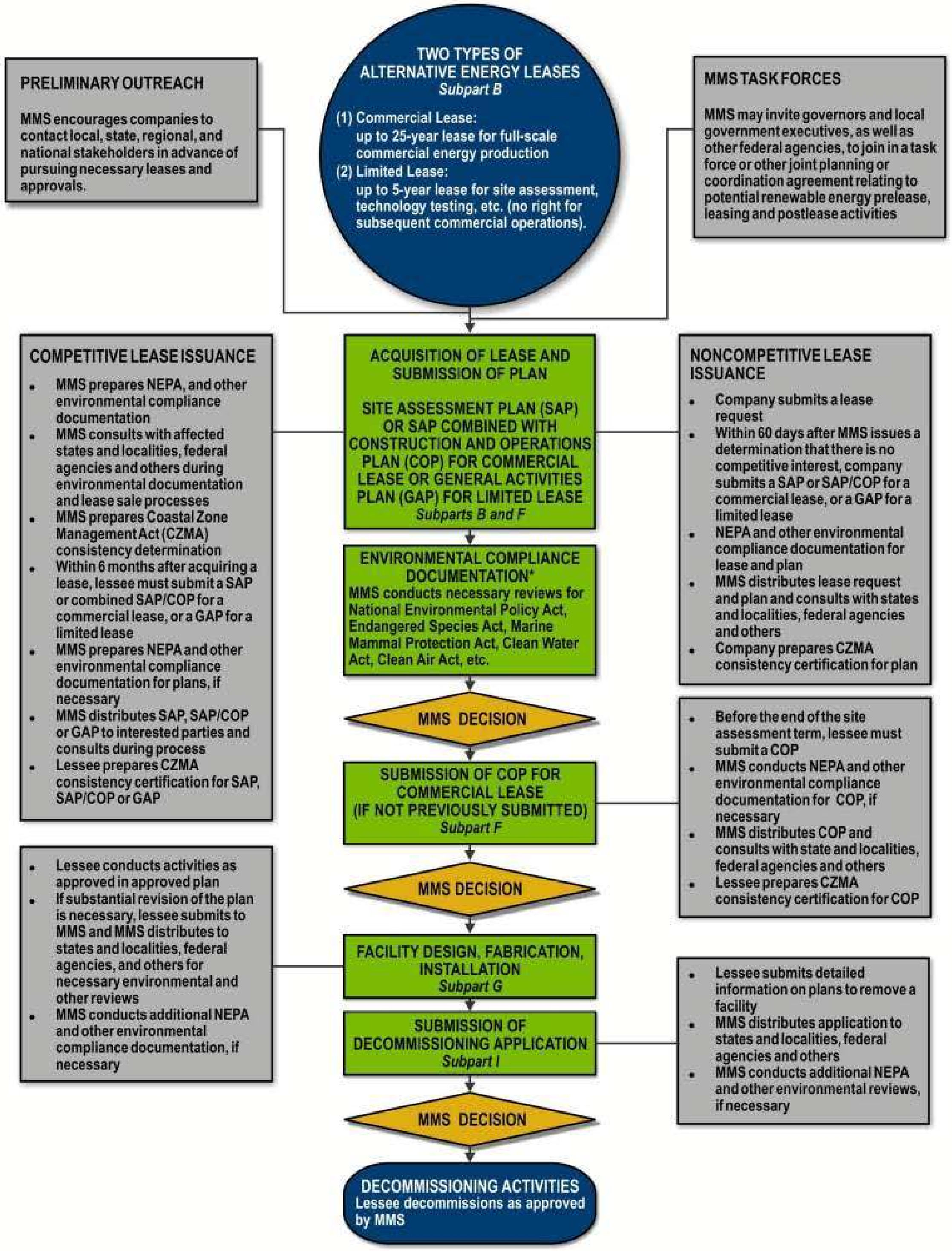
EPAct 2005 requires the issuance of competitive leases, although the rule allows for a noncompetitive process if no competitive interest exists in a particular area of the OCS after public notice (Figure 7-3). If competitive interest exists, BOEM will follow the competitive process outlined in the regulatory framework (§§ 210–225) and conduct an auction. If competitive interest does not exist, BOEM will move forward with the noncompetitive process outlined in the regulatory framework (§§ 226–231). BOEM begins the competitive process by issuing a “Call for Information and Nominations” to announce interest in leasing an area and to solicit relevant information. After this call, BOEM evaluates the nominations and information received, determines the leasing area to be analyzed under NEPA (and suitable alternatives), issues a proposed sale notice to inform the public and request comments on lease terms and conditions, and ultimately issues a final sale notice announcing the details of the auction at which bids for leases will be accepted.

Some factors that BOEM will consider in determining competitive interest include (Bradley 2009):

- Site locations
- Timing and type of proposed activities
- Infrastructure
- Anticipated power production and likely purchasers
- Environmental and resource data and information
- Qualifications to hold an OCS lease.

As shown in Figure 7-3, issuance of a commercial lease either competitively or noncompetitively requires NEPA review (see Section 7.4.2). It is likely that a lease sale Environmental Impact Statement (EIS) and associated consultations must be completed, which could take a minimum of 18–24 months. After acquiring a lease, the lessee must receive approval of required plans—a Site Assessment Plan (SAP) for construction of a data collection facility and associated activities and a Construction and Operations Plan (COP) for full build-out of the commercial generating facilities. In the final rule preamble, MMS assumed that geophysical and geotechnical surveys would be conducted either pre- or postlease under a permit from the USACE Nationwide Permit Program. MMS did nonetheless encourage developers to coordinate activities with MMS as well as USACE (§§ 285.605, 285.610, 285.625, 285.645), because this process has not been tested across the USACE Districts (MMS 2009e).

NEPA review is also required for these plans, calling for an Environmental Assessment (EA) or EIS for each, depending on the depth of analysis accomplished for each preceding step. For example, if a lease issuance EIS analysis is robust enough to cover the leasing scenario, as well as subsequent site assessment and construction and operations scenarios, the need for subsequent NEPA analysis when a plan is submitted could be minimized or fulfilled completely by the initial analysis. If initial analyses are not so robust, subsequent separate analyses will be needed for each plan, resulting in a longer, sequenced fulfillment of NEPA requirements. The regulatory framework is flexible enough to accommodate either approach, but the key to achieving efficiencies in review and approval of leases and plans is the availability of information for analysis. Thus, it is incumbent on the developers to develop and submit complete plan information as early as practicable to foster timely and efficient NEPA analysis in support of their projects.



TWO TYPES OF ALTERNATIVE ENERGY LEASES
Subpart B

(1) Commercial Lease:
up to 25-year lease for full-scale commercial energy production
(2) Limited Lease:
up to 5-year lease for site assessment, technology testing, etc. (no right for subsequent commercial operations).

PRELIMINARY OUTREACH

MMS encourages companies to contact local, state, regional, and national stakeholders in advance of pursuing necessary leases and approvals.

MMS TASK FORCES

MMS may invite governors and local government executives, as well as other federal agencies, to join in a task force or other joint planning or coordination agreement relating to potential renewable energy prelease, leasing and postlease activities

COMPETITIVE LEASE ISSUANCE

- MMS prepares NEPA, and other environmental compliance documentation
- MMS consults with affected states and localities, federal agencies and others during environmental documentation and lease sale processes
- MMS prepares Coastal Zone Management Act (CZMA) consistency determination
- Within 6 months after acquiring a lease, lessee must submit a SAP or combined SAP/COP for a commercial lease, or a GAP for a limited lease
- MMS prepares NEPA and other environmental compliance documentation for plans, if necessary
- MMS distributes SAP, SAP/COP or GAP to interested parties and consults during process
- Lessee prepares CZMA consistency certification for SAP, SAP/COP or GAP

ACQUISITION OF LEASE AND SUBMISSION OF PLAN

SITE ASSESSMENT PLAN (SAP) OR SAP COMBINED WITH CONSTRUCTION AND OPERATIONS PLAN (COP) FOR COMMERCIAL LEASE OR GENERAL ACTIVITIES PLAN (GAP) FOR LIMITED LEASE
Subparts B and F

NONCOMPETITIVE LEASE ISSUANCE

- Company submits a lease request
- Within 60 days after MMS issues a determination that there is no competitive interest, company submits a SAP or SAP/COP for a commercial lease, or a GAP for a limited lease
- NEPA and other environmental compliance documentation for lease and plan
- MMS distributes lease request and plan and consults with states and localities, federal agencies and others
- Company prepares CZMA consistency certification for plan

ENVIRONMENTAL COMPLIANCE DOCUMENTATION*

MMS conducts necessary reviews for National Environmental Policy Act, Endangered Species Act, Marine Mammal Protection Act, Clean Water Act, Clean Air Act, etc.

MMS DECISION

SUBMISSION OF COP FOR COMMERCIAL LEASE (IF NOT PREVIOUSLY SUBMITTED)
Subpart F

- Before the end of the site assessment term, lessee must submit a COP
- MMS conducts NEPA and other environmental compliance documentation for COP, if necessary
- MMS distributes COP and consults with state and localities, federal agencies and others
- Lessee prepares CZMA consistency certification for COP

MMS DECISION

FACILITY DESIGN, FABRICATION, INSTALLATION
Subpart G

- Lessee conducts activities as approved in approved plan
- If substantial revision of the plan is necessary, lessee submits to MMS and MMS distributes to states and localities, federal agencies, and others for necessary environmental and other reviews
- MMS conducts additional NEPA and other environmental compliance documentation, if necessary

SUBMISSION OF DECOMMISSIONING APPLICATION
Subpart I

- Lessee submits detailed information on plans to remove a facility
- MMS distributes application to states and localities, federal agencies and others
- MMS conducts additional NEPA and other environmental reviews, if necessary

MMS DECISION

DECOMMISSIONING ACTIVITIES

Lessee decommissions as approved by MMS

* Environmental compliance documentation will be as comprehensive as possible as early in the process as practicable. For example, if an applicant nominates an area for lease and submits a combined SAP/COP along with its nomination, MMS will conduct one comprehensive environmental review covering lease issuance, proposed SAP activities, and proposed COP activities. Thus, subsequent additional reviews may tier off the initial comprehensive review and focus on specific new issues.

Source: BOEM June 2010

Figure 7-3. OCS renewable energy process

Commercial leases have a site assessment term of 5 years in which to complete site characterization activities and prepare a COP for submission to MMS. The COP describes all activities and installed facilities to be used to gather, transport, transmit, generate, or distribute energy from the lease. If a project is deemed "complex or significant," which is likely for all commercial-scale generating facilities, the lessee must submit two additional reports before construction and installation: a Facility Design Report (FDR) and a Fabrication and Installation Report (FIR), as described in Subpart G. Also, the lessee must submit a Safety Management System, as described in Subpart H (MMS 2009b). The results of surveys and studies undertaken prelease must be described in the plans that are subsequently submitted (Final Rule, Subpart F) (§§ 285.610(b), 285.626(a), 285.645(a)). As discussed previously, if the COP is submitted with the SAP, NEPA reviews could take place simultaneously (§ 285.601(d)), reducing review time within the approval process. Though not required by EPAct, BOEM will conduct scheduled and unscheduled inspections of the OCS facilities and any vessels engaged in authorized activities. The inspection procedures are detailed on the BOEM regulatory compliance Web site at http://www.boemre.gov/regcompliance/inspect.htm. As specified in Subpart I, the agency will also review applications for decommissioning plans.

MMS began the leasing process under the final framework by establishing state task forces before issuing Requests for Interest (RFI). An RFI is a formal invitation for submissions of interest in obtaining one or more commercial leases from MMS, and it serves as the first step in the leasing process (Bradley 2009). The task forces help MMS comply with the requirement of EPAct 2005 calling for coordination and consultation and are a forum for MMS to share information about leasing activities with state and other government officials and for those officials to supply input on the implementation of the framework. MMS has named Delaware, New Jersey, and Rhode Island as priority states because those states made significant progress in preparing for OCS renewable energy development while the MMS regulatory framework was being developed. In addition to these three states, task forces are being pursued with North Carolina, Massachusetts, Virginia, Maine, New York, Maryland, and other states that have initiated offshore wind activities (MMS 2009f). As of December 2009, MMS had held task force meetings in Delaware, Rhode Island, Massachusetts, New Jersey, Virginia, and Maryland (MMS 2009c). Further solidifying development of an offshore program at MMS, Interior Secretary Salazar established an Atlantic Renewable Energy Office to manage and implement the renewable energy program (Quimby 2009).

In April 2010, MMS released the first RFI for Commercial Leasing for Wind Power on the Outer Continental Shelf Offshore Delaware under the new renewable energy framework (MMS 2010c). The RFI invited developers to submit descriptions of their interest in obtaining a commercial lease in the OCS lease areas off the coast of Delaware and asked other interested and affected parties to submit relevant comments and information. Several areas have been excluded because of NOAA fisheries concerns and potential conflicts with shipping lanes, among other reasons. The RFI detailed specific information that developers should submit. The Delaware RFI was developed in consultation with the state task force. The MMS announced that two entities responded to the RFI, and they are considering the responses before deciding the next steps concerning commercial wind leasing off Delaware. One of the entities, NRG Bluewater Wind, currently holds an interim lease in Delaware, which allows them to hold the lease for 5 years and to build a meteorological (met) tower (MMS 2009f).

BOEM asks interested and affected parties to submit the following information to indicate their interest in OCS leases:

- A description of the specific whole or partial OCS blocks or areas within the RFI area that are of interest for commercial development, including any required buffer area. Any indications of interest identifying areas greater than what would be reasonably necessary to develop a proposed commercial wind facility will not be considered as valid indications of interest. In addition, BOEM will not consider any areas outside of the RFI area in this process.
- A description of the objectives and the facilities necessary to achieve those objectives.
- A schedule of proposed activities, including those leading to commercial operations.
- Available and pertinent data and information concerning renewable energy and environmental conditions in the area of interest, including energy and resource data and information used to evaluate the area of interest.
- Documentation demonstrating that the applicant's qualifications to hold a lease as set forth in 30 CFR §285.107, including documentation demonstrating technical and financial capabilities of constructing, operating, maintaining, and decommissioning the facilities. Financial qualification can include documentation of access to sufficient capital to complete development. Examples of documentation of technical qualification can include evidence of international or domestic experience with renewable energy projects or other types of electric-energy-related projects.

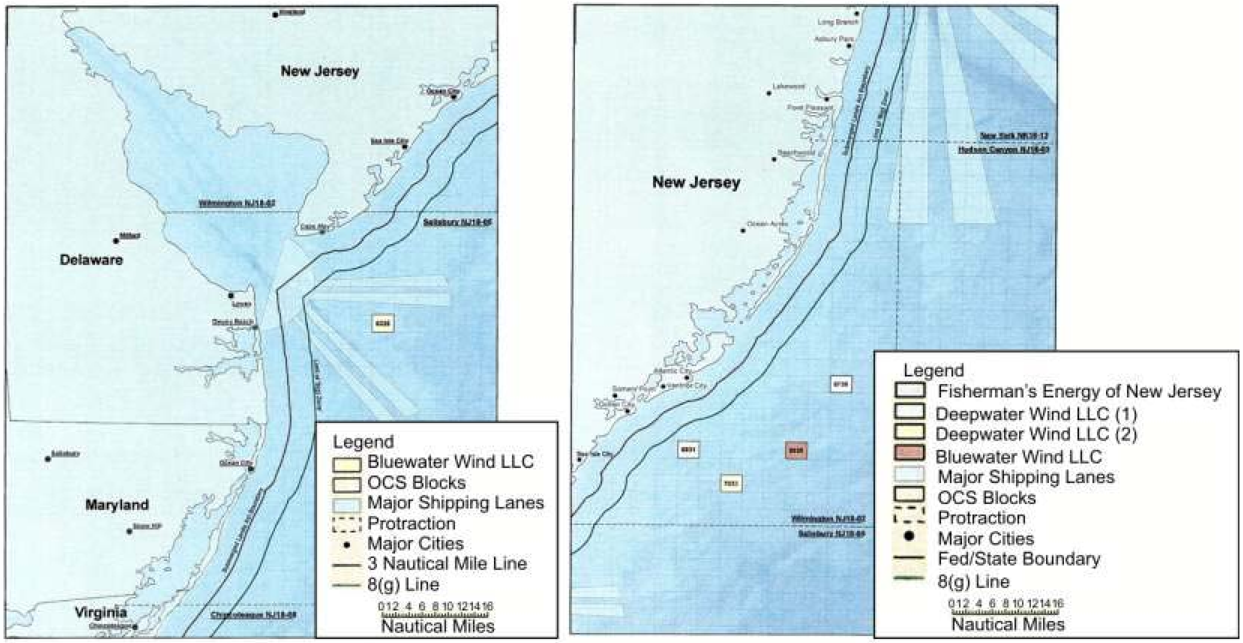
7.3.2.2 Limited Lease

In November 2007, MMS announced the interim policy for regulating renewable energy on the OCS (72 FR 214, pp. 62673–62675). Although it did not allow offshore wind projects to proceed, the interim policy engaged developers in a leasing process that allowed meteorological or marine data collection for 5 years (MMS 2007a). From the original 16 lease areas selected, five project applications were submitted, and MMS subsequently prepared a multiproject EA in cooperation with the USACE (Pardi 2009; MMS 2008b). The EA examines the potential effects of wind resource data collection activities offshore of Delaware and New Jersey during the 5-year life of the lease. Activities authorized by the leases include construction, operation, and decommissioning of seven meteorological towers with oceanographic data collection devices. The NEPA compliance path also included other environmental consultations with appropriate agencies, including examining endangered species and essential fish habitat.

Following the completion of the EA, five limited leases were offered on five OCS blocks off the coasts of Delaware and New Jersey (Figure 7-4; Clark et al. 2009, Pardi 2009):

- NRG Bluewater Wind Delaware LLC
- NRG Bluewater Wind New Jersey LLC
- Fisherman's Energy of New Jersey LLC
- Deepwater Wind LLC (two offerings).

As of November 2009, four of these leases had been executed (the exception was lease block area 6738—Deepwater Wind; MMS 2009d). The limited lease applies to operational rights for activities that support alternative energy, such as installing a met tower. The leases may be renewed, but cannot be converted to a commercial lease without being subject to a separate commercial lease process (Portman et al. 2009, 72 FR 214, pp.62673–62675). At present, it is unclear what the disposition of these lease sites will be after the 5-year limited lease period.



Source: Pardi 2009 (permission granted from BOEM).

Figure 7-4. OCS interim policy limited lease areas

Implementing an actual project will be important to assessing how the regulation works in practice, because several uncertainties remain. One uncertainty is estimating the time it takes from the initial bidding process to securing a permit for constructing a project. As noted previously, sequential NEPA analyses will take significantly longer to complete than combined analyses. Also, regulatory steps such as combining the lease sale and site assessment activities into one review will reduce potential timelines (MMS 2009b). Another uncertainty remains in how current projects under development, especially those with a limited lease, will be able to convert their lease to a commercial lease, and how the data they gather, such as resource assessments, will be handled, because of privacy concerns. Additionally, states have begun to hold competitive bids to preselect preferred developers for offshore wind, and the relationship to the federal process is still unclear. Finally, questions remain as to how developers will fulfill the needs of various reporting requirements. Although most utility-scale developments will probably take place in federal waters in the long term, to expedite initiation of offshore wind and the benefits to local and regional economies, projects may be developed first in state waters (Dhanju and Firestone 2009). On the other hand, state projects will also face unexpected hurdles such as PPA approvals and legal gaps such as provisions for conveying state submerged lands. Examples include Deepwater Wind's Block Island project, Fisherman's Energy's near-shore New Jersey project, and the LEEDCo project in Lake Erie adjacent to Cleveland, Ohio. Each of these state water projects are relatively small demonstration projects. In August 2010, Duke Energy's Pamlico Sound project was cancelled citing the "lack of economies of scale" for the proposed three-turbine project, although the company will continue data collection and feasibility studies with the University of North Carolina (AWEA 2010).

The regulatory framework has continued issuance of limited leases to authorize data collection and technology testing activities. Although it is unlikely that developers will wish to compete for a limited lease with a 5-year term, all leases are subject to the competitive requirement in EPAct 2005, so the framework describes both competitive and noncompetitive processes. Limited lease issuance also requires NEPA analysis, but it is likely that an EA would fulfill the requirement, because the leases do not authorize commercial generation and are for a term of only 5 years. Limited leases require a General Activities Plan (GAP) outlining the particular activities and operations to be undertaken. The GAP activities must undergo NEPA analysis, most likely documented by an EA. As with commercial leases, combined analysis of lease issuance and GAP activity scenarios could foster timely and efficient NEPA documentation.

7.4 NEPA Compliance and the BOEM Program

Any offshore wind power lease or permit issued by the federal government, or such a project undertaken by the federal government, would be subject to NEPA review (NEPA 1969). As the lead agency, BOEM is responsible for preparing the NEPA document and coordinating all federal, state, and local agency reviews as well as public comments. NEPA requires the consideration of potential environmental causes and effects of the proposed action (project) and a range of alternatives before an agency makes a decision to approve a project in federal waters. NEPA establishes requirements for preparing an EA or an Environmental Impact Statement (EIS). Under NEPA, an EIS is required for "major federal actions significantly affecting the quality of the human environment." Although various public and other stakeholders can suggest divergent and conflicting concepts for the requisite scope of work, the lead agency—in this case, BOEM—determines the level of NEPA documentation needed in accordance with the current state of knowledge and the thresholds of proposed impacts and benefits.

All federal agencies have the authority to define certain types of actions or projects as "categorically excluded" if the project is expected to have minimal environmental effects that can be mitigated. Most federal agencies have designated "routine actions" in which categorical exclusions are issued without an EA or EIS. Some types of oil rig installations and operations in the Gulf of Mexico are considered routine actions that do not require any NEPA analyses (CEQ 2010b). If the agency determines that some level of environmental analysis is needed, an EA may be prepared. Thereafter, the federal agency makes a "determination of significance" and either issues a Finding of No Significant Impact (FONSI) for the EA or determines that further assessment in the form of an EIS is required. An analysis must be made, and a FONSI issued or an EIS completed, before a federal agency can approve the construction and installation of a proposed action or project such as a wind generation plant. In some cases, the agency decides to prepare an EIS and skips the EA and FONSI determination. Who pays for the NEPA documentation and the studies needed to support the analyses could be changing. In the near future, the cost of NEPA document preparation and associated baseline studies might be borne by the government in some competitive cases. The Cape Wind pioneers, on the other hand, have been responsible for all the costs associated with the NEPA document, including ecological studies to fill gaps in knowledge. Government-sponsored and peer-reviewed environmental studies would assist in building the knowledge base and closing some significant gaps (see Section 8).

The lead agency preparing an EIS follows various standard procedural steps to complete the NEPA process. The following steps are outlined in the federal regulation:

- Define the purpose and need for the project
- Scope the environmental issues
- Coordinate public scoping hearings
- Incorporate public comments into the draft document
- Analyze a set of reasonable alternatives
- Design and implement environmental surveys and investigations to assess the cause and effect of the proposed action/project (in some cases, the developer/lessee may be responsible conducting such surveys and investigations)
- Establish thresholds of potential impacts to understand the context and intensity of the impacts, including adverse and beneficial ecological impacts
- Identify mitigation and monitoring strategies
- Examine the impacts of decommissioning.

7.4.1 The PEIS

To comply with NEPA, MMS determined that establishing the Renewable Energy and Alternate Use Program was a major federal action requiring a PEIS. After a period of development and review, the final PEIS for the program was published in November 2007 (MMS 2007b) and the Record of Decision (ROD) was published in January 2008 (MMS 2007c).

The PEIS has two purposes. First, it discusses potential environmental consequences of establishing the program and alternatives to establishing the program. Second, it establishes a baseline framework to mitigate environmental consequences through policy development and best management practices. The PEIS is broad in scale and does not focus on site-specific issues. It is a general review of the technologies involved in harnessing offshore wind, waves, and ocean currents for energy production and associated potential environmental effects. Further, the PEIS focuses on those technologies that are expected to be economically viable by 2014. The PEIS does not analyze renewable energy activity on the OCS off Alaska or Hawaii because commercial deployment of these technologies is not expected to be feasible in those areas in this timeframe. Because any project proposed under the program must comply with NEPA, subsequent documentations of environmental reviews are expected to tier off and reference the PEIS (Section 1508.28).

7.4.2 Federal Regulatory Nexus and NEPA Compliance

Although it is still determining the full extent of the NEPA review for OCS projects, BOEM is likely to require EISs for the first several commercial-scale projects. During the NEPA document preparation, BOEM will solicit input from other federal agencies with regulatory authority over the marine resources and the coastal region. During these consultations, the gaps and overlap of institutional and regulatory authorities become more apparent (Adams 2002). Numerous federal agencies in addition to BOEM, Federal Energy Regulatory Commission (FERC), and the USACE have significant ocean roles and responsibilities that will involve them in offshore renewable energy and development processes. Appendix A lists federal agencies and their interests in renewable energy activity on the OCS—an abbreviated list is shown in Table 7-2 below. In this section, the focus is on the maze of regulatory authorities governing specific activities at sea, including oversight of transmission lines, marine mammals and fisheries, and coastal zone management. State agencies also actively participate in this process under their own NEPA regulations, or State Environmental Policy Acts (SEPAs; see Section 7.5). Offshore developments must bury subsea transmission lines below state submerged lands (i.e., the first 3 nm) to connect the transmission line to the coast; this also involves the state in the approval process for offshore energy projects in federal waters.

The FERC maintains authority over interstate electricity transmission as well as the interconnection between the generator and the regional power network. Oversight of submarine power transmission line placement in federal waters, however, is shared between FERC and the USACE. Installing submarine cable systems, cable landfall transition structures, and the offshore wind park is subject to the regulatory permitting review and approval of USACE under Section 10.

Additionally, jurisdiction over the right of way of power transmission lines on the OCS was delegated to DOI under EPAct with the authority to grant a lease, easement, or right of way for renewable energy related uses of the OCS (Burton 2002). But FERC asserted additional authority over siting of ocean energy projects whose generator apparatus is physically located in the ocean (e.g., wave, ocean, tidal, and current power devices as opposed to offshore wind turbines) under the Federal Powers Act (Federal Power Act 1920). In one project, FERC won an administrative legal case affirming its involvement in permitting wave power projects in navigable waters (FERC 2003). Potential oversight by MMS for offshore wind and FERC for hydrokinetic project licenses created some jurisdictional battles as well as consternation in the renewable energy industries. MMS and FERC, however, signed a Memorandum of Understanding (MOU) to clarify responsibilities related to hydrokinetic projects on the OCS, but their roles and responsibilities are still uncertain, including who manages the NEPA documentation (FERC and MMS 2009).

NOAA has jurisdiction in some areas based on its responsibilities to protect and manage marine sanctuaries, marine national monuments for which it has been assigned jurisdiction, and portions of some estuaries. Any projects in or around a marine sanctuary or any protected area will be subject to NOAA review and approval (National Ocean Service 2010). In addition, NOAA administers the Coastal Zone Management Act (CZMA), a voluntary federal-state partnership in which states and territories develop their own coastal management programs (CZMP 2010). After NOAA approves a state's program, the state can review federal actions, licenses, or permits that could require land, water use, or natural recourse for "federal consistency," ensuring that the project follows enforceable policies of the state's coastal management program.

The U.S. Fish & Wildlife Service (FWS) and the National Marine Fisheries Service (NMFS, or NOAA Fisheries) also play an important consultation role in the NEPA process because they each have jurisdiction over some marine endangered species (including designating critical habitat) and marine mammals. NMFS also plays an important role in managing commercial fishing, including designating essential fish habitat. NOAA Fisheries is responsible for implementing the Marine Mammal Protection Act (MMPA) of 1972 prohibiting, with limited exceptions, the take of marine mammals in U.S. waters, including species of whales, dolphins, porpoises, seals, and sea lions (MMPA 2007). The incidental take provisions require the applicant to mitigate the taking to the lowest level possible, and to monitor and report results to NOAA Fisheries (U.S. Department of Commerce 2000). Incidental Harassment Authorizations (IHAs) allow for taking of marine mammals by "harassment" for a specified lawful activity that takes place for no more than 5 years per authorization. IHA criteria for acoustic harassment, when they have been finalized by the NMFS (U.S. Department of Commerce 2010), will be of particular interest for offshore wind because marine mammals could be affected by pile driving during of wind farm construction.

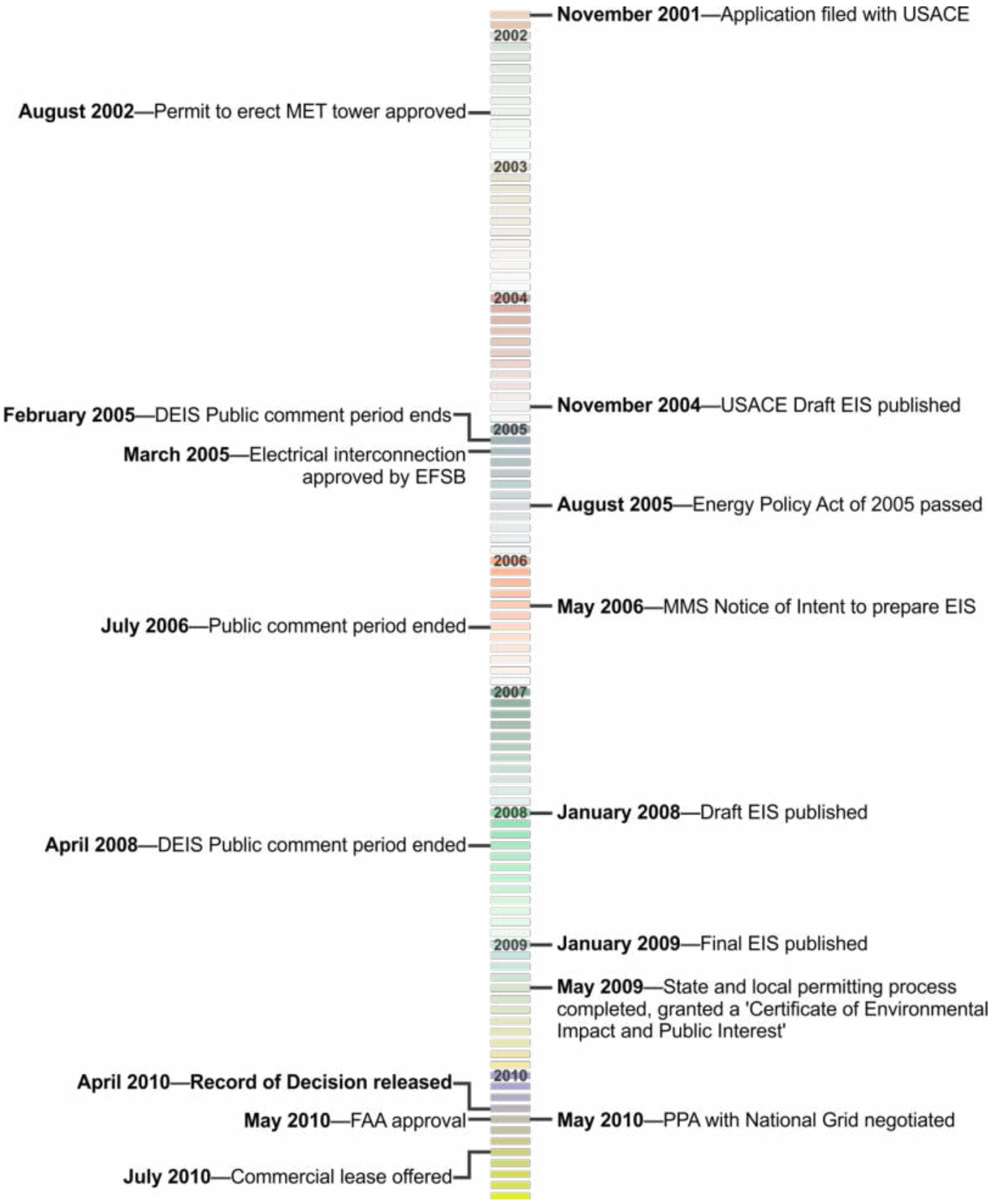
Within DOI, the National Park Service and FWS are responsible for protection and conservation of natural resources, including national parks and wildlife refuges. To clarify potential competing interests between energy deployments and habitat and species protections, MMS and FWS recently signed an MOU on migratory birds. FWS has jurisdiction over migratory birds and eagles under the Migratory Bird Treaty Act and the Bald and Golden Eagle Act. The MOU clarified that MMS will protect and enhance habitat of migratory birds during energy extraction, from, in this case, offshore wind farms (FWS and MMS 2009).

7.4.3 Cape Wind History: Challenges and Lessons Learned

In 2001, Cape Wind Associates, LLC submitted an application to the USACE to develop a wind farm in Nantucket Sound, off Massachusetts. The project originally proposed 170 wind turbines in Horseshoe Shoal for 454 MW of maximum electrical output, 4.7 miles from the nearest point on land. At that time, no specific departmental jurisdiction or oversight existed for offshore wind projects in federal waters. Acting under Section 10 authority of the Rivers and Harbors Act of 1899, USACE assumed the lead in the coordinating process. In 2002, Section 10 permit approval to install a meteorological tower was granted. About 17 different government agencies were involved in the Cape Wind NEPA document preparation and consultation processes. In 2004, the USACE released the Cape Wind draft EIS for public comment (Kaplan 2004). A year later, when MMS assumed expanded permitting authority under EPAct 2005, it requested that additional information be included in the DEIS to address all aspects of its "cradle to grave" jurisdiction. It took several more years of additional biological and ecological surveys, resource agency consultations, and public comment periods for the new NEPA process. In January 2009, MMS published the Final EIS (MMS 2009g and Cape Wind 2010).

One of the final agency challenges, before the issuance of the ROD, involved the National Park Service's Keeper of National Register of Historic Places. The Service determined that Nantucket Sound is eligible for listing in the National Register of Historic Places. In January 2010, Interior Secretary Kenneth Salazar announced that "… it is now time to move the Cape Wind proposal to a final decision point" and that he was "prepared to take the steps necessary to bring the permit process to conclusion" (MMS 2010b). He announced the ROD in April 2010. The Cape Wind project illustrates important lessons about navigating the federal permitting process and negotiating with resource agencies regarding data gaps and uncertainties. As mentioned previously, the federal and state governments may in the future share in paying for the expenses to prepare the NEPA document and support studies that fill in knowledge gaps, but in this case, these financial and schedule commitments were borne by the developer. Certainly, different sites will have different community as well as agency concerns.

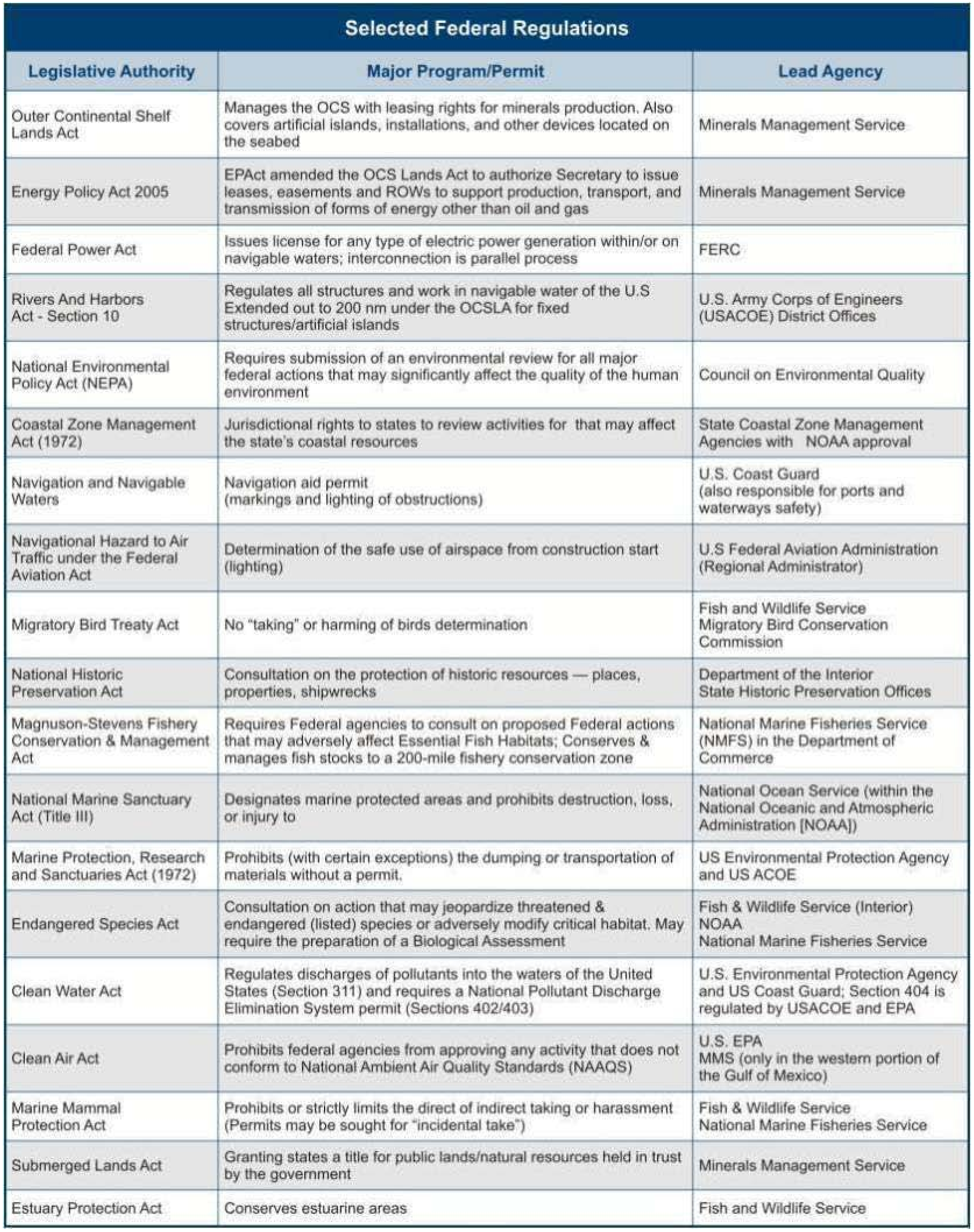
Another lesson relates to the critical nature of early community and state involvement because that might stave off future citizen suits. The current BOEM leasing process involves a state task force and other stakeholders at the inception of the application process. Cape Wind Associates first proposed this site without any specific agency procedures for offshore wind. Given the contentious nature of this first utility-scale project proposed in the nation, the developers completed more than 500 public presentations over the last 9 years, and many of them took place outside the required public hearing process (Pachter 2010). The timeline in Figure 7-5 is a chronology of the Cape Wind project milestones.



Source: Cape Wind Associates, LLC 2010; MMS 2009d; MMS 2009g.

Figure 7-5. Cape Wind history and timeline

Table 7-2. Selected Relevant Laws



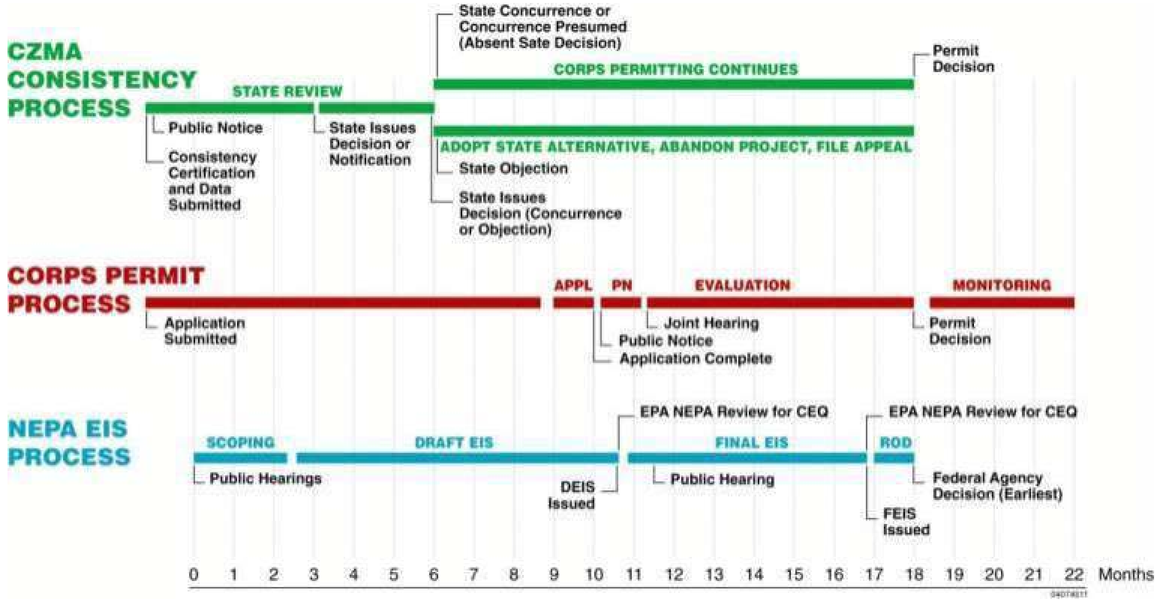
Selected Federal Regulations		
Legislative Authority	**Major Program/Permit**	**Lead Agency**
Outer Continental Shelf Lands Act	Manages the OCS with leasing rights for minerals production. Also covers artificial islands, installations, and other devices located on the seabed	Minerals Management Service
Energy Policy Act 2005	EPAct amended the OCS Lands Act to authorize Secretary to issue leases, easements and ROWs to support production, transport, and transmission of forms of energy other than oil and gas	Minerals Management Service
Federal Power Act	Issues license for any type of electric power generation within/or on navigable waters; interconnection is parallel process	FERC
Rivers And Harbors Act - Section 10	Regulates all structures and work in navigable water of the U.S Extended out to 200 nm under the OCSLA for fixed structures/artificial islands	U.S. Army Corps of Engineers (USACOE) District Offices
National Environmental Policy Act (NEPA)	Requires submission of an environmental review for all major federal actions that may significantly affect the quality of the human environment	Council on Environmental Quality
Coastal Zone Management Act (1972)	Jurisdictional rights to states to review activities for that may affect the state's coastal resources	State Coastal Zone Management Agencies with NOAA approval
Navigation and Navigable Waters	Navigation aid permit (markings and lighting of obstructions)	U.S. Coast Guard (also responsible for ports and waterways safety)
Navigational Hazard to Air Traffic under the Federal Aviation Act	Determination of the safe use of airspace from construction start (lighting)	U.S Federal Aviation Administration (Regional Administrator)
Migratory Bird Treaty Act	No "taking" or harming of birds determination	Fish and Wildlife Service Migratory Bird Conservation Commission
National Historic Preservation Act	Consultation on the protection of historic resources — places, properties, shipwrecks	Department of the Interior State Historic Preservation Offices
Magnuson-Stevens Fishery Conservation & Management Act	Requires Federal agencies to consult on proposed Federal actions that may adversely affect Essential Fish Habitats; Conserves & manages fish stocks to a 200-mile fishery conservation zone	National Marine Fisheries Service (NMFS) in the Department of Commerce
National Marine Sanctuary Act (Title III)	Designates marine protected areas and prohibits destruction, loss, or injury to	National Ocean Service (within the National Oceanic and Atmospheric Administration [NOAA])
Marine Protection, Research and Sanctuaries Act (1972)	Prohibits (with certain exceptions) the dumping or transportation of materials without a permit.	US Environmental Protection Agency and US ACOE
Endangered Species Act	Consultation on action that may jeopardize threatened & endangered (listed) species or adversely modify critical habitat. May require the preparation of a Biological Assessment	Fish & Wildlife Service (Interior) NOAA National Marine Fisheries Service
Clean Water Act	Regulates discharges of pollutants into the waters of the United States (Section 311) and requires a National Pollutant Discharge Elimination System permit (Sections 402/403)	U.S. Environmental Protection Agency and US Coast Guard; Section 404 is regulated by USACOE and EPA
Clean Air Act	Prohibits federal agencies from approving any activity that does not conform to National Ambient Air Quality Standards (NAAQS)	U.S. EPA MMS (only in the western portion of the Gulf of Mexico)
Marine Mammal Protection Act	Prohibits or strictly limits the direct of indirect taking or harassment (Permits may be sought for "incidental take")	Fish & Wildlife Service National Marine Fisheries Service
Submerged Lands Act	Granting states a title for public lands/natural resources held in trust by the government	Minerals Management Service
Estuary Protection Act	Conserves estuarine areas	Fish and Wildlife Service

7.5 State Permitting Challenges

As noted in Section 3, permitting processes vary from state to state, and the length of the approval process varies considerably (Kopf 2009). Even if a project is located in federal waters, developers must receive state permission for transmission cables making landfall, for connecting with the grid (including building substations), and for shipping and dredging activities (Firestone et al. 2004).

The states can also review proposed renewable energy activities and their environmental effects for consistency with their federally approved coastal zone management programs pursuant to the CZMA (CZMP 2006), which strengthens the role of the state in OCS renewable energy leasing and development process and associated NEPA review. State agencies oversee the state coastal management plans to determine whether a proposed activity is consistent with state policies. If the proposed activity is consistent with the state coastal zone plan, federal permits can be granted. If the review finds inconsistencies, the state can choose to negotiate conditions with the applicant or it can deny the permit and the applicant can ask the Secretary of Commerce to override the state decision (15 CFR 930). This CZMA process varies from state to state, and typically the states have 6 months to determine consistency. In addition, within 3 nm from the coast, the Great Lakes, and other inland water bodies, an applicant for a federal permit also must obtain a 401 Water Quality Certification under the Clean Water Act (CWA) to ensure that the project meets state water quality standards (i.e. thermal pollution, pollution, changes to water flow, and turbidity).

Figure 7-6 shows the USACE process that will govern offshore renewable energy development in state waters and the Great Lakes and its relationship to NEPA and CZMA reviews. USACE will most likely lead the federal permitting responsibilities along with the state natural resource agencies in those states (see Section 3 for state project information and Section 7.5.1 for a Great Lakes overview). The USACE Section 10 permit relates to structures altering or obstructing navigable federal or state waters (e.g., a wind turbine), but it does not refer specifically to energy-related projects and it does not allow for ownership or leasing of the seabed by a developer (River and Harbors Act 1899). USACE's authority to regulate potential obstructions to navigation extends to artificial islands, installations, and other devices located on the OCS seabed by Section 4(f) of OCSLA of 1953 (43 USC § 1333).Thus, the USACE Section 10 permit is issued for the approval of the design and construction of the turbine structures and transmission cable to shore without conveying property rights for the sea floor or providing for certification or periodic inspections (River and Harbors Act [USACE 1899]). In addition to Section 10, the USACE authority is grounded in Section 404 of the 1972 CWA, in which Congress broadened USACE's mission to include restoring and protecting the nation's water quality. Under the CWA, however, its jurisdiction extends only 3 nm from shore. A USACE Section 10 permit will be required for all renewable energy projects on the OCS, but BOEM will be the lead agency for such projects and the Section 10 permit process will be incorporated into the overall leasing and development processes under the BOEM regulatory framework.



Source: Adams 2002.

Figure 7-6. Relationships among the USACE Section 10 permit, CZMA consistency determination, and the NEPA EIS process (timelines are approximations)

Under the Submerged Lands Act (2002), states are permitted to lease state-owned lands, but typically such a lease is not granted until all federal and state permits and approvals have been gained. Over the last several years, several states are developing new rules relating to leasing state submerged lands in relation to offshore wind (Michigan GLWC 2010; Texas GLO 2009), and other states such as Massachusetts, Rhode Island, and New Jersey are developing marine spatial planning policies. In some states (e.g., Virginia and Massachusetts), projects must receive local as well as state approval. States have jurisdiction over activities within state waters, but projects located within navigable waters may be in areas of federal jurisdiction, as discussed previously.

Some states also have their own NEPA regulations and public review process, but they can collaborate with federal agencies to combine documents into one (as Massachusetts did with the Cape Wind EIS for MMS and the state environmental impact report). The NEPA process requires consultation with all relevant state agencies having jurisdiction over resources that may be affected by a proposed project, including historical properties, archaeological sites, and tribal resources. Also, local planning and zoning boards and tribal nations may have interests that would be affected. Some states agencies that regulate the generation of power will require that projects demonstrate “public convenience and necessity.” The necessity is sometimes discussed only as a need for power generation in a given area rather than as a need for renewable energy (Kimrey 2008; Renewable Energy Policy Project 2003). The Great Lakes are an example of a complex regulatory structure for bodies of water that overlap multiple state, tribal, and international boundaries.

7.5.1 Great Lakes

With eight states and two Canadian provinces claiming jurisdiction over the waters of the Great Lakes, numerous competing interests and activities relate to offshore wind energy. Considered state waters because the coastal states own the bottomlands (the land lying below the ordinary high water mark) of the lakes, the state agencies will play central roles in siting and permitting offshore wind projects. Each state issues Great Lakes bottomlands permits under the authority of Part 325, Great Lakes Submerged Lands (1955 PA 247) and the Natural Resources and Environmental Protection Act (1994 PA 451, as amended). This permit protects the waters of the Great Lakes and the Great Lakes bottomlands. In addition, a Section 10 permit from the USACE is required for most activities that alter the Great Lakes coastal areas, including offshore wind projects. As mentioned previously, because BOEM does not have regulatory authority, it is likely that the USACE will serve as the lead federal permitting agency. In addition, the lakes border lands of Native American tribes and the Canadian provinces of Ontario and Quebec. These create unique regulatory challenges, for example, where 35 tribal nations have rights in and around the shores of the Great Lakes.

7.6 Structural Safety Certification

The bulk of the U.S. effort in offshore wind industry development has been expended in permitting, site selection, site evaluation, and preconstruction studies aimed at obtaining regulatory approval. Once approval is obtained, however, which has happened so far only for Cape Wind and a very few state projects, the project developers will face a new set of regulatory hurdles to demonstrate that wind turbines are designed, manufactured, and installed to withstand the site-specific conditions.

7.6.1 BOEM Infrastructure Authority

A major portion of the new BOEM domain will be to ensure the structural safety of offshore wind turbines by certifying and monitoring construction of the turbines, their substructures, and the associated infrastructure. Although no such process currently exists in the United States for land-based wind turbines, most European countries require turbine certification compliance with some recognized group of international standards to ensure structural integrity.

The BOEM is responsible for regulating the development of oil and gas reserves in the U.S. OCS waters. The bureau has significant experience with the design, fabrication, and installation of offshore structures, so it is appropriate that it assumes this role for wind energy projects as well. The authority granted to BOEM by EPAct 2005 to oversee offshore wind energy installations includes reviewing and approving plans for:

- Engineering design and structural safety
- Installation and construction
- Operation
- Ongoing maintenance throughout the life of the structure
- Decommissioning.

BOEM is also responsible for any inspections that may be needed to ensure compliance with the final approved plans and continued conformity with the original design as the project ages.

7.6.2 Offshore Codes and Standards

During the early 1990s, the wind energy industry—through the International Electrotechnical Commission (IEC)—began to establish international standards for land-based wind turbines. Technical Committee 88 (TC88) was established to develop and manage a suite of applicable standards for wind turbines. The primary standard for structural design requirements is IEC 61400-1 Edition 3 (IEC 2005). It defines design classes, external (environmental) conditions for each design class, design load cases, fault conditions that must be included in the design, procedures for assessing all static and dynamic loads, electrical requirements, and methods for assessing the site-specific suitability of the turbine. Perhaps the most important part of the standard is a detailed definition of the turbulent wind environment. Because the detailed characteristics of wind are so important to unsteady aerodynamic load distributions along the rotating blades, it is crucial that this part of the external conditions be defined consistent with analytical theory used for rotor load estimation.

In 2000, IEC/TC 88 began to develop an offshore wind turbine standard, Offshore Requirements for Wind Turbines, IEC 61400-3 (IEC 2010). It defers to IEC 61400-1 for the wind turbine aspects of the design requirements and relies on existing mature standards for setting general support-structure requirements. The IEC offshore committee surveyed structural guidelines for offshore oil and gas structures, including the American Petroleum Institute (API), International Standards Organization (ISO), Det Norske Veritas (DNV), and Germanischer Lloyd (GL) guidelines, and attempted to use them as the basis for the new IEC 61400-3 requirements. A European-funded project Requirements for Offshore Wind Turbines (RECOFF) included formal comparisons of these different standards and assessed the suitability for wind turbines (Frandsen et al. 2005). The RECOFF study concluded that for most “support structure” requirements, standards such as API and ISO could be used. The crucial deficiency, however, was the manner in which dynamic loads were estimated. Wind turbines are uniquely subjected to both wind and wave stochastic loading, and both loading sources are nearly equal in importance with respect to dynamic excitation of the wind turbine. IEC 61400-3 is the only international standard that specifically considers these offshore wind turbine issues. It is less mature than other international standards and guidelines, but because it is based on earlier standards, it represents an integrated version of all the work that preceded it. Also, because it is part of a series of international standards that consider the broader wind industry’s needs (such as verification testing for performance, structural design compliance, power quality, gearbox design requirements, and small turbines), it is the best available standard for the issues of structural safety for offshore wind turbines.

Codes such as the IEC 61400-3 and API RP 2A-LRFD (1997) have some overlapping design requirements for wave and current loading conditions. A direct comparison of the IEC and API standards shows, however, that other specific differences should be integrated. Examples of the differences include the following:

- The IEC uses a 50-year return period for defining extreme environmental design conditions, and API RP 2A-LRFD (1997) uses a 100-year return period for defining design conditions for high-consequence platforms.
- API RP 2A-LRFD (1997) prescribes three levels of design wave height based on the platform type and its failure consequence—IEC requires that designs use the measured site wave-height statistics and wind environment and adjusts component safety factors based on the consequence of that component failing.
- API RP 2A-LRFD (1997) is a basis for the design of offshore structures subject to wave, wind, current, and earthquake loading conditions; it does not, however, consider the scope and range of all conditions required for designing wind turbine support structures. Similarly,

IEC 61400-3 lacks some of the detailed provisions given by API RP 2A-LRFD with respect to some offshore engineering practices.

These are some examples of the code differences, but the greatest challenge is to develop a full understanding of the conflicting requirements and the real differences in safety levels for these codes so that a guideline can be developed to clarify what BOEM will require from each developer. This comparison must also evaluate the similarities and differences in the failure consequence for the types of facilities. These consequence-of-failure issues should include human life safety, environmental impact, energy supply reliability, and economic factors. Ultimately, BOEM must determine the areas where existing standards are applicable and resolve any conflicts that may exist in establishing equivalent safety requirements for the design of offshore wind turbine systems.

The best approach will most likely use IEC standards with API RP 2A-LRFD (1997) and other standards to fill critical gaps. MMI Engineering compared structural reliability (Dolan et al. 2009) and concluded that the IEC offshore wind standard and the API RP 2A-LRFD (1997) standard supplied similar levels of safety for offshore wind turbines in three reference sites in U.S. waters (Dolan et al. 2009). Although this study gave needed assurance that API and IEC could be combined to address both the offshore foundations and substructure (API 1997; API RP 2A-LRFD) as well as the wind turbine itself (IEC 61400-3), it was not comprehensive enough to fully address tropical storms that frequent the Atlantic coastline and the need for specifications for turbines to withstand their impact. The need for this work has been recognized by IEC/TC-88 and will be examined by a follow-on maintenance team that will revisit IEC 61400-3 begining in 2010.

7.6.3 Type versus Project Certification

Very few legal requirements exist concerning structural safety in land-based U.S. wind energy installations and no single agency is responsible for those that do exist. The structures must meet local and state building codes, and the electrical systems must meet electrical standards. Both of these, however, are inadequate for defining wind turbine design requirements, and no overarching permitting process addresses structural safety. Instead, the process is commercially driven. Owners and operators choose to require type-certified wind turbines for their projects. The turbines are usually certified to IEC or other European standards.

Recognizing that the offshore certification process is unique, IEC/TC 88 drafted a second edition of its wind turbine certification scheme IEC 61400-22 (IEC 2010), which passed the final voting stage and is being prepared for IEC executive approval. This new edition will rely on IEC 61400-3 for technical requirements as well as define the certification process. Both IEC 61400-3 and IEC 61400-22 assume that the turbine will be certified to a set of design classes specified in IEC 61400-1 Edition 3, and the support structure will be designed to site-specific conditions. The standard development process assumes that multiple parties will be responsible for different aspects of the project and offers guidance for each phase of the project. It allows for using other standards for the support structure, such as API RP 2A-LRFD (1997), ISO, DNV, and GL Windenergie Group specifications (though the last two specifications are heavily influenced by API for their offshore support structure guidance).

One primary technical difference in these design standards relates to the fact that wind turbines are mass-produced as opposed to the custom, single-unit design for each platform in the oil and gas industry. After final permitting of wind plants, many turbines of the same design type are installed (hence, the term “type certification” for a turbine that meets a generic design class rather than site-specific environmental conditions), and most likely the same design has operated in other sites, lending experience to the pitfalls of any new installation. Of course, the physical environmental conditions of each new site must be integrated into the engineering evaluation of site suitability, which may be problematic in some hurricane areas where extreme conditions can exceed the design loads of the type-certified turbine. The IEC recognizes that turbines will be designed and tested long before most projects are even conceived. Thus, the IEC standards require and give guidance to evaluating the suitability of a type-certified turbine for specific site conditions. This assessment to evaluate single-unit type certified wind turbines in the context of a multiple-turbine array should become part of new BOEM regulations. In accordance with IEC, this is called project certification, but BOEM has not yet adopted an approach in this regard.

Also, project certification follows the offshore wind facility through installation but does not include ongoing monitoring throughout the life of the project. With oil and gas installations, operations have a greater degree of inherent risk associated with human life safety and environmental safety, as exemplified by the Deepwater Horizon disaster in the Gulf of Mexico in April 2010, which leaked millions of gallons of oil for nearly 3 months and took the lives of 11 men on board. Although the work on wind turbines cannot be considered risk-free, the lower consequences of failures must be taken into account when prescribing long-term inspection and operational measures to control unmanned wind projects, with consequences that are mostly economic and borne by the developer. The degree to which BOEM will require inspections of offshore wind turbines is yet to be determined.

7.6.4 Structural Safety Compliance

BOEM’s basic requirements for oil and gas installations are similar to the quality system of IEC 61400-22 wind turbine project certification. Many wind turbine manufacturers are familiar with these basic steps, especially the third-party engineering evaluation. Many differences exist, however, between offshore wind plants and oil and gas operations. The critical technological differences should be reflected in the standards. A significant part of the cost and economic viability of offshore wind plants will depend on the specific structural safety requirements chosen by BOEM.

As detailed previously, all commercial utility-grade wind turbines undergo extensive type-certification evaluations based on IEC or similar standards. Financial institutions are increasingly requiring expert evaluations of land-based turbine designs and installations along with periodic operations surveillance.

BOEM requires the following steps to comply with current oil and gas project permitting requirements for structural safety:

1. Approval of a plan for exploration drilling of certain sectors of OCS
2. A preliminary project plan to develop full production of that OCS sector (a prepermitting step to avoid gross misconceptions and agree on the fundamental steps required for project permitting)
3. Detailed engineering design documentation for all aspects of the project (generally defined by API RP 2A-LRFD [1997])
4. Third-party evaluation of the project plans and engineering documentation by a BOEM-approved engineering consultant experienced in offshore oil and gas installations

5. BOEM review of the third-party engineering evaluation and reconciliation of any discrepancies between BOEM requirements and the project documentation
6. Third-party oversight of all aspects of the project installation, commissioning, operations throughout the life of the structure, periodic inspections of structural health, and finally decommissioning.

This process, with its sector specification applicable to oil and gas, may not be effective in the near term for offshore wind. In this regard, the BOEM "does not want to limit the possibilities of development in federal waters by identifying locations" for development, but will seek industry proposals through a "call for interest" that is not limited to predetermined sectors (MMS 2007b).

The final rule, CFR 285, released in April 2009, addresses, among other things, specific issues related to the design, installation, and safety of offshore wind facilities, but not a detailed scope of requirements. This phase of the project follows the process of obtaining a lease for the project site, which was covered earlier. Most offshore wind turbines will be delivered to U.S. projects from manufacturers with a type conformity certificate, but this will not guarantee that they are suitable for installation at a specific site. To address this, BOEM requires developers to submit design and installation documents for BOEM approval. These documents, outlined in Subparts F through J, are as follows:

- Facility Design Report
- Construction and Operating Plan
- Fabrication and Installation Report
- Safety Management System
- Decommissioning Plan.

The review and oversight of these documents can be carried out by a certified verification agent (CVA), a third-party evaluator hired by the developer to conduct a full evaluation of the project and assure BOEM that the project has been developed in accordance with best practices. The qualifications and selection process of CVAs are still being discussed. In June 2010, an independent committee, Offshore Wind Energy Turbine Structural and Operating Safety, was formed under the Transportation Research Board (TRB) of The National Academies to consider this issue and make recommendations to BOEM (The National Academies 2010). In addition, AWEA, under the direction of the American National Standards Institute (ANSI), formed a national group under their standards coordinating committee made up of experts from the wind industry, the oil and gas industry, government, certifying bodies, and classification societies to establish a recommended roadmap, or guideline, to advise and inform BOEM and the U.S. offshore wind industry on design methods and standards applicable to offshore wind. The combined efforts of these two groups will lead to a more comprehensive approach to offshore turbine development in the United States, and will give BOEM an opportunity to clarify the regulations governing offshore wind turbines while strengthening the rules to ensure uniform safety.

7.7 Findings and Conclusions

The lack of U.S. wind energy policies and the evolving institutional and regulatory processes governing the planning, siting, and deployment of offshore wind projects present serious challenges. In June 2010, MMS was reorganized and renamed BOEM. These new activities and bureaucratic reorganizations have created significant regulatory uncertainties. The following conclusions describe findings based on the current evolutional rules and structures.

- A price placed on carbon emissions would accelerate the transition toward offshore wind. National policies specifically designed to accelerate deployment of offshore wind energy would influence greatly the direction of institutional and regulatory mechanisms on both state and federal levels. Recent steps taken by the Obama administration outline a national renewable energy strategy, though as yet specific standards, deployment goals, and long-term policy mechanisms for offshore wind are lacking.
- The White House's Executive Order 13547 and the formation of the National Ocean Council begin regional coastal and marine spatial plans that will involve frequent and robust engagement strategies under the leadership of CEQ (CEQ 2010a). This initiative, however, does not have a renewable energy or offshore wind focus.
- The CEQ-led CMSP framework is now a building block for a more consistent ocean policy that will balance competing uses of the OCS such as offshore wind resources and an ecosystem-based vision for the nation's coastal waters. Selecting candidate sites and analyzing potential cumulative effects will involve mapping compatible and conflicting areas of human use along with performing scientific assessments across the marine environment. This marine spatial planning process is essential for large-scale development of offshore wind.
- Several states are also moving toward marine spatial planning for state waters (e.g., Michigan, Massachusetts, Rhode Island, and New Jersey)—this will greatly assist the federal government in identifying potential sites for renewable energy. Federal leadership is critical for an efficient process that links marine spatial planning with candidate sites for offshore wind energy.
- As described in Section 6, national scenarios and modeling efforts have considered offshore wind, and these have been widely vetted and disseminated. Deployment scenarios include 54 GW by 2030 based on the scenarios presented in the 20% report (DOE 2008a) and NREL's Renewable Energy Futures (REF) study that projects a range of future deployment scenarios by 2050 (Pre-press 2010). How would the current regulatory structures evolve to support these developments in a sustainable manner? For example, if we consider the 54 GW scenario by 2030, it could involve more than one-hundred 500-MW facilities over 20 years or five utility-scale projects installed per year. The current paradigm for leasing and permitting and the potential rate of deployments would not only be slow but also probably be unrealistic to support the deployment of 54 GW by 2030.
- The release of the MMS rule (now authorized under BOEM) in the second quarter of 2009 was a clear step in establishing a regulatory pathway for siting offshore wind plants. The Cape Wind ROD and the issuance of the first commercial lease on the OCS in 2010, the release of the RFI for commercial leases in Delaware, and the formation of several state task forces demonstrate a forward movement in the federal agency.

- Other signs of movement are visible on the federal level. In June 2010, DOE and DOI signed an MOU to spur cooperation in wind technology siting and permitting, resource characterization, technology standards, public engagement, and establishment of deployment goals (MOU 2010). This milestone forges an important federal working relationship to accelerate the offshore wind industry and overcome barriers. It is hoped that these activities will facilitate developments "by pursuing priority leasing and efficient regulatory processes for sites with high, commercial-scale offshore wind and water power development potential."
- The nation's regulatory structure should develop integrated national and state energy codes and standards for offshore wind. These will allow for efficient review and approval of project siting and safe and efficient permitting processes. This requires updating national laws and oversight agencies. The TRB of the National Academies is addressing this issue and will make recommendations to BOEM (The National Academies 2010). It is strongly recommended that BOEM adopt the TRB findings.
- The patchwork of federal regulations and fragmented institutions governing ocean uses, along with the MMS reorganization to BOEM, subjects developers and states to protracted processes for siting and permitting. Underlying concerns about this relatively new technology, gaps in the knowledge base, and new legal interpretations (e.g., Clean Air Act) are contributing to the delays in resource agency decision making. As we have seen in Europe, setting national offshore wind targets and government funding of priority environmental studies could help create more efficient decision timelines and fill in gaps in rules more effectively.
- Because the permitting and leasing processes are tied to NEPA compliance and the assessment of environmental and social effects of installations, building the knowledge base about the marine environment and the coastal communities at site-specific and regional locations is essential and must be done more rapidly to address gaps and uncertainties.
- The NEPA requirements need to be examined by high-level agency decision makers and the CEQ. The process needs to reflect the level of risk posed by offshore wind compared to other alternatives on the OCS and the life-cycle options for electricity supply (see Section 8 for more details on a risk framework).
- Possible opportunities for more efficient NEPA compliance procedures may involve defining new categorical exclusions for testing activities on the OCS; substituting requirements for shorter preconstruction studies with longer term, postconstruction monitoring programs, jointly funded with industry and government; and creating binding timeframes for agency consultations along with additional resources to assess permit applications more expeditiously. These ideas would also be relevant to state governments, many of which have their own NEPA statutes.
- The federal government must partner with state governments in coastal areas and the Great Lakes to create an offshore wind strategy. Activities in state waters could accelerate the offshore wind industry to help meet their RPS goals and to realize socioeconomic benefits. The states, however, must more rapidly develop their leasing structures and cooperate with their resource agencies. A strategic partnership between federal and state governments is essential for siting and permitting offshore wind in the United States.

- Stakeholder engagement through the NEPA process must also be examined. Although this is a valuable mechanism for involving the public, it is not sufficient in itself for building partnerships and community support for transitioning to a gigawatt-scale offshore wind industry. Long-term commitments to work with state and local communities undergoing transitions will help set the stage for accelerated market penetration (see Section 8).

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8.0 Environmental and Socioeconomic Risks of Offshore Wind Projects

8.1 Introduction

This section looks at the potential risks and uncertainties associated with siting, constructing, and operating offshore wind facilities within a gigawatt-scale deployment strategy. Balancing varied social interests (e.g., lower energy costs, quality of life, energy independence, and reduced power plant emissions and waste streams) with ecological considerations (e.g., habitat health, species and resource protections, and coastal management) will require a careful analysis of competing values to understand and optimize this interplay for the benefit of society. This section summarizes different sectors of risk, based on the available evidence from Europe (see Section 8.5) and building on previous synthesis reports such as *Worldwide Synthesis and Analysis of Existing Information Regarding Environmental Effects of Alternative Energy Uses on the Outer Continental Shelf* (Michel et al. 2007), the Cape Wind Final Environmental Impact Statement (FEIS; MMS 2009a), and recent state-funded research. Several analytical constructs and themes frame environmental and social concerns related to offshore wind development:

- Applying coastal and marine spatial planning (CMSP)as national policy under the leadership of the Council on Environmental Quality (CEQ)-led National Ocean Council, as described in Section 7. The principles of ecosystem-based management and adaptive management to protect, restore, and improve stewardship of the ocean are related directly to siting of offshore wind on the Outer Continental Shelf (OCS) along with a robust stakeholder strategy to determine use conflicts and compatibilities (ERG 2010).
- Comparing the potential risks to other threats in the coastal and marine environment, because marine systems are affected by multiple stressors (Crain, Kroeker, and Halpern 2008). In the environments where wind farms are proposed in the United States, there are already known stressors to both humans and the marine environment (Halpern et al. 2008). Reliance on the oceans has come at a cost (Millennium Ecosystem Assessment Report 2005).
- Ensuring that the length of time and depth of field surveys and research to fill data gaps reflects the proper level of risk posed by offshore wind as compared to other alternatives on the OCS and the life-cycle options for electricity supply (see Section 8.2).
- Focusing on individual sectors of scientific analyses (i.e., mammals, birds) at a particular site or region, driven by National Environmental Policy Act (NEPA) compliance and resource agency consultations. But sector-by-sector studies do not capture the sensitivities of the ecosystem and communities or cumulative effects. An alternative analytical framework—an integrated risk analysis—is proposed that includes environmental and social risks, but also is a more powerful analytical tool encompassing broader areas such as technology choices, transmission, public engagement, and siting strategies (see Section 8.2.2).

The need to transform our energy portfolio is underscored by climate change impacts that will dramatically affect the ecosystems as well as the economies of the United States (NRC 2010a, 2010b; Karl, Melillo, and Peterson 2009; IPCC 2007). For example, the oceans are becoming more acidic, coastal ecosystems are seriously threatened by sea level rise, and freshwater resources and food security are also threatened. Offshore wind has the potential to be a significant, low carbon energy source that can help reduce the climate change threat and reduce conventional fuel impacts, but the current state of our oceans, coasts, and Great Lakes needs to be taken into account as offshore wind energy is added to the mix.

Siting offshore wind farms can affect ecosystems and communities in a variety of ways. Understanding the potential risks and creating the means with which to anticipate and mitigate harmful effects will be important components in moving offshore wind to the forefront of the renewable energy field. The next section briefly discusses the state of the coasts and ocean in terms of multiple stressors. Section 8.3 outlines an analytical approach to assessing risks and benefits, Section 8.4 discusses in some detail how an integrated risk framework contributes to a better understanding of potential effects, and Section 8.5 reviews European studies assessing offshore wind projects.

8.2 Comparing Analytical Frameworks

Risk frameworks are being developed to address environmental concerns of offshore wind installments (Ram 2009; Nunneri et al. 2008). One critical ecological concern, particularly of resource agencies and nongovernmental organizations (NGOs), is whether or not offshore wind turbines could entail a tipping point for fragile populations of marine animals and birds as well as ecosystems (NSF 2009). Several potential scenarios outline the additive role of stressors in altering the health of the ecosystem. Ecosystems, however, are complex. Eliminating one species could supply habitat for another competing species to occupy that niche. In turn, the ecosystem may still function as previously or change depending on that organism. In some areas, offshore wind farms have increased local biodiversity by acting as artificial reefs (Fayram and de Risi 2007; Petersen and Malm 2006). Wilson and Elliott (2009) argue that building habitat and possibly increasing ecological carrying capacity could be a means for mitigation. Careful attention should be paid, however, to the actual physical and chemical make-up (e.g., gravel, rocky outcrop, seagrass beds) of the habitat lost.

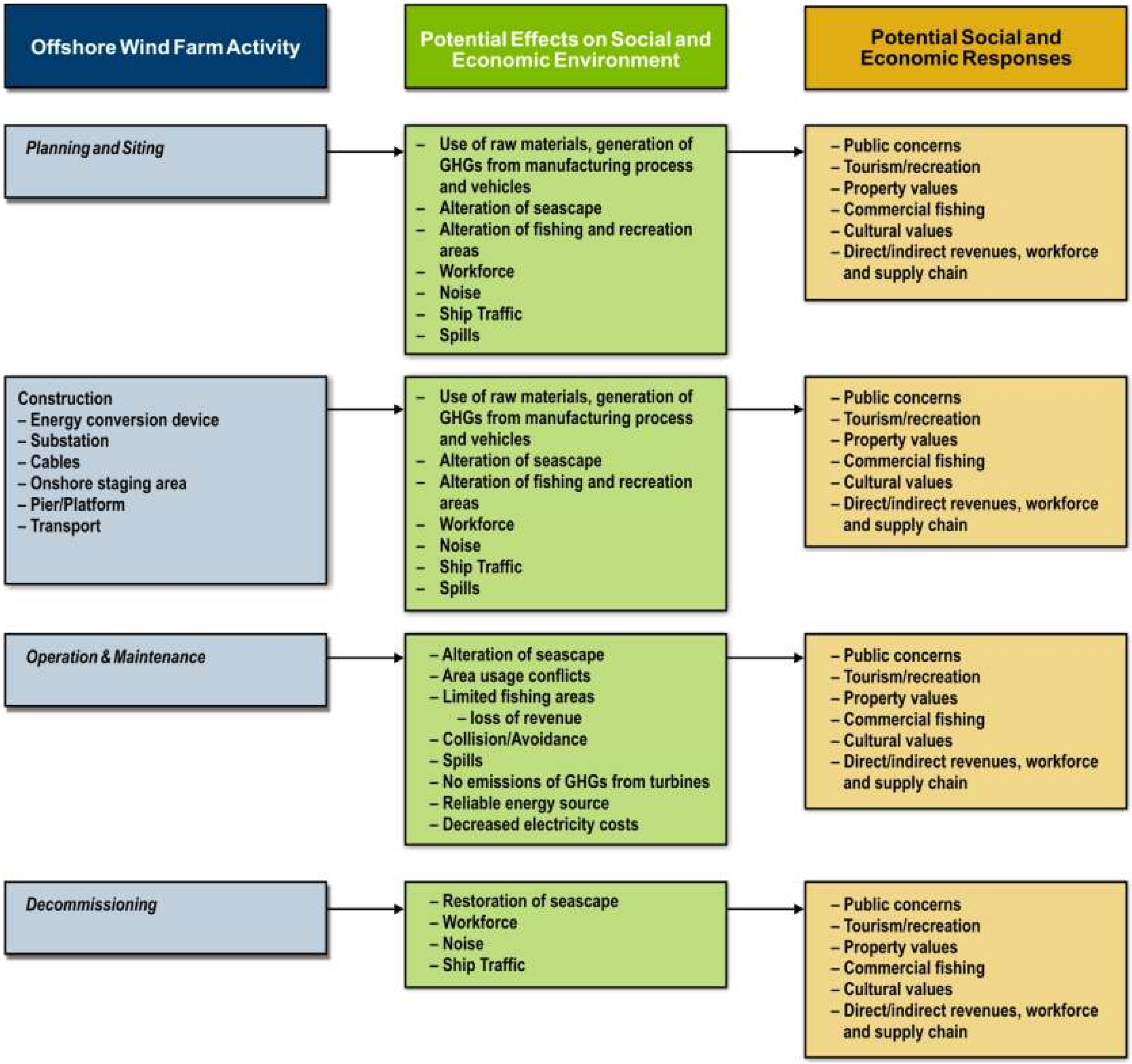
8.2.1 NEPA-Related Approaches

Physical, biological, and social areas of risk uncertainty have been identified with offshore wind energy development and have been the focus of well-established studies in Europe. Studies are also beginning in the United States, within both the Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEM; formerly the Minerals Management Service [MMS]) and state governments. For example, the Cape Wind FEIS has volumes of original survey work that are good overviews of the potential physical and biological effects (MMS 2009a). The New Jersey Department of Environmental Protection (NJDEP) recently completed almost 2 years of avian, turtle, and mammal surveys in areas related to offshore wind, and a final report was released in the summer of 2010 (NJDEP 2010).

As Section 7 explains, both the European and North American approaches to assessing offshore wind development risks are driven primarily by the requirements of permit applications and agency consultations, along with NEPA compliance. The expert community is learning that NEPA may require extensive data collection because of gaps in the knowledge base. Further, the data that do exist may not be sufficient to assess fully the risks or gain public acceptance, even though public hearings and comments are required as part of the process. More consistent engagement and analysis of stakeholder and decision maker views will have to complement the formal NEPA compliance requirements, as learned through the Cape Wind process and other energy technology siting. As summarized in Section 8.5, European experiences with strategic environmental assessments, analogous to the U.S. Programmatic Environmental Impact Statements (PEISs) and regional EISs, have already been important learning opportunities for North America. Extensive preconstruction surveys required to compensate for knowledge gaps and large uncertainties will be moderated or reduced as we better define the potential risks in comparison to other activities in the marine milieu.

Figure 8-1 demonstrates a sector-by-sector impact approach oriented to offshore wind farm activities, including siting, construction, operation, and maintenance. The critical first and final stage activities (i.e., planning, siting, and decommissioning) were added to the original graphic to show the life-cycle approach for any project. Although the two columns listing possible “effects” and “responses” is relevant for NEPA related analysis that focuses on sector specific impacts, (i.e., noise, ship traffic) some important factors are still missing due to the complexity. This limits the utility of this approach for understanding ecosystem-based or societal effects from offshore wind deployments. Figure 8-1 does not examine the probabilities of these effects occurring, quantification or magnitude of effects, and major uncertainties. These are the factors needed to capture the actual risks and benefits of wind.

This figure as well as the NEPA-related approach for evaluating potential impacts of offshore wind energy facilities focus on sector-by-sector assessments of the proposed action, including an EIS or environmental assessment (refer to Section 7), or a permit application prepared by a government agency or a private developer or both. Perceptions of significant risks relate to important but narrow agency regulatory missions such as the Migratory Bird Treaty Act (MBTA), where even one bird collision is forbidden by statute. An integrated risk approach, by contrast, which integrates scientific knowledge and comparative data with risk assessment and management, gives a wide spectrum of decision makers and stakeholders the analyses needed for making decisions and mitigating potential risks that are relevant. Such an integrated knowledge base serves as a systematic overview of the major ecological, human health, and socioeconomic risks.



Source: Adapted from Gill 2005.

Figure 8-1. Offshore wind farm activity and socioeconomically relevant interactions

BOEM classified impacts related to NEPA analysis from negligible to major, as shown in Table 8-1 and applied to the Cape Wind EIS (see Appendix B). This classification, however, also does not produce essential data about probability or uncertainty of the potential effects. This approach may also confuse severity and magnitude of the risk with irreversibility. In other words, although complying with the NEPA rules is central to responsible offshore wind deployment, both NEPA-related approaches do not address the fundamentals of whether the potential risk is one that is likely to occur and create a real concern to a receptor or whether it is an unavoidable trivial risk. These are the details that concern the resource agencies and the coastal communities, but could be addressed systematically and quantitatively by a risk analysis approach. Indeed, it is exactly for these considerations that the methods and analysis of risk assessment were created.

Table 8-1. Classification of Impacts in a NEPA Document

Classification	Environmental	Societal
Negligible	Not measurable	Not measurable
Minor	Avoidable with proper mitigation; removal would allow complete recovery of affected source; potentially unavoidable	Avoidable with proper mitigation; not disruptive to routine functions of community; removal of impact would allow for complete reversal
Moderate	Unavoidable; some permanent impacts; affected resource viable; potentially complete recovery	Unavoidable; impacts reduced via mitigation; adjustment by affected community; potentially complete reversal
Major	Unavoidable; affected resource's viability threatened; incomplete recovery	Unavoidable; impacts reduced via mitigation; unacceptable disruptions; incomplete reversal

Source: MMS 2009a.

8.2.2 An Integrated Risk Framework

Ever since the 1983 publication of the National Research Council's *Risk Assessment in the Federal Government: Managing the Process,* federal and state agencies as well as many global corporations have widely applied risk assessment and integrated risk frameworks to a range of environmental and health issues. A well-established set of tools and methods comprise an integrated analytical approach for assessing potential problems and making decisions related to technology deployments (NRC 1983). Risk assessments can also serve as a focal point for cooperation among local communities and state and federal government agencies. Further, they can build the knowledge base and approaches for determining how safe is "safe enough" and identify the major trade-offs among different technology and policy choices. For offshore wind energy deployments, risk assessment can help determine the level of seascape impacts to marine habitats that might be considered tolerable and how wind energy risks could be balanced with climate change benefits and risks associated with conventional energy development.

Well-executed risk assessments also can identify major divergences between public perceptions and expert judgments. A wealth of literature is available on risk paradigms (NRC 2005; Gregory 2002; NRC 1996) and ecological risk assessments and their application to an array of health threats and environmental problems (NRC 2008b). A recent National Research Council (NRC

2009c) review of risk assessment practices lists 53 U.S. Environmental Protection Agency (EPA) reports on risk assessment and their regulatory programs. Risk analyses have been applied to numerous other industries, including nuclear power, chemical and heavy metals industries, food safety, and aviation.

An integrated risk framework is, fundamentally, a logic structure that sets the stage for assessing a spectrum of potential areas of risk associated with deploying gigawatt-scale renewable energy supplies across the national landscape. Risk assessment informs decision making but does not serve as the sole basis for making decisions. Such decisions always involve a range of issues—such as siting strategies, technology developments, and industry workforce needs—that may be important.

Beyond technical issues, the "values" placed on wildlife and habitats are complex and must be assessed across an array of stakeholders and communities and within the regulatory statute. This is not a step-by-step process, and it does not reflect a linear scientific process for solving a problem. An integrated risk framework is a set of interactive logical steps that allow for feedback loops. As a number of NRC reports, particularly *Understanding Risk* (NRC 1996), have described, the interactive nature of this framework shows that stakeholder involvement and public perception are critical at every stage of assessment, deliberation, decision making, and implementation.

An integrated risk framework gives federal, state, and local decision makers and their stakeholders a common ground for analyzing and managing risks and devising policies and effective siting strategies. This approach is a "big picture" analysis of how the various scientific and analytical pieces fit together at any site or region—or indeed, at the national coastal and marine spatial planning level—and how the potential environmental and social effects in one area compare with those at other sites and with different technologies. By integrating fragmented research sectors, decision makers and stakeholders are better able to evaluate candidate sites that reflect the complex risk challenges.

Figure 8-2 shows an example of an integrated risk framework that could be applied to the decision problem of evaluating how gigawatt-level offshore wind energy could be part of a national energy strategy and build a knowledge base to support this decision. Of course, no risk assessment would include a detailed analysis of every box in the diagram, but the diagram does show a systematic framework for the range of questions or potential concerns arising from siting decisions across the country. Defining the "decision problem" could be applied to large scale deployments or a choice between wind and another energy supplies or to a specific project or site.

8.2.2.1 Tier 1: Sector Risk Analysis

Sector risks (e.g., wildlife, habitats, oceans and land use) will, of course, vary depending on the specific technology deployed, the specific site considered, the scale of the deployment, and the stakeholder concerns at particular locations. The essential difference with the previous analytical approaches in Figure 8-1 and Table 8-1 is that the integrated risk framework summarizes for each sector risk quantitative data on the probability of occurrence, the magnitude of the consequences by sector, and major uncertainties. As demonstrated by European offshore projects, risk challenges are very site specific, and this makes it difficult to determine where and when potential problems may arise. A broader overview may ensure that significant risks or public perceptions will not be missed. Specific "tools" or metrics are applied to each sector risk (e.g., radar for avian risks and tracking migration patterns for habitat risks). The next step is “risk characterization and uncertainty analysis.” The sector risk characterization and uncertainty summary provides an overview of the risks and compares them across sectors to evaluate what might be the least or the most significant. Details about the current knowledge base of sectoral risks have been gained mostly in Europe and, accordingly, the evidence is presented in Section 8.5.

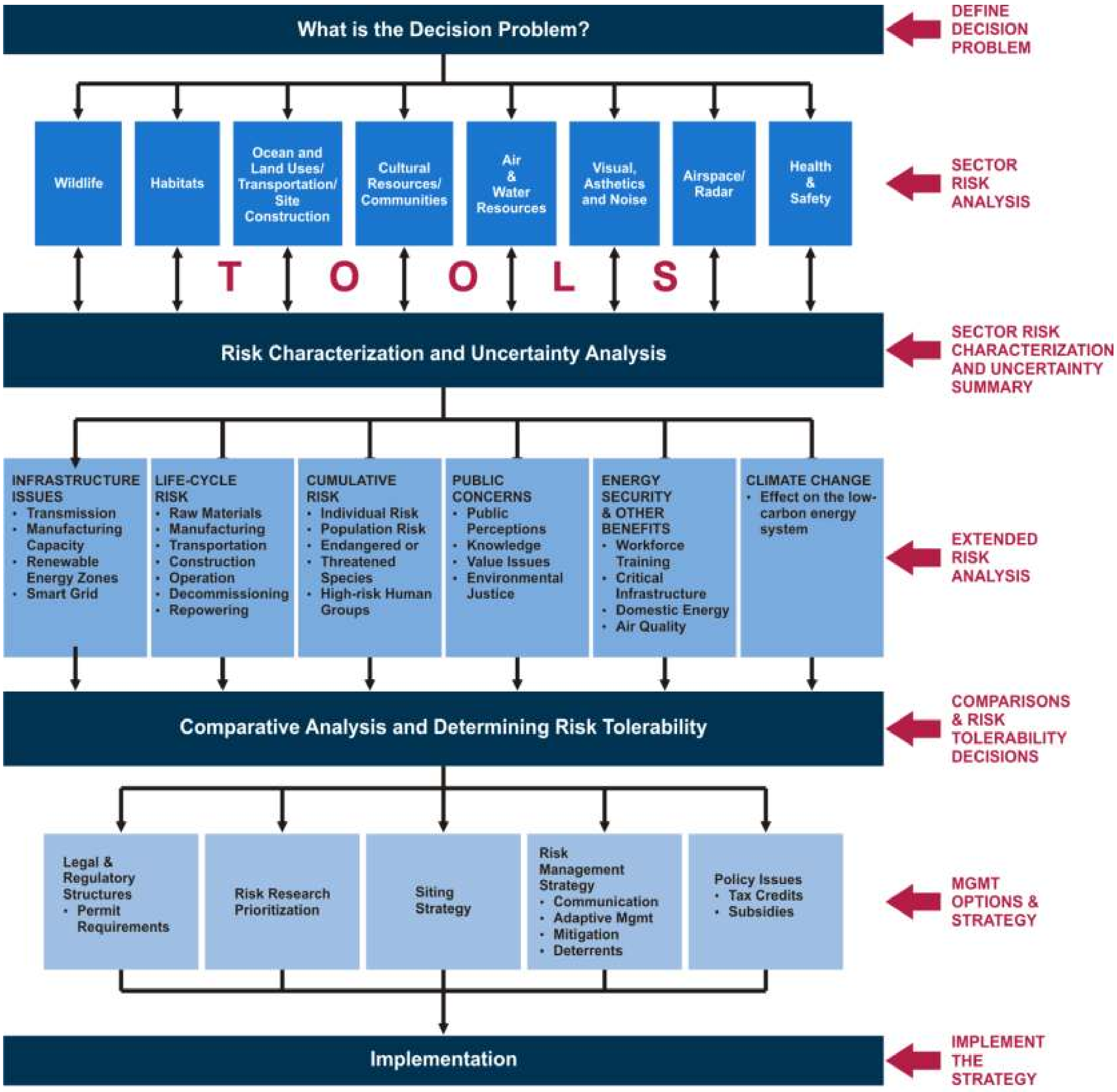
8.2.2.2 Tier 2: Extended Risk Analysis

Moving down the Figure 8-2, the framework then supports an “extended risk analysis” by broadening the number of issues assessed, such as infrastructure issues (e.g., transmission) and life cycle risks. This is a proactive approach to the complex issues related to siting new energy technology options as well as transmission siting. It is beyond the scope of this technical assessment to address all of these important issues in detail, but three areas of the extended risk analysis are briefly described, as illustrations of the types of analysis eventually needed: life-cycle risks, cumulative risks, and public concerns.

8.2.2.3 Life-Cycle Risk

Every potential wind energy site has a unique set of potential risks and benefits, given the geographic diversity across coastal cities and states—navigation could be the principal problem at one offshore wind site and recreational use conflicts might be the principal concern at other locations. This is a challenge that all energy supply options face, and so analysis is needed across risks and sites to identify both the principal problem areas and the benefits.

The wind turbine life cycle (manufacturing, transportation, planning and construction, operations, monitoring, maintenance, and decommissioning) has fewer environmental risks than conventional energy generation because impacts are primarily temporal and localized. Life-cycle assessments show that the wind energy manufacturing and construction phase generates the largest risks owing to raw materials production and components assembly. This phase accounts for approximately 85% of emissions (NRC 2009). The operations and maintenance phases are not considered significant because electricity production from wind energy operations does not produce emissions. Further, these processes take place only once during a turbine’s life, and so their impacts have been estimated to be relatively small (Tester et al. 2005). Because of these one-time life-cycle effects, wind energy appears to hold substantial promise for reducing carbon dioxide (CO_2) and other harmful emissions that pose ecological and health risks. A 2007 study by the National Academies of Science (NAS) estimated that wind energy would offset the amount of CO_2 produced in national electricity generation by 4.5% by 2020 (NRC 2007), based on the U.S. Department of Energy (DOE) scenario of future wind energy installation (DOE 2008a).



Source: Ram 2009.

Figure 8-2. A framework for integrated risk analysis of gigawatt-scale wind energy deployments

The impacts to the environment from fossil-fuel energy generation result from all phases of its life cycle—extraction, transportation, storage, combustion, and decommissioning. This life cycle also means human and biological impacts as well as ecological and financial effects associated with importing fossil fuels, stemming, in part, from acid precipitation, ozone pollution, mercury contamination, and oil spills. Likewise, the life cycle of nuclear power production, albeit not generating carbon emissions during operation, involves long-term, large-scale, known impacts associated with extraction, transportation, heating and cooling, and disposal of nuclear wastes, notwithstanding the potential for catastrophic risks from accidents and terrorism. Offshore wind has a different and likely a more benign set of impacts. The reduced impacts of offshore wind should be weighed against these more significant potential life-cycle effects.

Uncertainty and risk need to be evaluated in the context of different energy facilities and considered comparatively if the nation moves into a gigawatt-scale deployment scenario. A sound evaluation of the merits of offshore wind power will involve comparative analyses and life-cycle effects of other alternative electricity-generating facilities as well as land-based wind energy facilities. Several energy life-cycle assessment reports support the idea that wind impacts, which may still have significance, are small compared to other generating sources (NRC 2009; ExternE 1995). The most recent NRC report concludes that even though life-cycle damages were not fully quantified (in aggregate for 2009), any potential damages associated with wind turbines are small.

8.2.2.4 Cumulative Risks

A cumulative effect refers to those impacts that result from the incremental impacts of an action when added to other past, present, and reasonably foreseeable future actions. For offshore wind, cumulative effects comprise the combination of, and interactions between, effects from offshore wind farms that accumulate over time—considering background conditions already existing at the site in addition to social, economic, and technological interactions. Assessing cumulative risk is challenging because such effects:

- Are highly site-specific
- Often have a significant time lapse between the environmental change and the onset of consequences
- May involve interactions between ongoing natural processes and human-induced changes as well as altered conditions resulting from past human activities
- Are synergistic within a natural/cultural resource base in which different types of potential changes may create unexpected effects.

Defining (or bounding) the extent of the problem is a first-order challenge that has to be analyzed within NEPA and by other environmental assessment research. In European waters, marine spatial planning is beginning to take hold to account for the potential cumulative effects of multiple projects. Bounding the extent of this uncertainty and the threshold—or assessing the point at which the effect becomes significant—is an important yet difficult task. Regulators face challenges in considering the cumulative effects that offshore farms may have within the context of other developments and uses of the ocean—such as bird migratory corridors, commercial fishing by-catches, recreational boating, electric power needs from renewable resources, and safety. As these assessments are made, they should take into account the current limitations in the United States in experience with and understanding of offshore wind energy. Such assessments need to be regularly updated as the risk research program evolves and additional monitoring results become available. Cumulative-effect research is in its infancy in Europe, although there have been attempts to develop assessment approaches. One suggested approach to assessing risk levels to species or natural resources is to compare risks at the "end of the pipeline" to the initial impacts on those species or resources.

8.2.2.5 Public Concerns

Wind turbines are simultaneously an old and a new technology. In general, people understand what windmills look like and how they work. The wind machines that generate power today, however, are substantially different from those of the past. The transformation of this technology along with a wider geographic diversity of sites has generated changing perceptions and reactions from communities across the nation. Various public entities see both benefits and risks associated with deploying offshore wind energy. The most careful analysis of this in the United States is the Cape Cod study Firestone and colleagues conducted in 2005 (Firestone and Kempton 2007; Firestone et al. 2005). The authors found that the majority of the sampled population expect negative impacts. The most frequently given factors influencing their position (beginning with the most frequently cited) were aesthetics and impacts on the local fishing industry, recreational boating, property values, environmental impacts, tourism, and electricity rates. Supporters of the then-proposed development are generally younger and have at least some college education, whereas those opposed are more likely to earn more than $200,000 per year and expect to see the turbines in their daily routine.

Scale may also be a relevant issue. The Firestone and Kempton study found a 32% increase in support for the Cape Wind project (including a 19% increase by opponents) if it becomes the first of 300 such offshore wind developments around the country (Firestone and Kempton 2007; Firestone et al. 2005). They also found that that 60% agreed that a larger deployment of offshore wind power would contribute to U.S. energy independence, but only 30% of respondents felt that it would help stabilize global climate change. From these findings, the authors call attention to the need for stakeholders to better recognize these substantial benefits from offshore wind development to overcome their concerns about potential, site-specific, adverse environmental effects.

A well-documented pattern emerges: the core of opposition to wind energy development is the environmental community, and the primary issues of contention are potential environmental impacts (Pasqualetti 2004). Firestone and Kempton (2007) found that anticipated environmental effects were the most important drivers for both support and opposition of Cape Wind (MMS 2009a; see Appendix B for more details). According to previous technological controversies, project acceptance in the end is not always an issue of majority support. A committed and well-connected opposition has a strong ability to act as a veto group in society, regardless of the merits of a new project.

Early stakeholder involvement and better understanding of social effects are essential as more projects are proposed and sited along coastal communities. “The timing of risk communication entails a difficult tradeoff between the social imperative to inform without delay and the need for full scientific information and analyses” (Kasperson 1986). Beyond the public involvement procedures required under the NEPA regulations, a carefully conceived and ambitious public education program is essential. Wind power projects may bring a sense of town pride and energy independence, which would have significant qualitative benefits at the individual and community levels. It should also be recognized, however, that the issue may pit community residents against each other. For large-scale wind developments, nearby communities will serve as staging areas and be subjected to developmental activities. Commercial-scale wind projects may bring job benefits but, at the same time, alter the traditional character of the community and its relationship to marine activities. Thus, even where net regional benefits are realized because of wind energy development, self-perceived “winners” and “losers” may appear at the local level as a result of that development.

8.2.2.6 Climate Change

As noted previously, a 4.5% reduction in carbon would appear to have major implications that could reduce the ecological effects from climate change estimated by the four Intergovernmental Panel on Climate Change (IPCC) assessments and examined by the U.S. government and research institutions (NRC 2010a, 2010b; Karl, Melillo, and Peterson 2009). DOE estimated that the U.S. electricity sector could avoid 825 million tons of CO_2 by integrating 20% wind energy (including 54 GW of offshore wind) into the U.S. electricity system by 2030 (DOE 2008a). Moreover, the adverse effects of global warming estimated by IPCC in its four assessments (e.g., IPCC 2007) involve ecological and social impacts that far outweigh the risks associated with wind energy. The benefits of wind energy in mitigating climate change and other energy issues need to be considered together with the negative impacts in estimating and comparing risks involved in different energy sources (NRC 2010).

8.2.2.7 Comparative Analysis and Determining Risk Tolerability

With the two tiers of risk assessment in place, including all the boxes from “sector risk analysis” and “extended risk analysis” in Figure 8-2, comparisons and risk tolerability decisions can now be made. This critical step places the estimate of risk from offshore wind energy in the context of other known risks and establishes priorities (Davies 1996). In general, the most appropriate comparative risk assessments of wind energy development come from analyzing risks associated with other energy generation sources. A recent U.S. study discusses the challenges of applying comparative risk assessments to energy choices and notes the importance of this analytical framework for future decision making (NRC 2007). Beyond comparisons to the impacts from other energy sources, a valuable perspective on the scale of impacts can be gained from comparisons with other impacts. For birds, for example, it can be informative to examine bird collisions with wind turbines within the national context of other stressors on various water birds, including by-catch from fishing and loss of habitat from coastal development (FWS 2002; Erickson et al. 2001). In this case, extrapolating bird fatality rates from existing land-based wind farms for a projected wide-scale national deployment plan—even using conservative numbers—would give some sense of the potential magnitude of avian death risk. Of course, these estimations should be augmented by species-specific and localized effects as well as population impacts. In addition, given the significant uncertainties surrounding many environmental and health problems, comparing the risks helps prioritize which uncertainties require most urgent attention and resources and how scarce dollars to support needed research can best be allocated. Comparative analysis is at the heart of effective assessment and decision making. Integrated risk assessment gives capabilities not present in the required NEPA-related list making.

8.2.2.8 Tier 3: Management Options and Strategy

Following the comparative analysis, the next tier in Figure 8-2 involves various “management options and strategy.” To provide some insight into these analyses, two areas will be addressed below, including “risk research prioritization,”“siting strategies, and “adaptive management.”

The various stages of deploying an offshore wind farm—planning, siting, installing, operating, and decommissioning—all have risks. But these risks need to be placed within a proper context. As stated previously, environmental risks can occur at any stage, but it is the construction phase that generates the largest temporal impacts. Because wind energy is not subject to catastrophic risks as are other fossil fuel and nuclear energy supply technologies, best management practices and mitigation strategies may be useful for managing current risks and uncertainties with wind energy.

Without an integrated approach, states and regions are susceptible to prioritization of risk impacts based on legal or regulatory drivers rather than actual impacts to communities or ecosystems. Some example drivers include the MBTA, the experience at the last site of deployment (e.g., radar interference), or the complexities of protecting endangered species (e.g., Indiana bats, whooping cranes). All of these issues trigger sensitivities within the communities that are responsible for managing these risks, but it is a commonly used reactive approach. This approach allocates resources to one issue at a time without assessing the actual level of ecological or human risks. The wind turbine studies conducted to date have substantially enlarged our knowledge base of some land-based sector risks (e.g., bird and bat collisions, radar interference, and property values) but have not made much progress measuring uncertainties analyses and developing comparative frameworks.

A major finding is that risk research prioritization can fill gaps in the knowledge base and define the uncertainties that surround the risk problems at stake. Important considerations are involved: How much can the risk be reduced through further research and in what timeframe? How deep or removable are the uncertainties? Do uncertainties arise from data needs, modeling, or the lack of adequate scientific understanding of the risk phenomena? Most important, how do the uncertainties interact with the significance of the risk? Where will further research and assessment to reduce uncertainties most contribute to reducing overall risk and a more informed decision making process (Ram 2009)?

8.2.2.9 Siting Strategies

A robust siting policy is needed for industry decisions about the wind resources and cost-competitiveness. It would consider competing uses of the ocean and community concerns. A well-conceived siting policy would avoid coastal areas with intense competing uses and sensitive habitats. The CEQ-led national policy is to develop coastal and marine spatial planning guidelines to assist in the sustainable development of the U.S. oceans. Further, the National Oceanic and Atmospheric Administration (NOAA) and BOEM are developing a Multipurpose Marine Cadastre to produce maps and geographic information system (GIS) tools to support marine spatial planning and avoid use conflicts. A well-developed literature database exists on siting controversial facilities and should be taken into account in future wind energy siting decisions (Kunreuther, Susskind, and Aarts 1991).

Regulations will need to allow for an efficient process for permits and approvals that allows timely reviews of applications and a reasonable level of flexibility to support this new industry. Moreover, siting policies will need to reflect the sensitivities of competing and complementary uses of the ocean to multiple stakeholders. As yet, siting considerations in wind energy development have largely centered on relevant technical issues concerning the areas of substantial wind resource availability and the potential for connection to the energy grid. Moving from the current 1%–2% of the energy supply to 54 GW by 2030 requires a broader, more robust approach to wind plant siting. Siting strategies must go beyond narrow technical appraisals of sites to include collaborative approaches with potential host states and communities. Well-developed risk communication and stakeholder involvement programs will be essential. In certain circumstances, a regional approach with federal policy support will be necessary.

8.2.2.10 Adaptive Management and Monitoring Programs

A prudent, yet flexible, deployment strategy will need to integrate monitoring with adaptive management approaches and risk mitigation strategies identified through the NEPA process (DOI 2008; Williams, Szaro, and Shapiro 2007). The research approach will need to be one of learning through experience—it must also flexible enough to easily accommodate and integrate new information and improved risk knowledge as it becomes available. This approach can be designed to involve universities and NGOs that function as centers of excellence in various regions. The United States can learn from European Before and After Construction Impact (BACI) study methods applied to several offshore wind plants. Cumulative effects will need to be considered within the context of a comparative approach relative to other energy sources. An integrative approach is needed to allow current techniques and methods to be used in a context of uncertainty, with an understanding that the onset of a serious unanticipated impact may require significant modifications to a project's site or design.

Our experience tells us that "obvious" impacts of today at particular sites may not actually be, and often are not, the showstoppers of tomorrow. A more systematic assessment that incorporates principles of adaptive management would allow a better understanding of the probabilities of impacts or consequences at widely separated sites and diverse marine environments—from the Great Lakes fresh water to the warm waters of the Gulf and across to the Mid-Atlantic. Estimating probabilities of the risk occurring may be just as central as the possible magnitude of the impacts and consequences. It also is a systematic approach to comparing risks, assessing priorities, and formulating management strategies rather than reacting to the fear of uncertainty or what a special interest group finds resonates with their constituency.

8.3 Sectoral Risks: Considering the European Experience

After the European Union (EU) committed to the Kyoto Protocol and reducing greenhouse gas emissions in 2002 (UNFCCC 2010), several nations began comprehensive energy-planning exercises to evaluate how wind power could contribute to this new renewable energy pathway. Offshore wind projects have been deployed and are planned off the coasts of Denmark, Sweden, the United Kingdom, Netherlands, Germany, Finland, and Ireland. More deployments are anticipated off the coasts of Spain, France, and Belgium in the next few years (EWEA 2010; see also Section 3).

The early experiences of these countries offer valuable lessons about offshore wind power development (see Table 3-2). But they can only serve as guidelines rather than blueprints in the United States because of the differences between economic, political, biological, and geophysical conditions. Using mechanisms such as financial incentives, policy constructs, and streamlined permitting requirements, European nations are increasing their offshore wind development. For offshore wind developments, the EU requires extensive environmental impact assessments similar to the EISs required for NEPA compliance for any U.S. major development. European planning for offshore wind energy has thus involved setting specific deployment targets, devoting significant resources to preparing strategic environmental assessments, mapping specific development sites using GIS , performing multiyear field studies, and instituting BACI analyses for demonstration programs.

Scientifically rigorous BACI studies track changes in the marine environment and follow the project from conception to turbine installation to monitoring during operation and maintenance. The design includes pre- and postconstruction studies to examine changes in behavior and abundance of a target species, and other temporal and spatial ecological measures associated with an impact.

Table 8-2 summarizes the offshore wind farm studies conducted in Europe. Important lessons learned from these studies include:

- Methods and technologies to measure changes in marine resources from the effects of construction, operation, and maintenance
- Lessons about what worked and what did not work in pilot baseline investigations and monitoring programs
- Indicators of significant environmental and socioeconomic effects that can be used to establish study priorities early on, ensuring limited resources are used cost-effectively
- Methods for determining cumulative effects of marine activities
- Analytical tools for strategic site assessments to help determine the amount of ocean space suitable for offshore wind developments and to screen for potential conflict of use
- Techniques for encouraging public involvement and accessing public response and acceptance.

Through these studies, Europe has accumulated a body of evidence regarding the potential environmental impacts from an offshore wind project, because wind farms have been operating in the waters of Europe since the early 1990s. Several early comprehensive studies were sponsored by the EU, including Concerted Action on Offshore Wind Energy in Europe (CA-OWEE) and Concerted Action for Offshore Wind Energy Deployment (COD). In 2005, COD compiled the available studies in a searchable electronic database and summarized the findings in a final report, stating that "the COD work on the establishment of an environmental body of experience has brought an important overview of the present state of knowledge in this up to now unknown field" (COD 2005). Also, two Greenpeace International reports that summarize environmental impact assessment studies in Europe were prepared by Deutsches Windenergie Institute (Greenpeace International 2005) and Deutsche WindGuard GmbH (Greenpeace International 2000). The Danish government instituted another comprehensive study approach, along with their utility partners/developers, DONG Energy (formerly Elsam Engineering and ENERGI E2), for the offshore demonstration projects Horns Rev and Nysted; this approach used BACI methods as well as multiple scientific and stakeholder review committees (DONG Energy et al. 2006).

Since 2005, European nations have invested millions of dollars in research priorities targeted to areas with large deployment goals and projects installed. Many of these larger, national studies have been separated into individual sector analyses, which have gone through the peer-review process and have been published in scientific journals. Peer review of study design and results enhances the credibility of the study. In some cases, however, studies are prepared by the developer and do not undergo rigorous peer review. A rigorous process of gathering evidence builds public confidence in the research and assessments being conducted as well as in the results.

Since the passage of EPAct 2005 and the beginning of the offshore regulatory program, U.S. government agencies looked at the results of these European studies and initiated several site-specific studies, particularly along the Atlantic coast. As the only completed EIS on offshore wind energy in the nation, the Cape Wind EIS establishes some precedent for assessing environmental and societal impacts, but this is an evolving area of development (see Appendix B for a detailed summary of the EIS findings). In the last several years, state governments have also begun to prepare baseline studies to support their planning processes and build a knowledge base (Table 3-4 in Section 3 summarizes these studies). Also, BOEM has supplemented its environmental studies program, historically focused on oil and gas in the Gulf region, to add regions with potential offshore wind deployments. A sampling of these projects includes the following, and a more complete list is available at http://www.gomr.mms.gov/homepg/regulate/environ/studiesprogram.html. As the list shows, social and community issues remain understudied:

- Determining Night Time Distribution of Long-Tailed Ducks Using Radio Telemetry
- Effects of Pile Driving Sounds on Auditory and Non-Auditory Tissues of Fish
- Compendium of Avian Information and Comprehensive Geodatabase
- Energy Market and Infrastructure Information for Evaluating Alternative Energy Projects for OCS Atlantic and Pacific Regions
- Evaluation of Visual Impacts on Historic Properties
- Meteorological and Wave Measurements for Improving Meteorological and Air Quality Modeling
- Potential for Interactions between Endangered and Candidate Bird Species with Wind Facility Operations on the Atlantic OCS.

Table 8-2. Summary of European Large-Scale, Multidisciplinary Studies of the Environmental Effects of Offshore Wind Farms

Program	Involvement	Study Location	Areas of Focus
Danish Monitoring Program http://www2.dmu.dk/AtmosphericEnvironment/aq_besk/bop.htm	Denmark—University, industry, government, and other stakeholders	North Sea	Determine effects on marine environment, including mammals, fish, birds, artificial reefs, socioeconomics, noise emissions, temperature gradients, benthic fauna, public issues, electromagnetic fields
Research at Alpha Ventus (RAVE) http://rave.iset.uni-kassel.de/rave/pages/welcome	Germany—Federal Ministry of Environment	North and Baltic seas	Assess effects on marine environment, evaluate standards for environmental impact assessments, study marine mammals, birds, fish, and benthos
BeoFINO Ecology of Benthic Organisms and electromagnetic fields (BeoFINO) http://www.offshore-wind.de/page/index.php?id=11631&L=1)	Germany—Federal Ministry of Environment	North and Baltic seas	Determine effects on marine environment and develop methods and criteria to analyze danger to life and habitats
FINO 3 http://www.fino3.de/joomla15/index.php?option=com_content&view=article&id=169&Itemid=357	Germany—Federal Ministry of the Environment	North Sea	Established three offshore research platforms, noise emissions
Mechanisms to Protect Nature and Environment http://www.offshore-wind.de/page/index.php?id=11633&L=1	Germany—University of Berlin	North Sea	Adapting Strategic Environmental Assessment (SEA), environmental impact assessments, and Habitats Directive to the offshore environment
Impact on Marine Endotherms (MINOS) http://www.wattenmeer-nationalpark.de/themen/minos/minos_en.html	Germany—Federal Ministry of Environment	North Sea	Habitats, migratory routes, hearing, and sensitivity of porpoises, seals, and sea birds
Offshore Wind Energy and Environmental Protection Forum (FOWEUM) http://www.offshore-wind.de/page/index.php?id=11640&L=1	Germany—Ministries, state governments, environmental groups	North Sea	Support exchange of information and build consensus on environmental protection and nature conservation

We@Sea http://www.we-at-sea.org/	Netherlands—Industry, environmental, and university	North Sea	Siting and environmental issues, impact assessments
Far and Large Offshore Wind (FLOW) http://www.flow-windpark.nl/	Netherlands—Industry, university, and other stakeholders	North Sea	Environmental issues
Collaborative Offshore Wind Research Into the Environment (COWRIE) http://data.offshorewind.co.uk/	United Kingdom of Great Britain and Northern Ireland—Government, industry, university, and other stakeholders	Irish and North seas	Marine mammals, birds, cultural, soundscape, fish, shellfish, benthos, data, and radar
Department for Business, Enterprise, and Regulatory Reform (BERR) http://www.berr.gov.uk/ and Department of Energy and Climate Change (DECC) http://www.decc.gov.uk/en/content/cms/what_we_do/uk_supply/energy_mix/renewable/policy/offshore/offshore.aspx	United Kingdom and Northern Ireland	Irish and North seas	Marine spatial planning, stakeholder dialogues, strategic environmental assessment, public perception surveys of awareness and attitudes

European studies as well as the Cape Wind EIS have identified critical areas of potential impacts and areas where the potential outcomes are not well known. These are the priority topics for discussion in this section:

- Avian impacts
- Acoustic impacts to marine mammals
- Impacts on fish and benthos communities
- Electromagnetic fields
- Visual effects
- Ship collisions
- Other socioeconomic effects.

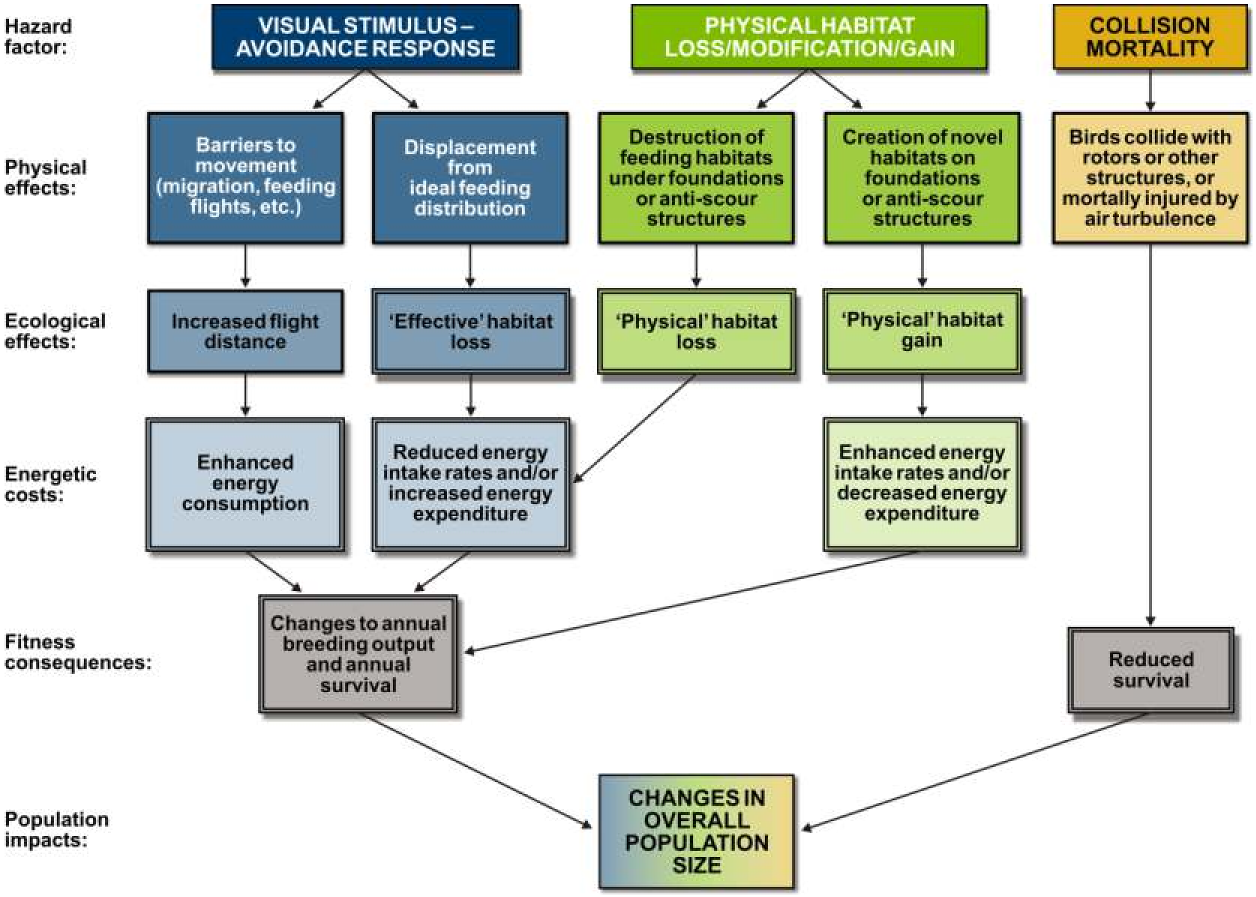
As mentioned elsewhere, other risks that are not included here, such as noise impacts to workers, radar interference, military uses of the ocean space, and cultural resource impacts, need further examination.

8.4 Avian Risks

Figure 8-3 shows the potential effects of offshore wind farms on birds. The major risks from offshore wind turbines to sea birds and resting birds include:

- Collisions and mortality
- Physical habitat loss from displacement

- Visual stimulus/avoidance response and barrier effects, including fragmentation of the ecological habitat network (e.g., migration pathways, breeding or feeding areas).



Source: Energetics, Fox et al. 2006

Figure 8-3. Potential effects of offshore wind farms on birds

Of these risks, assessments suggest that collisions and barrier effects (disturbance) could have the largest impacts on sea birds and resting birds (COD 2005). In most cases, bird collisions with offshore wind turbines are only a minor problem (Greenpeace International 2005). A key concern in the topic of avian risk, however, is the potential harm done to endangered species, where the loss of one individual could have a measurable impact. Quantitative risk estimates for collision, however, are difficult to calculate for several reasons:

- Results are highly site specific and therefore can often appear contradictory (Desholm and Kahlert 2005).
- Inadequate data exist on bird migration routes and flight behavior (Exo, Hüppop, and Garthe 2003).
- Impacts vary for different bird species.
- Measurements account only for bird carcasses that are found.
- The range of methods includes thermal imaging, microphone, and visual observations.

- There may not be a direct correlation between pre- and post-construction avian presence.

Several offshore facilities studies suggest minimal or no significant impacts on bird life from offshore wind farms (CA-OWEE 2001). Precautionary risk reduction and mitigation measures are available to reduce potential risks from wind turbines, including:

- Monitoring and understanding transient and resident bird behaviors
- Siting in areas with lower activities (e.g., avoiding high-density and migratory waterfowl areas, breeding areas, and migratory areas of species of concern)
- Reducing the potential for cumulative effects through careful monitoring and siting.

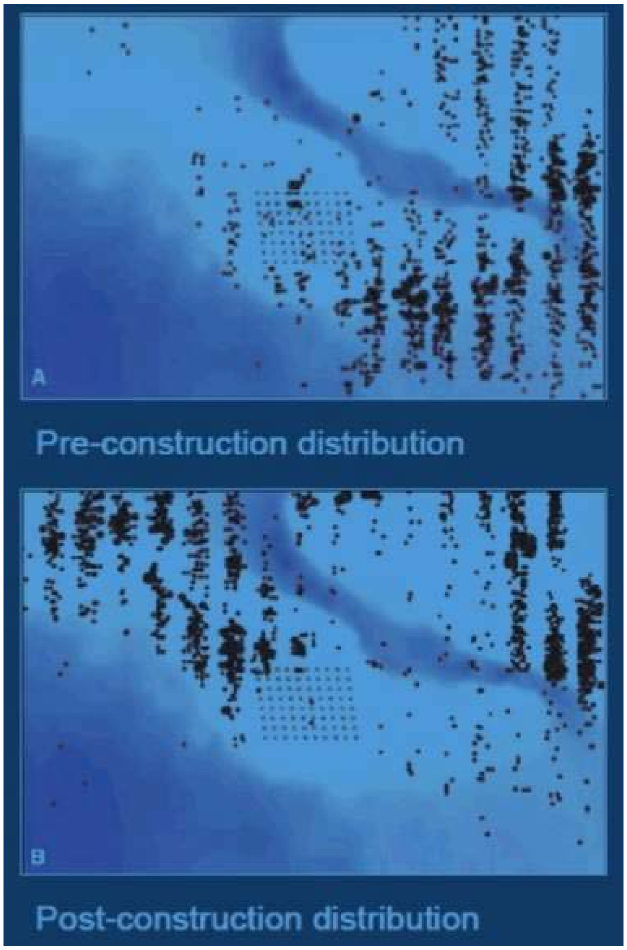
In contrast, relatively high collision mortality rates have been recorded in isolated instances at a few poorly sited, land-based wind farms in areas with large concentrations of birds such as Altamont Pass in California and Tarifa in Spain (BirdLife International 2003). A recent presentation at the IEA Wind Task 28 meeting in October 2009 summarized the latest avian research from land-based wind studies (Strickland 2009). Individual projects affected individual birds rather than populations after informed siting and other impact reduction measures were taken. No studies documented detrimental effects to birds as a result of wind farm lighting. For offshore wind, a recent study of 1.5 million migrating seabirds from Swedish wind farms in Kalmarsund concluded that the fatality risk was only 1 in 100,000 passing seabirds (Pattersson 2005). Offshore wind farms in the United States would most likely be placed along the eastern coast in the Atlantic, in the Great Lakes, and in the Gulf of Mexico, which are all part of major flyways for hundreds of thousands of migrating birds (Figure 8-4). The USFWS estimates that 7 to 10 million birds use the Mid-Atlantic to North Atlantic shoals areas.

Source: http://www.fws.gov/migratorybirds/NewReportsPublications/flyways.html; Michael A. Johnson, North Dakota Game and Fish, photographer

Figure 8-4. Biological flyways through the continental United States

A recently published study of sea birds at offshore wind farms near Blyth, England, found that numbers of Cormorants (*Phalacrocorax carbo*) decreased after construction, but numbers of Terns (*Sterna sandvicensis*) and Great Black-backed Gulls (*Larus marinus*) increased (Rothery, Newton, and Little 2009). Further, in 352 hours of observation, no collision mortality was observed and most seabirds flew below blade height. Hüppop et al. (2006) reported considerable variation in migration intensity for birds migrating over the North Sea and most collision mortalities as assessed by dead birds on the platforms (586 total from 2003–2006) were Thrushes. Nonsong birds represented 2% of the mortalities (Hüppop et al. 2006). This study also concluded that rain and wind gales probably increased the incidence of collisions.

In Denmark, radar studies have shown that migrating birds largely avoid flying through the Nysted wind farm. These studies revealed that 35% of the birds flew through the area before construction, but only 9% flew through following construction, although individual behavior is somewhat species specific. Environmental monitoring at the Horns Rev I wind farm in Denmark by DONG (Elsam Engineering and ENERGI E2 2005) following the first year of operation found that most bird species also exhibit avoidance behavior, which may reduce the probability of collisions with the wind turbines (Figure 8-5).



Source: DONG Energy et al. 2006.

Figure 8-5. Eider distribution at Horns Rev

Despite these relatively comprehensive studies, there are still questions about the length of time needed to assess bird activity before construction. Preconstruction avian studies should be balanced by comparable post-construction avian studies. For example, the avian studies at the offshore wind farms near Blyth, England, began 26 months before turbine construction, continued through construction, and lasted 32 months after construction (Rothery, Newton, and Little 2009). Further, a recent presentation by the FWS suggested that 3 years of studies for shoal areas may be required to adequately assess the resident and migratory bird populations.

The avoidance behavior of birds is highly site and species specific. Although avoidance can present other risks related to habitat loss and greater energy consumption of the species because of longer flight paths, this behavior could also reduce the probability of collision risks. A postconstruction survey conducted at Horns Rev I found that habitat loss for the common scoter caused no change in activity, and a second survey in 2006 observed large numbers of the common scoter in the wind farm. These observations illustrate that long-term monitoring is often necessary to fully track ecological shifts. Additionally, barrier effects at the Nysted wind farm, measured as additional energy expenditure caused by longer flight patterns around the periphery of a wind farm, were assessed in studies conducted from 1999 to 2005 (Masden et al. 2009; Petersen et al. 2006). For common eiders, the additional energy expenditure caused by avoidance behavior equated to about 0.5 km of extra flight distance, which is not significant compared with the 1,400-km migration episode.

Offshore wind plants may diminish foraging and resting opportunities for some bird species because of the ocean footprint. For example, Horns Rev I tower sections occupy only approximately 0.1% of the total wind area of the project. By comparison, land-based wind farms and their supporting infrastructure (such as substations and roads) generally occupy 1%–2% of the land (Elsam Engineering and ENERGI E2 2005). Even with the limited footprint of offshore wind farms, siting multiple wind farms in an area may diminish the attractiveness or suitability of an area to a particular species, and over time this could result in the cumulative effect of reducing the presence of this species in that area. Sea birds and resting birds appear to be less at risk of collision and habitat loss than migrating birds because they may adapt better to offshore wind farms because of their ability to habituate around the wind site (COD 2005).

Despite the lack of evidence to date that would suggest that offshore wind farms pose a major risk to individual birds or populations, this issue remains high in public and regulatory concern. Given the difficulty in assessing collisions at sea and the relatively large general variation in flocks from year to year at sites, biologists should be careful to apply BACI principles at their study sites and should use caution when formulating their conclusions. When designing BACI analysis, a great deal of effort goes into identifying suitable reference areas. Additionally, data must be collected on bird feeding behavior, including information on the abundance and distribution of prey. Precautionary measures and adaptive management principles are available to reduce and mitigate such risks as understood today. Some decision makers would argue that carefully siting wind farms away from bird migratory paths, bird habitats, and large concentrations of higher risk species may be an effective way to minimize avian interactions with wind turbines. Mark Desholm, an ornithologist with the National Environmental Research Institute (NERI) at Arhaus University, suggests prioritizing migratory bird species for assessment. He states, “It will always be important to focus attention and direct the resources towards the most sensitive species to ensure cost-effective environmental assessments in the future . . .” (Desholm 2009).

Indeed, initial reasons for excluding sites because of risk perceptions are not always the best reasons for site selection, as indicated by some notable case studies. For example, observations at the Nysted demonstration project, which is sited directly in an intensive eider migratory path, suggest that cautiously siting wind farms away from bird migratory pathways may not be a strict requirement (DONG Energy et al. 2006). Even though avian activity is abundant in the area, the wind farm has not posed an unreasonable risk. Another example is Horns Rev I, which is a habitat for harbor porpoises. If Danish developers had decided not to build Horns Rev I because of concerns about the harbor porpoises, they would not have explored the potential effects and found that the mammals still use the area as much as before the wind farm was established (C. Boeson, personal communication, May 31, 2007).

Nocturnal birds attracted to lighting on offshore oil platforms sometimes circle the platform for minutes or even hours, especially on overcast nights. One study of this behavior hypothesizes that birds become reluctant to leave the area of light, especially when they lack visual clues for orientation such as the moon and stars (Russell 2005). This nocturnal circling places birds at a greater risk of colliding with the platform itself. Bird fatalities from collisions with oil and gas platforms are more common in the fall, when migrating birds fly past the facilities in hours of darkness. A single Gulf of Mexico platform is estimated to cause an annual average of 50 avian deaths from collisions (Russell 2005). For offshore wind towers in the North Sea, lighting has been implicated as a potential cause of the increase in collision incidents during periods of fog, rain, or wind gales (Hüppop et al. 2006).

The Cape Wind EIS does not give definitive numbers of potential avian risk mortalities for all species observed during their monitoring studies because “calculating the risk of collision to species or groups of birds is difficult because of a paucity of information identifying exposure to collision” (MMS 2009a). A collision model for all bird species, however, estimated that 260 bird fatalities would occur annually (MMS 2009a). In addition, the FWS estimated that over the life of the project (~20 years), there would be 80 to 100 Roseate Tern fatalities and 10 Piping Plover fatalities (MMS 2009a). Both species are classified as threatened under the Endangered Species Act. Massachusetts Audubon (www.massaudubon.org) released their final position on the Cape Wind project on June 24, 2010: “Following nearly a decade of independent research and review, Mass Audubon has concluded that the Cape Wind Energy Project (Cape Wind) will not pose an ecologically significant threat to the birds and associated marine habitat of Horseshoe Shoal and Nantucket Sound. As an important component of our support for responsible development of clean, renewable energy and to reduce the worst effects of climate change, we support this project.”

8.5 Other Flying Animals

Bats and insect populations may also be affected by offshore wind farms. For land-based wind farms, bat fatalities can reach significant numbers and are a critical concern (Cryan and Barclay 2009). As with land-based wind farms, the potential impacts to bats and insects at offshore wind farms include collisions as well as energy expenditures. Additionally, for insects, the wind farms may serve as a refuge area. Although there are no published studies on insects and offshore wind farms, there are some limited data on bats. It is well understood that bats migrate over water from landmass to landmass; however, it is not well known how they do this (Ahlén et al. 2007). Studies off the coast of Scandinavia found that bats were more exposed and at greater risk of collision when hunting insects near the upper parts of the turbines (Ahlén et al. 2007). Bats did not avoid the turbines but hunted close to the turbines—they also rested on the platforms. Hunting behavior was not influenced by blade movement, but insect hunting was observed more during calm weather (Ahlén, Baagøe, and Bach 2009; Ahlén et al. 2007). In general, migrating and foraging behaviors of bats offshore are not well understood, but as offshore wind farms are proposed along the coasts of the United States, there will be a need for better understanding.

8.6 Fish and Benthos Risks

A few studies demonstrating a range of results have been published on the effects of offshore wind farms on the fish and benthic communities. Possible direct and indirect effects of a wind plant include:

- Temporary disturbance or long-term elimination of benthic communities from construction activities
- Changes in species composition and species numbers
- New habitat (e.g., artificial reefs, shellfish beds) serving as habitat for invasive species
- Hearing impairment in fish from low-frequency, hydrodynamic/acoustic fields from the wind turbines
- Changes in habitat conditions as a result of altered sedimentation and current
- Impacts to elasmobranchs and other marine species caused by electromagnetic fields from transmission lines.

One study of the fish and benthic communities in a Swedish wind farm in the Baltic Sea found increased numbers of demersal fish and blue mussels around the turbines but lower concentrations of algae compared with other areas (Wilhelmsson, Malm, and Ohman 2006). Another study conducted on Swedish wind farms in the Baltic Sea found increases in the biomass of blue mussels and motile crustaceans but decreases in the biomass of algae compared with sites farther away from the turbines (Wilhelmsson and Malm 2008). Invasive species have also been documented on wind turbines in both Danish (DONG Energy et al. 2006) and Swedish offshore wind farms (Wilhelmsson, Malm, and Ohman 2006).

Sounds transmitted through the water by wind farm construction, operation, and maintenance may also affect marine animals. A study conducted by the UK Department of Energy and Climate Change found that sounds generated by offshore wind turbines are in the same range of frequencies as those generated by existing shipping, fishing vessels, wind, and waves, and therefore would contribute only a relatively low background noise (during operation) to the preexisting noises (see Table 8-2 for a list of various anthropogenic sounds). During construction and decommissioning, placing and removing the monopile structures creates noise. During the operation phase, 20 years in most cases, offshore wind turbines produce sound through the movement of the rotor blades and gearbox and vibration of the structure, creating three paths for sound movement—through the air, water, and ground.

Adverse effects to fish caused by noise include physiological stress such as an increase in cortisol, hearing impairment, and behavioral changes (Kikuchi 2009). Although a 2003 report from an offshore wind farm in Norgersund demonstrated no negative impacts on fish caused by noise (ETNWE 2003), other studies demonstrate the opposite. Significant data gaps do, however, exist (Simmond and Dolman 2008). A recent laboratory study examined the swimming behaviors of two native species of fish (roach, three-spined stickleback) and their reactions to single-frequency sounds and noise generated by an offshore wind turbine in the Baltic Sea (Andersson et al. 2007a, Andersson et al. 2007b). The roach exhibited escape behavior and the three-spined sticklebacks exhibited twitching behavior (Andersson et al. 2007b).

Table 8-3. Intensities of Different Anthropogenic Sounds

Source	Intensity (dB re 1μPa at 1 m)
Threshold of human hearing	0
Threshold of human pain	140
Large tanker	177
Icebreaker	183
Military search sonar	230+
Ship siren at 30 m	130
Pile-driving at 30 m (Sweden)	140–>180
Pile-driving at 1 m (UK)	262
Pile-driving at 400 m (Germany)	180
Light traffic	50
Wind in trees	50
Rural nighttime background	20–40
Quiet bedroom	35
Land-based wind farm at 350 m	35–45
Car at 40 mph at 100 m	55
Jet aircraft at 250 m	105

Source: Compiled from AWEA 2010; DOE 2008b.

The effects of electromagnetic fields (EMFs) emitted by electrical cables must also be assessed. These effects will be site specific and depend on the length of the cable and the method for burying the cable (such as with a plow or trenching). Potential effects from EMFs include disorientation in fish, especially sharks and rays, as well as a slight increase in sediment temperature in the area of the transmission lines (COD 2005). Several studies conducted by Denmark, the United Kingdom, and Greenpeace found the effects of EMFs on the marine environment to be negligible (COWRIE 2007: Elsam Engineering and ENERGI E2 2006; Greenpeace International 2005). A recent report by Gill et al. (2009) for COWRIE, however, found that elasmobranchs (e.g., sharks and rays) in the benthos did respond to the presence of EMFs of the type and intensity associated with undersea cables. The response, however, appeared to be species or individual specific. Some species appeared to move less and others appeared to move more while the cable was transmitting. Given the ambiguity of their results, they suggest further monitoring of offshore wind sites as well as more experimental studies.

Transmission cable installation may also impact fish and benthic communities. These construction effects are certainly not unique to the offshore wind industry, because the telecommunications and other electric power sectors also bury cables. Methods that minimize seabed disturbance through cable trenching and burial are recommended for offshore wind construction. Several options minimizing the impacts on fish and the benthic communities from cable installation include using proven construction methods for reducing the effect of structures and cables on existing fish stocks, food sources, and spawning activities; using antiscouring substrate at the foundation bases to mitigate erosion; and placing cables in a fishing exclusion zone. Considering potential impacts during structure foundation design could also minimize scouring, sediment redistribution, and current flow.

Fisheries are an important factor in the economies of all areas where offshore wind farms may potentially be sited. The British Department of Energy and Climate Change oversees the Fisheries Liaison with Offshore Wind and Wet Renewables (FLOWW) Group in the United Kingdom. Members of FLOWW include representatives from the fishing industry, renewable energy developers, and government regulators. FLOWW was organized to facilitate a dialogue between key energy and fishing stakeholders concerning issues between the two industries. These issues include the types of fishing permitted within a wind farm and best practice guidelines for coexistence. FLOWW meets four times a year and is developing a framework for assessing the value of fishing activities and disruptions or displacement caused by offshore wind farm development and negotiating commercial compensation (UK Department of Business, Enterprise, and Regulatory Reform 2010).

Overall, offshore wind farms have the potential to have a positive effect on fish and benthos through the creation of a restricted zone, of habitat, and of areas that could be used for mariculture. A 2005 environmental impact assessment conducted by DONG found that a wind farm would be a net gain for fish and benthic populations because trawling would be restricted around the wind farm under a 1992 Danish Executive Order (No. 939), which prohibits trawling within 200 m of sea cables (Elsam Engineering and ENERGI E2 2005). In the United States, Cape Wind Associates does not plan to restrict any recreational or commercial fishing activities in the Nantucket area (MMS 2009b). According to Fayram and de Risi (2007), wind turbines in the Adriatic Sea have the potential to act as “fish-aggregating devices” for bluefin tuna and other species, and they suggest designating the areas around wind farms as marine protection areas.

Offshore wind turbines may be new habitat for species. The monopile provides up to 2.5 times the amount of area lost through placement (Wilson and Elliott 2009). Although this new habitat is likely to be different than the habitat lost, it will be a refuge and food source for species. There is a long history of artificial reef complexes associated with offshore platforms throughout the world (Artificial Reefs 2010). To maximize the carrying capacity of the area around the monopiles and prevent scour, developers can use different substrates to simulate different environments and thus attract a variety of species. For example, gravel would simulate a gravel seabed, boulders would simulate a rocky outcrop, and synthetic fronds would simulate sea grass beds (Wilson and Elliott 2009).

Offshore wind farms also represent an area that has the potential for multiple uses. Some European communities are pushing to integrate mariculture within the lattice work of the turbines in offshore wind farms. The turbines would be used as points of attachment, allowing economically viable and harvestable species such as blue mussels and algae to thrive (Buck et al. 2008). This concept, however, is not without its opponents. In a recent survey of several different offshore wind farm user groups (i.e., environmental protection, public administration, maritime economies, tourism, offshore wind energy, fisheries, research, and policy), the fisheries group expressed predominantly negative attitudes toward the multiuse concept. A few reasons for the dissension include concern over the loss of other mussel fisheries, feasibility, loss of more fishing grounds, and safety risks (Michler-Cieluch and Kodeih 2008).

8.7 Marine Mammals

The effects of offshore wind farms on marine mammals are not considered to be a priority risk area based on the evidence to date (CA-OWEE 2001). Several potential effects are possible, though, including the following:

- Loss of habitat resulting from sound emissions
- Disruption of animal sonar systems through vibrations and low frequency sound emissions
- Fragmentation of migratory pathways
- Collision with underwater substructures.

The EU project COD concluded after an extensive review of Danish monitoring studies that the “offshore wind farm-induced effects are less severe than might have been anticipated.” Compared with other human activities in the marine zone, particularly fishery-related noise (DONG Energy et al. 2006) and ship traffic, risks from the sound emissions of single offshore wind facilities appear low (DONG Energy et al. 2006). A Greenpeace study found that “seals and grey seals are not significantly disturbed by the presence of offshore wind turbines” (Greenpeace International 2000).

NERI, which is responsible for tagging seals, found a short-term impact to marine mammals during the construction phase as a result of the high sound levels caused by driving the piles into the seabed. To mitigate this potential effect on nearby mammals, deterrent devices such as “pingers” and a seal scare were used before construction to disperse the mammals and thereby reduce these temporal effects. Another study of harbor porpoises in the Baltic Sea found that the mammals left the area during construction at the Nysted wind farm (Carstensen, Henriksen, and Teilmann 2006).

Many marine mammals move into different waters depending on their biological needs. The presence of offshore wind farms may create fragmentation of their habitats. Coupled with other stressors such as by-catch, prey depletion, and pollution, concern for the overall welfare of marine mammals is growing. Further, as more wind farms are erected in waters offshore, such as those of the North Sea, there will be greater competition for habitat. The seasonal distribution of harbor porpoises was followed for 4 years (2002–2006) in North Sea waters of the German exclusive economic zone (EEZ) (Gilles, Scheidat, and Siebert 2009). Hot spots (highly concentrated areas) for foraging were noted as well as times when the populations were at their lowest. It was estimated that up to 39% (worst-case scenario) of the harbor porpoise stock in German EEZ waters could be affected in some way by offshore wind farm production (Gilles, Scheidat, and Siebert 2009).

Precautionary risk reduction and mitigation measures to reduce potential risks to marine mammals from sound emissions include:

- Avoiding areas with dense populations of marine mammals
- Avoiding construction operations such as pile driving during peak migration periods
- Applying noise-reduction measures or pingers or both, particularly before and during construction

- Reducing or limiting boat traffic
- Avoiding marine mammal protection areas.

8.8 Turbine Fluid Leakage and Containment

Although they use no liquid fuel, wind turbines contain small amounts of various kinds of lubricating oils, liquid coolants, and greases necessary for the operation of the turbine's gearboxes, pumps, fans, compressors, and other mechanical elements. If leaks occur during maintenance or operation, turbines have hermetically sealed decks to contain any fluid leakage. These sealed decks can hold the full amount of fluid until it can be safely recovered.

Concern has been raised over the potential for oil leakage from oil-cooled transformers in wind projects. Turbines to be used for typical wind development would use dry-type (air-cooled) step-up transformers to bring the wind electricity from nominal turbine voltages of 480–690 V up to a distribution range of about 32 kV. No danger of leaks would be possible from this type of transformer. Each turbine would feed power to a common transformer electric service platform that serves as an electrical substation centrally located inside the wind plant. A substation to support a 400-MW wind farm would require four large transformers, each containing about 10,000 gallons of circulated dielectric cooling oil. To prevent this fluid from escaping into the environment in the event of a leak, each transformer would be mounted on a sealed compartment capable of holding 150% of the volume of transformer's oil. In addition, each containment compartment is mounted to a secondary containment storage tank capable of capturing 100% of the oil should all four transformers leak. Possible leakage from each turbine's emergency backup diesel generators is safeguarded by a 1,000-gallon diesel oil storage tank. Thus, the likelihood of even a small leak of fluid into the environment is remote.

New fluid technologies also mitigate the potential for environmental damage from transformer oil leakage. Alternative dielectric coolants produced from seed oils and food additives contain no petroleum, halogens, or silicones. In addition to being both nontoxic and biodegradable in soil and water, such coolants are markedly less flammable than oil coolants. Because of the stringent containment requirements and the expanded use of more environmentally friendly fluids in wind energy substation transformers, potential dangers posed by oil leakages from offshore wind energy projects constitute a very low risk. Regardless of this risk, EPA containment standards would apply.

8.9 Ship and Air Collisions

An offshore wind plant poses some potential risk of collisions between turbine systems and other sea users such as commercial and recreational vessels. Such collisions would pose not only safety risks but also the potential for environmental damage, including the release of pollutants in the form of fuel or oil. These risks are certainly a siting consideration, suggesting the need to avoid particularly busy maritime areas, shipping routes, traffic nodes, and fishing hot spots. On the other hand, some analysts classify turbines as aids to navigation that may serve to prominently indicate the navigational hazards associated with the shallow areas where projects are likely to be located in the foreseeable future. Measures will need to be taken to prevent collisions (e.g., navigation exclusion zones, distance requirements for routes, mapping on navigation charts, and warning lights) or to respond rapidly to them (e.g., emergency response and rescue). Collision risks have been investigated at some length in the United Kingdom and

Germany, with a particular focus on risk reduction. A risk assessment for the proposed Horns Rev II wind farm concluded that the likelihood of ship-to-ship collision is “significantly higher” than the probability of a vessel colliding with a wind turbine (ENERGI E2 2006). At the Nysted offshore wind farm in Denmark, some 48,000 boats pass annually through the shipping lane 8 km south of the wind farm and its was found to cause only “minimal hindrance” to commercial traffic (Elsam Engineering and ENERGI E2 2005).

Some assessments focused on possible collisions between land-based or offshore turbines and low-flying civil or military aircraft. Considerable attention has been paid to the effect of wind farms on the efficacy of radar systems and the potential for increased risk of aircraft collision or interference with defense systems. The United Kingdom conducted several years of study and initiated collaborations with military entities about potential effects on radar systems and mitigation strategies. These studies found that some level of the interference from wind turbines can be mitigated with improved radar hardware, filtering software, or gap-filling radar systems (BWEA 2010). Most recently, some land-based projects in the U.S. Midwest have experienced siting delays as the result of concerns regarding potential radar impacts to civilian aircraft or nearby military installations. Overall, collision risks are generally well understood and are unlikely to present a significant obstacle to offshore wind energy, provided these interactions and risks are considered carefully in the siting process and reasonable precautionary measures are taken to avoid the perceptions or realities of national security risks (COWRIE and BERR 2007).

8.10 Socioeconomic Risks

An offshore wind energy project could potentially produce diverse social and economic effects, particularly on nearby coastal communities, including the following:

- Positive and negative effects on other human activities (e.g., recreation, entertainment, tourism, and fishing)
- Valuation of the aesthetics of the natural landscape/seascape and its effect on real estate
- Interference or competition with key fishing grounds or other local land/sea uses
- Positive and negative impacts on communities, whether nearby or remote (such as nearness to staging areas for construction or decommissioning)
- Potential community conflict between project supporters and opponents
- Mostly positive effects on employment and economic stimulation from staging, construction, and operation and maintenance
- Improved electrical price stability
- Decreased dependence on foreign sources of fuel/energy.

Important in evaluating the full socioeconomic impact of a development, the “multiplier effects” of wind development on a local economy are threefold. These effects include direct effects from local manufacturing and construction activities as well as expenditures during operation, indirect effects from increased demand for local goods and services, and induced effects, which capture the increase in wealth from the direct and indirect local spending by people involved in the wind farm development and operation (Tegen, Goldberg, and Milligan 2006).

Job generation and positive economic growth are two important factors for local communities. The effects on employment and local expenditures appear quite modest to date, although the renewable energy market has generated a significant employment base in Europe. For example, the Cape Wind EIS estimates an increase of 391 full-time workers during construction and 50 full-time workers during permanent operation of the 130 wind turbines (MMS 2009a). At the Horns Rev wind site in Denmark, more than 1,700 man-years of local jobs were created during construction and 2,000 man-years will be created over the 20-year life of the project. About one-fourth of these jobs were locally based.

Tourism is a complex issue with great uncertainty. In highly trafficked tourist areas with significant revenues going to local businesses, as well as to the state treasury, there are legitimate fears about any potential negative impacts to tourism. Although there is much to suggest that changes in tourism will be positive, the Cape Wind EIS anticipates that changes to the character of the area by the presence of wind turbines may deter people or change the type of activities in which they indulge (MMS 2009a; Landscape Institute and the Institute of Environmental Management and Assessment 2002). On the other hand, although some European projects faced initial reluctance from local communities because of these concerns, following construction, the communities saw a positive increase in tourism as people traveled to see operating offshore turbines (MORI Scotland 2002). In a survey conducted in July 2009 of coastal New Jersey communities, 89% of respondents (1,003 total) said that the presence of an offshore wind farm would not affect their plans to visit Atlantic City (Schulman 2009). Alternatively, in Germany, tourist operators fought vociferously to block offshore wind farm development in some communities (Gee 2010). As with potentially affected issues, the potential effects of offshore wind projects on tourism will be highly site specific, depending on the state of the local economy, compatibility of project siting with other uses of the ocean, and early stakeholder involvement. A sociological study conducted in communities near the Danish Horns Rev I and Nysted wind farms found that preconstruction apprehension, primarily concerning the visual impact, largely turned into acceptance once the wind farm began operation. The study suggested that this preconstruction antipathy resulted from an unrealistic perception of what would be the true aesthetic impacts, and that acceptance of the development spread as individuals became accustomed to the view (Elsam Engineering 2005).

Further, studies of public perception and tourism in communities near land-based wind farms in Scotland, Australia, and Germany found no noticeable decreases in tourism (MORI Scottish Renewables Forum 2002; N.I.T. GmbH 2001),and several studies reported that the wind farms boosted the tourism industry, with more curious sightseers coming to the area. A 2003 European Wind Energy Association (EWEA) public perception poll found that 81.3% of frequent tourists and 80.5% of occasional tourists felt “neutral to very positive” about near-shore wind farms (EWEA 2003).

Surveys of local residents along the North Sea coast found that attitudes toward offshore wind were seeded in three main aspects:

- The view of the sea as a natural space
- The local identity of an area linked to the local landscape

- Perceptions of renewable energies in combination with attitudes toward climate change and sea level rise (Gee 2010).

Onshore, any potential effect to the tourism industry would come from the visual aesthetic. Temporary noise impacts on land would occur in a limited area only when the underground transmission cable was being installed. In fact, looking at case studies of land-based and offshore wind farms in Europe, Australia, and the United States, the Cape Wind EIS concludes that the Cape Wind development will most likely have a negligible impact on recreation and a positive impact on tourism in Cape Cod and on Nantucket and Martha's Vineyard (MMS 2009a). Some aspects of tourism could be enhanced by the presence of a wind farm through local boat and aerial tours. Educational institutions could also take advantage of the wind farm to draw attention to energy issues and the environment.

8.11 Visual Effects and Aesthetics

The Cape Wind project shows that the perceived visual effects of an offshore wind development can be as significant to public acceptance of offshore wind farm siting as impacts to birds, mammals, and fish. Martin Pasqualetti, an expert in the public perception of energy and the aesthetic values of communities, described the situation of the Cape Wind project as one where "wind is colliding with the wishes of a prosperous and politically astute residential corps bent on protecting existing scenic and recreational qualities that it has come to cherish" (Pasqualetti 2004). Visual impacts involve a host of considerations, including the following:

- Scale of the wind farm
- Prevailing weather conditions
- Change in landscape and seascape features, configurations, or general appearance
- Distance from sensitive receivers (people or animals)
- Intrusion of technology into natural landscapes or seascapes
- Presence of other developments in the foci area
- Effects on coastal recreation and tourism
- Effects on cultural communities.

It is already clear that the sensitivity of local coastal populations is highly site specific. Figure 8-6 is a visual perspective of Horns Rev, one of the largest wind energy projects in the world, with 80 turbines capable of producing 160 MW. A few European studies have examined changes in the visual landscape/seascape, focused primarily on methodological issues in analyzing public perceptions and values and developing approaches for landscape assessment (DONG Energy et al. 2006). In Denmark, the presence of offshore turbines did not affect the residents' willingness for more turbines in the future, though the positive attitude could be jeopardized by too many wind farms (Ladenburg 2009a).

Photos courtesy of DONG Energy.

Figure 8-6. Previsualization of the Horns Rev I wind farm from Blåvands Huk (top) and actual post-construction photograph from Blåvands Huk (bottom)

Distance of the farm from shore and prevailing weather conditions that affect visibility can mitigate visual impacts. At Horns Rev I, a very limited sampling of the public revealed a strong preference for offshore wind farms to be located farther from the coast to preserve the impression that nature is unaffected by a human enterprise (Elsam Engineering and ENERGI E2 2005). COD (2005) concluded that "the importance of a positive attitude toward wind energy must not be underestimated." When these perceptions were analyzed with others from other sites in Denmark, it was clear that prior experience with offshore wind farms had an influence on the types of visual impacts people experienced and that positive perception of offshore wind farms was influenced by distance to the coast (Ladenburg 2009a).

Beyond public sentiment, an additional area of legal concern is the potential for visual or other impacts to historic sites designated in the National Register. If there is the potential for a development to affect a recognized historic site, the regulatory process would require additional review and oversight of the proposed development as per Section 106 of the National Historic Preservation Act (NHPA) of 1966. In creating procedural obligations to study the impacts of federal actions, NHPA can be seen as a close analogue to NEPA, where NHPA does for historic sites what NEPA does for the environment (San Carlos Apache Tribe vs. United States 2005). Before being permitted, the Cape Wind project was reviewed under Section 106 of NHPA because of the importance of the view of the seas in the cultural and religious rites of the Wampanoag tribe of Massachusetts. It was determined in part, however, that although the area has great historic and cultural significance, it is not untouched landscape with several cell phone towers, undersea cables, and other structures of modern life (DOI 2010).

The impact of a visible wind farm on property values has also been an issue of concern. A 2003 case study on the possible impact of 11 land-based U.S. wind farms on local property values found that property values within the “viewshed” did not perform any worse than those in a comparable region with no wind turbines. Additionally, a significant majority of projects studied revealed that property values within the wind power development’s viewshed grew at a faster rate than property values in a comparable region (Renewable Energy Policy Project 2003). More recently, Hoen et al. (2009) studied the sale of almost 7,500 homes within 10 miles of 24 existing wind farms in nine states and found no statistically significant evidence that wind farms lower property values. At present, it is not known how values of coastal residences in the United States will be affected by the presence of an offshore wind farm.

8.12 Findings and Conclusions

A new paradigm is needed for thinking about the range of environmental and social risks of offshore wind developments, and it will need to be embodied in forward-looking state and federal energy policies. A diverse portfolio approach to energy development will include both land-based and offshore wind energy as important components in the energy mix. This new analytical paradigm is framed in the context of comparative sector risks with other energy technologies and is not limited to sector-by-sector risk analyses.

An integrated and comparative risk framework can serve as a comprehensive assessment of the costs and benefits of deploying an offshore wind farm as opposed to proceeding with some other energy choice. Rather than the sector-by-sector approach, an integrated risk framework begins to give federal, state, and local decision makers and their stakeholders a common ground for analyzing and managing risks and devising public policies and effective siting strategies (Ram 2009). Moreover, an integrated perspective helps build the knowledge base required for the national marine spatial planning initiative.

- **Knowledge base**—Known sectoral risks from the European studies include the following:
    - Potential risks to specific species of bird and marine populations, changes to aesthetic values and viewsheds, effects on recreational uses of the sea and

    tourism, competing use of the outer continental shelf, and human valuation (real estate) of seascape environments are the primary risk concerns for offshore wind power facilities, based on studies and experiences to date.

    - Avian collisions resulting from wind turbine interactions may affect endangered species and species of concerns that already face a panoply of anthropogenic risks. To date, no installations in Europe have had significant impacts on bird or bat populations or habitats.
    - The largest risk found so far from studies at European wind plants stem from the noise generated during the construction phase. The impacts from pile driving were potentially significant in the short term, although recent experience suggests that these risks can be mitigated to some degree (see Section 5).
    - Residents living near a wind site can have concerns about visual impacts, which can become a larger public concern. There are uncertainties relating to how coastal communities react or accept changes to the seascape when turbines are in their view. This area requires more research to better understand how visibility would affect public acceptance.
    - Effects on tourism could be an issue, but actual effects appear to be minimal. This can be a concern to some communities that depend on beach traffic and the resulting local revenues and tax base, but the evidence is ambiguous.
    - The possibility of a ship colliding with a turbine poses a potential significant risk because the result would affect safety and the marine environment should fuel or oil leak from a disabled ship or the turbine. No reported incidents have occurred, however, to date from existing wind projects, and so probabilities might be low.
    - Studies of land-based wind projects show minimal to no effects on real estate prices and property values because of the presence of wind turbines, although studies have yet to been done on coastal communities.
    - Comparisons with other energy sources (such as fossil fuels and nuclear) indicate that the overall risks of offshore wind are relatively benign and not catastrophic (such as breached coal ash ponds, nuclear waste impacts).

- **Risk priorities**—A finding of this analysis is that wind energy is not subject to catastrophic risks, as are other energy supply technologies. Best management practices and mitigation strategies are useful perspectives on managing current risks and uncertainties with wind energy. A major finding is that prioritizing risk research is needed to best fill gaps in the knowledge base and to understand more adequately the uncertainties that surround the risk problems at stake.
- **Siting strategies**—A prudent siting policy is sensitive to industry decisions about the wind resources and cost-competitiveness, considers competing uses of the ocean, and takes into account community concerns. Siting strategies must go beyond narrow technical appraisals of sites to include collaborative approaches with potential host states and communities. Well-developed risk communication and stakeholder involvement programs will be essential. In certain circumstances, a regional approach with federal policy support will be necessary.

- **Adaptive management**—A prudent, yet flexible, deployment strategy will need to integrate monitoring with adaptive management approaches and risk mitigation strategies identified through the NEPA process (DOI 2008; Williams, Szaro, and Shaprio 2007). The research approach will need to be one of learning through experience, yet it must be flexible enough to easily accommodate and integrate new information and improved risk knowledge as they become available.
- **Stakeholder engagement**—The benefits and costs of offshore wind to a community's environmental, social, and economic factors will need to be discussed with stakeholders within the context of other sources of energy, sustainability, and anticipated impacts of climate change. A risk communication program must focus on risks, uncertainties, and local concerns and distinguish among the needs of different stakeholder groups. Current experiences indicate that leadership will be needed in these areas and that interested states and regional organizations will play a central role along with the federal agencies.

8.13 References

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Appendix A: Interagency Coordination

Table A-1. Applicable Laws and Responsible Agencies Related to Renewable Energy Development on the Outer Continental Shelf

Statute/Executive Order (E.O.)	Responsible Federal Agency/Agencies	Summary of Pertinent Provisions
National Environmental Policy Act of 1969, as amended (NEPA) (42 U.S.C. 4321 et seq.)	Council on Environmental Quality (CEQ)	Requires federal agencies to prepare an Environmental Impact Statement (EIS) to evaluate the potential environmental impacts of any proposed major federal action that would significantly affect the quality of the human environment, and to consider alternatives to such proposed actions.
Endangered Species Act of 1973, as amended (16 U.S.C. 1531 et seq.)	U.S. Fish and Wildlife Service (FWS); National Oceanic and Atmospheric Administration (NOAA) National Marine Fisheries Service (NMFS)	Requires federal agencies to consult with the FWS and the NMFS to ensure that proposed Federal actions are not likely to jeopardize the continued existence of any species listed at the federal level as endangered or threatened, or result in the destruction or adverse modification of critical habitat designated for such species.
Marine Mammal Protection Act of 1972, as amended (16 U.S.C. 1361-1407)	FWS (walruses, sea and marine otters, polar bears, manatees and dugongs); NMFS (seals, sea lions, whales, dolphins, and porpoises)	Prohibits, with certain exceptions, the take of marine mammals in U.S. waters by U.S. citizens on the high seas, and importation of marine mammals and marine mammal products into the United States.
Magnuson-Stevens Fishery Conservation and Management Act (also known as the Fishery Conservation and Management Act of 1976, as amended by the Sustainable Fisheries Act) (16 U.S.C. 1801 et seq.)	NMFS	Requires federal agencies to consult with the NMFS on proposed federal actions that may adversely affect essential fish habitats necessary for spawning, breeding, feeding, or growth to maturity of federally managed fisheries.
Marine Protection, Research, and Sanctuaries Act of 1972, as amended (33 U.S.C. 1401 et seq.)	U.S. Environmental Protection Agency (EPA); U.S. Army Corps of Engineers (USACE); NOAA	Prohibits, with certain exceptions, the dumping or transportation for dumping of materials including, but not limited to, dredged material, solid waste, garbage, sewage, sewage sludge, chemicals, biological and laboratory waste, wrecked or discarded equipment, rock, sand, excavation debris, and other waste into ocean waters without a permit from the EPA. For ocean dumping of dredged material, the USACE is given permitting authority.
National Marine Sanctuaries Act (16 U.S.C. 1431 et seq.)	NOAA	Prohibits the destruction, loss of, or injury to any sanctuary resource managed under the

Statute/Executive Order (E.O.)	Responsible Federal Agency/Agencies	Summary of Pertinent Provisions
		law or permit, and requires federal agency consultation on federal agency actions, internal or external to national marine sanctuaries, that are likely to destroy, injure, or cause the loss of any sanctuary resource.
E.O. 13186, Responsibilities of Federal Agencies to Protect Migratory Birds (January 10, 2001)	FWS	Requires that federal agencies taking actions likely to negatively affect migratory bird populations enter into Memoranda of Understanding with the FWS, which, among other things, ensure that environmental reviews mandated by NEPA evaluate the effects of agency actions on migratory birds, with emphasis on species of concern.
CZMA of 1972, as amended (16 U.S.C. 1451 et seq.)	NOAA Office of Ocean and Coastal Resource Management (OCRM)	Specifies that coastal states may protect coastal resources and manage coastal development. A state with a coastal zone management program approved by NOAA OCRM can deny or restrict development off its coast if the reasonably foreseeable effects of such development would be inconsistent with the state's coastal zone management program.
Clean Air Act, as amended (CAA) (42 U.S.C. 7401 et seq.)	EPA; MMS	Prohibits federal agencies from providing financial assistance for, or issuing a license or other approval to, any activity that does not conform to an applicable, approved implementation plan for achieving and maintaining the National Ambient Air Quality Standards (NAAQS). Requires EPA (or an authorized state agency) to issue a permit before construction of any new major stationary source or major modification of a stationary source of air pollution. The permit—called a Prevention of Significant Deterioration (PSD) Permit for stationary sources located in areas that comply with the NAAQS, and a Nonattainment Area Permit in areas that do not comply with the NAAQS—must control emissions in the manner prescribed by EPA regulations to either prevent significant deterioration of air quality (in attainment areas), or contribute to reducing ambient air pollution in accordance with an approved implementation plan (in nonattainment areas). Requires the owner or operator of a stationary source that has more than a threshold quantity of a regulated substance in a process to submit a Risk Management Plan to EPA.
Clean Water Act (CWA), Section	EPA; U.S. Coast Guard	Prohibits discharges of oil or hazardous

Statute/Executive Order (E.O.)	Responsible Federal Agency/Agencies	Summary of Pertinent Provisions
311, as amended (33 U.S.C. 1321); E.O. 12777, Implementation of Section 311 of the Federal Water Pollution Control Act of October 18, 1972, as Amended, and the Oil Pollution Act of 1990	(USCG); MMS	substances into or upon the navigable waters of the United States, adjoining shorelines, or into or upon the waters of the contiguous zone, or in connection with activities under the OCS Lands Act, or which may affect natural resources belonging to the United States. Authorizes EPA and the USCG to establish programs for preventing and containing discharges of oil and hazardous substances from nontransportation-related facilities and transportation-related facilities, respectively. Directs the Secretary of the Interior (MMS, now BOEM) to establish requirements for preventing and containing discharges of oil and hazardous substances from offshore facilities, including associated pipelines, other than deepwater ports.
Marking of Obstructions (14 U.S.C. 86)	USCG	The Coast Guard may mark for the protection of navigation any sunken vessel or other obstruction existing on the navigable waters or waters above the continental shelf of the United States in such manner and for so long as the needs of maritime navigation require.
CWA, Sections 402 and 403, as amended (33 U.S.C. 1342 and 1343)	EPA	Requires a National Pollutant Discharge Elimination System (NPDES) Permit from EPA (or an authorized state) before discharging any pollutant into territorial waters, the contiguous zone, or the ocean from an industrial point source, a publicly owned treatment works, or a point source composed entirely of storm water.
CWA, Section 404, as amended (33 U.S.C. 1344)	USACE; EPA	Requires a permit from the USACE before discharging dredged or fill material into waters of the United States, including wetlands.
Ports and Waterways Safety Act, as amended (33 U.S.C. 1221 et seq.)	USCG	Authorizes the USCG to implement, in waters subject to the jurisdiction of the United States, measures for controlling or supervising vessel traffic or for protecting navigation and the marine environment. Such measures may include but are not limited to reporting and operating requirements, surveillance and communications systems, routing systems, and fairways.
Rivers and Harbors Appropriation Act of 1899 (33 U.S.C. 401 et seq.)	USACE	Section 10 (33 U.S.C. 403) delegates to the USACE the authority to review and regulate certain structures and work that are located in or that affect navigable waters of the United States. The OCS Lands Act extends

Statute/Executive Order (E.O.)	Responsible Federal Agency/Agencies	Summary of Pertinent Provisions
		the jurisdiction of the USACE, under Section 10, to the seaward limit of federal jurisdiction.
Resource Conservation and Recovery Act, as amended by the Hazardous and Solid Waste Amendments of 1984 (42 U.S.C. 6901 et seq.)	EPA	Requires waste generators to determine whether they generate hazardous waste and, if so, to determine how much hazardous waste they generate and notify the responsible regulatory agency. Requires hazardous waste treatment, storage, and disposal facilities (TSDFs) to demonstrate in their permit applications that design and operating standards established by the EPA (or an authorized State) will be met. Requires hazardous waste TSDFs to obtain permits.
National Historic Preservation Act of 1966, as amended (16 U.S.C. 470-470t); Archaeological and Historical Preservation Act of 1974 (16 U.S.C. 469-469c-2)	National Park Service (NPS); Advisory Council on Historic Preservation; State or Tribal Historic Preservation Officer	Requires each federal agency to consult with the Advisory Council on Historic Preservation and the State or Tribal Historic Preservation Officer before allowing a federally licensed activity to proceed in an area where cultural or historic resources might be located; authorizes the Interior Secretary to undertake the salvage of archaeological data that may be lost because of a federal project.
American Indian Religious Freedom Act of 1978 (42 U.S.C. 1996); E.O. 13007, Indian Sacred Sites (May 24, 1996)	NPS; Advisory Council on Historic Preservation; State or Tribal Historic Preservation Office	Requires federal agencies to facilitate Native American access to and ceremonial use of sacred sites on federal lands, to promote greater protection for the physical integrity of such sites, and to maintain the confidentiality of such sites, where appropriate.
Federal Aviation Act of 1958 (49 U.S.C. 44718); 14 CFR part 77	Federal Aviation Administration (FAA)	Requires that, when construction, alteration, establishment, or expansion of a structure is proposed, adequate public notice be given to the FAA as necessary to promote safety in air commerce and the efficient use and preservation of the navigable airspace.
Federal Powers Act, 16 U.S.C 792-823a	Federal Energy Regulatory Commission (FERC)	BOEM will issue leases, easement and right-of-way for hydrokinetic projects located on the OCS. FERC will issue licenses for the construction and operation of hydrokinetic projects the OCS.

Appendix B: Summary of Studies Conducted on Resource Areas as Part of the Cape Wind Environmental Impact Statement

Cape Wind is the first proposed offshore wind project in the United States that completed its Final Environmental Impact Statement (FEIS)[16]), in January 2009 (see timeline in Section 7 for more details). The Record of Decision (ROD), approving Cape Wind's application for a lease, was announced in April 2010. The ROD modified the findings of the FEIS and is a snapshot of the outcomes and studies required for their permitting process as well as the potential environmental and socio-economic effects of the proposed Cape Wind Energy Project. As seen in Table B-1, although most areas were expected to experience negligible or minor impacts, the primary areas of concern from their analyses included effects to avifauna, cultural and historic resources, and aviation safety and navigation (*indicated by gray shading in the table).*

Table B-1. Cape Wind Project Studies

Resource Concern	Studies	Outcomes
PHYSICAL		
Geology	Characterization of the geology of the area using Geophysical/Hydrographic Surveys (yearly 2001–2005), geotechnical/sediment sampling, numerical modeling and engineering analysis and long-term data sets.	Created seafloor profiles based on measurements of several factors, including sediments, seafloor morphology, and water depths. Delineated acoustic targets. Modeled sediment transport. Determined sand wave movement. Concluded no salt or methane hydrate diapirs. Noted little seismic activity.
Noise	Characterization of above-water noise and underwater noise using the (24-h) equivalent sound level and the day-night sound level (above water: November–December 2002, underwater: October 2002).	Demonstrated that ambient and underwater sound levels increased as wind speed increased. Monitored above ground and underwater levels.
Physical Oceanography	Characterization of currents, waves, salinity, temperature, sediment transport, and water depth/bathymetry using long-term data sets and local measurements (waves: May 2003, September 2004).	Modeled flow of currents, wind-generated wave height, magnitude, and period for offshore area. Summarized salinities and temperatures based on long-term data sets. Modeled sediment transport under varying conditions using comprehensive two-dimensional transport model. Summarized bathymetric conditions.
Climate & Meteorology	Characterization of air temperature, wind conditions, precipitation and fog events,	Summarized ambient temperatures, wind conditions, precipitation and fog events, presence of hurricanes, and mixing height.

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[16] Minerals Management Service. (2009). Cape Wind Energy Project: Final Environmental Impact Statement. Herndon, VA: DOI.

Resource Concern	Studies	Outcomes
	hurricanes, and mixing height from long-term data (National Climate Data Center and local sources, e.g., wind buoys).	
Air Quality	Characterization of air quality based on long-term monitoring data National Ambient Air Quality Standards.	Summarized existing and regional air quality. Noted that offshore monitoring is an unknown because there are no monitoring stations in Nantucket Sound.
Water Quality	Characterization of the water quality of the coastal waters, onshore waters, wetlands from long-term data sets. Chemical and physical analysis of sediment at proposed coffer dam site	Summarized existing information: including Lewis Bay and Nantucket Sound are Class SA coastal and marine water bodies and onshore waters are Class B. Summarized locations of sites associated with releases/spills of petroleum products and hazardous substances in relation to land cable route. Noted that land-based construction would be located within the Cape Cod Sole Source Aquifer. Noted that proposed transmission cable system would not be prohibited by regulations of wetlands. Analyzed sediments were within established guidelines.
Electrical & Magnetic Fields	Baseline determinations of power frequency magnetic flux densities of along proposed land-based transmission cable route coupled with computer modeling to produce worst-case conditions reflecting peak loads (June 5–6, 2002).	Sources of EMFs include land-based existing overhead distribution lines; the Nantucket Cable, which runs underwater from Nantucket to Cape Cod; and the natural geomagnetic field of the earth.
BIOLOGICAL		
Terrestrial Vegetation	Characterization of salt marsh, freshwater wetland, and upland vegetation using review of existing studies, site investigations, and agency consultations.	Summarized the vegetation and defined the areas (e.g., upland, marsh, freshwater) along the proposed transmission cable route.
Coastal and Intertidal Vegetation	Characterization of vegetation using maps from the Massachusetts Department of Environmental Protection, geophysical studies, free diving, and visual observations (geophysical sonar studies: 2002, 2003, and 2005).	Summarized presence or absence of vegetation on adjacent beaches and described importance of shoreline in buffering storm damage. Summarized brackish and saline wetlands including salt marshes, shellfish waters, and navigable waters intersected by transmission cable. Determined presence/absence and composition of seagrass beds along proposed transmission cable route.

Resource Concern	Studies	Outcomes
Terrestrial and Coastal Faunas other than Birds	Characterization of mammals, reptilians, amphibians, freshwater fish, and invertebrates using data sets, published surveys and field surveys (2001–2002).	Summarized mammals known to inhabit the area based on historical surveys. Summarized known bat species in the area and their associated habitats, ranges, hibernations, and feeding patterns. Discussed need for information on the extent to which bats fly over coastal waterways. Proposed that only a few bat species would be capable of crossing Nantucket Sound in spring and fall during migration. Summarized reptile and amphibian species in the proposed area. Unable to assess fish species in Thornton Brook where the proposed transmission cable would cross because of dry conditions. Summarized invertebrates in the proposed area and highlighted the three state threatened and endangered species—comet darner (*Anax longipes*), New England bluet (*Enallagma laterale*), and water-willow stem borer (*Papaipema sulphurata*).
Avifauna	Characterization of birds in the proposed action area using existing data and aerial, boat, and radar surveys (March 2002–September 2006: Massachusetts Audubon Society Surveys: August 2002–September 2004).	Summarized Nantucket Sound's significance as part of Atlantic Flyway. Summarized species found in the area and their protection under the Migratory Bird Act and additionally for some, the Endangered Species Act. Conducted preliminary avian risk assessment. Summarized species, their concentrations, distributions, seasonalities, and behaviors.
Subtidal Offshore Resources	Characterization of shellfish, meiofauna, and plankton resources based on review of existing data and scientific literature, site assessments and field surveys (2001–2005), and agency consultations.	Summarized hard/soft bottom benthic communities in proposed action area. Noted new taxa, not found previously, on meteorological support pilings, but overall communities were similar to neighboring seafloor community. Summarized distributions and numbers for several shellfish species, including conch, quahogs, scallops, and clams. Identified proximity of proposed transmission cable route to commercial and recreational shellfish beds. Little information known on meiofauna and plankton residing in Nantucket Sound and within proposed area.
Marine Mammals	Characterization of marine mammals including acoustical impacts using scientific literature reviews and resource	All marine mammals in proposed action area are protected under Marine Mammals Protection Act (MMPA) and some are protected under Endangered Species Act

Resource Concern	Studies	Outcomes
	management agencies consultation	(ESA). Applicant will seek authorization with NOAA fisheries to allow for the accidental taking of marine mammals and acknowledges need to apply for Incidental Take Statement under ESA for MMPA authorization. Summarized cetaceans, pinnipeds, and sea turtle species with emphasis on population sizes, sightings, strandings, seasonal distributions, food and feeding behaviors, known disturbances. mortality factors. and impacts of acoustical disturbance.
Fish and Fisheries	Characterization demersal, pelagic fish and commercial and recreational fish and shellfish using data from NOAA fisheries and Massachusetts Department of Marine Fisheries (Mass DMF). Conducted surveys and reviewed existing surveys (Survey of Commercial and Recreational Fishing Activities, 2005; Recreational Intercept Survey, August–November 2002).	Summarized demersal and pelagic fish, commercial and recreational fish, and shellfish species with respect to population size, range, known migratory behavior, and catch size. Reviewed Massachusetts Fisherman's Partnership study (Weisma 2008), which focused on the impacts of wind turbine generator installations on the squid and fluke fisheries, which have major trawling grounds on Horseshoe Shoals and Nantucket Sound. Reviewed Survey of Commercial and Recreational Fishing Activities (2005), NOAA Marine Recreational Fisheries Survey, and Recreational Intercept Survey, looking at locations, types of fish caught, catch size, and economic data. More than 70 vessels draft fish commercially in Nantucket Sound, and local fishermen derive 50%–60% of livelihood from fishing in Nantucket Sound.
Essential Fish Habitat (EFH)	Performed Essential Fish Habitat assessment in compliance with Magnuson-Stevens Act using NOAA fisheries and Mass DMF data sets.	Summarized life histories and landings of demersal and pelagic fish and invertebrates.
Threatened and Endangered (T & E) Species	Characterization of endangered and threatened species in the proposed area through literature review, stock assessment reports, and consultation with agencies. Biological Assessment initiated by MMS in compliance with NEPA and ESA.	Summarized known ESA species including marine mammals, turtles, birds, and insects with respect to life histories, populations, status, distributions, and threats that would be potentially affected by proposed action.

SOCIOECONOMIC RESOURCES AND LAND USE		
Socioeconomic Analysis Area	Characterization of geographic scope of areas designated part of Region of Impact (ROI).	Described the potential impacts to ROI including potential increase in workforce, the building of infrastructure, and the use as a point of debarkment.
Urban and Suburban Infrastructure	Characterization of housing, services, and industries present in ROI.	Summarized numbers of housing units, percent ownership, and percent rental. Summarized industries and services including construction and manufacturing, educational, professional, scientific and technical, administration, support, waste management and remediation, accommodation, food, transit facilities, military activities, and energy.
Population and Economic Background	Characterization of demographic and economic data for ROI using current U.S. Census data.	Summarized population, age, race and ethnic composition, and education for Dukes, Barnstable, Nantucket, Bristol, and Washington counties using Census data Summarized current income levels, business activity by sector, employment, income and wealth, property values, and environmental justice considerations using local, state, and federal census data. Performed Environmental Justice Analysis.
Visual Resources	Characterization of visual resources associated with historic, religious, and recreational areas. Used assessments of simulation locations chosen with assistance from Massachusetts Historic Commission (MHC) and MEPA to represent worst-case visual impacts. Also employed field reconnaissance, background research, review of National Register of Historic Properties, and other MHC files.	Described 12 simulation locations and additional properties based on distance from proposed action, brief history of significance, whether or not it is registered with National Registry of Historic Places, photographs from different vantage points, and whether or not the proposed action would be viewable. Determined that wind turbines would most likely be viewable from some historic and recreational locations as well as large shoreline homes. Turbines would most likely be viewable from the waters around the island of Nantucket, Cape Cod, Martha's Vineyard and those of Nantucket Sound. Noted the concerns of the Wampanoag Tribe ("People of the First Light"), which requires an unobstructed view of the first light on the horizon to carry out many religious and cultural beliefs and practices. Description of recreational areas (e.g., beaches, marinas, simulation locations) that would potentially have a view of the proposed action. Noted transmission cable would be buried underground or within existing easement not considered an issue.

Cultural Resources	Defined Areas of Potential Effects (APEs) for land-based and offshore historical and prehistoric human cultural activities. Conducted archaeological surveys and marine sensitivity assessments, and compiled lists of historic structures within communities.	Noted land-based historical archaeological sites would not be affected. Identified 22 existing historic structures and districts within APE as well as Native American lands of the Mashpee Wampanoag Tribe. Noted the Mashpee Wampanoag Tribe considers all of Nantucket Sound to be part of their tribal lands. Summarized shipwrecks, potential Viking contact sites, and any sonar anomalies for the offshore site.
Recreation and Tourism	Characterization of recreational and tourism activities and assessment of potential impacts using Chamber of Commerce data, town surveys, and field observations.	Summarized potential impacts on various activities including birding, beach and shoreline activities, recreational boating and water sports, and recreational fishing.
NAVIGATION AND TRANSPORTATION		
Overland Transportation Arteries	Characterization of major and minor roadways and assessment of potential impacts.	Summarized major and minor roadways with respect to volumes and access points in relationship to their use as routes for transporting materials and as staging and loading areas. Summarized potential impacts to major and minor roadways from installation of the transmission cable.
Airport Facilities	Characterization of airports in the area and assessment of potential impacts.	Excluded high altitude jetways from assessment because they were not considered a factor. Documented that turbine array was not located in flight path where low-altitude instrument flight rules would apply. Documented that general aviation traffic must maintain a minimum clearance of 500 feet from any structure or vessel to be in compliance with federal regulations.
Port Facilities	Characterization of Nantucket Sound and smaller surrounding ports with respect to navigation by recreational and commercial vessels.	Identified main ship channels and other private and federal channels and assessed usage by recreational vessels (e.g., sail boats, kayaks, canoes, small boats) and commercial vessels (e.g., fishing boats, ferries, cruise ships, scientific vessels) defining peak usage and potential impacts. Summarized marinas and ports in the area that handle various traffic, though no deep draft traffic (e.g., container vessels). Documented marine events that may be affected by proposed action.

COMMUNICATIONS		
Communications: Radar, Television, Radio, Cellular, and Satellite Signals and Beacons	Characterization of main communications services (recreational, navigational and positioning, aviation and military surveillance radar) using FCC antenna structure databases. Federal Aviation Administration (FAA) study of the potential for turbines to interfere with communication instrumentation	Summarized AM, FM, and TV stations serving Cape Cod area. Summarized location of airport control towers and military radar facilities in relation to proposed action. FAA aeronautical study determined that the proposed turbines would not interfere with instrumentation needed for navigation or approach procedures. Noted proposed use of glass reinforced plastic composition blades to ensure minimum effect on communication facilities.

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14. ABSTRACT *(Maximum 200 Words)*

This report provides a broad understanding of today's offshore wind industry, the offshore wind resource, and the associated technology challenges, economics, permitting procedures, and potential risks and benefits.

15. SUBJECT TERMS
offshore wind energy; wind power; renewable energy

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
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