# U.S. Offshore Wind Energy: A Path Forward

A Working Paper of the

U.S. Offshore Wind Collaborative

October 2009

US Offshore Wind Collaborative

## Contributing Authors

**Steven Clarke**, Massachusetts Department of Energy Resources

**Fara Courtney**, U.S. Offshore Wind Collaborative

**Katherine Dykes**, MIT

**Laurie Jodziewicz**, American Wind Energy Association

**Greg Watson**, Massachusetts Executive Office of Energy and Environmental Affairs and Massachusetts Technology Collaborative

## Working Paper Reviewers

The Steering Committee and Board of the U.S. Offshore Wind Collaborative owe a debt of gratitude to the following individuals for their careful and thoughtful review of this Working Paper and for offering their invaluable comments and suggestions.

**Walter Cruikshank**, U.S. Department of the Interior

**Soren Houmoller**, 1st Mile (DK)

**Chris Jenner**, RPS Group (UK)

**Jim Manwell**, University of Massachusetts

**Walt Musial**, ex officio, National Renewable Energy Laboratory

**Bonnie Ram**, Energetics

## USOWC Board of Directors

**Cover:** The Middelgrunden offshore wind farm in the Øresund 3.5 km outside Copenhagen, Denmark. When it was built in 2000, it was the world's largest offshore farm with 20 turbines and a capacity of 40 MW.

# Table of Contents

# Introduction

The wind energy resources off the coasts of the United States are vast and plentiful. The U.S. Department of Energy (DOE) estimates that the wind resources along American ocean and Great Lakes coasts are capable of providing 900,000 megawatts (MW) of electricity—an amount nearly equivalent to the nation's current total installed capacity. These offshore wind resources are especially attractive because they are located in relative proximity to the country's largest centers of electricity use.

Offshore wind energy has great potential to address the United States' urgent energy and environmental needs; however, this game-changing domestic renewable energy source remains untapped. Currently, the European Union (EU) leads the world in offshore wind development. Pilot offshore wind projects were installed in Europe as early as 1990, and by the end of 2008, EU nations had installed more than 1,470 MW of offshore wind energy capacity. Additional EU projects currently under construction will bring this total capacity to 1,800 MW. China (1.5 MW) and Japan (1 MW) are also developing the technologies and know-how necessary to realize the potential of offshore wind energy resources.

The nascent U.S. offshore wind industry has arrived at a crossroads. President Barack Obama pledged to reorient the nation's energy agenda to reflect his commitment to a clean energy future. In announcing the federal administration's strategy for developing energy resources on the Outer Continental Shelf, U.S. Secretary of the Interior Ken Salazar spoke of building, "a framework for offshore renewable energy development, so that we incorporate the great potential for wind, wave, and ocean current energy into our offshore energy strategy."[1]

## Origins of the U.S. Offshore Wind Collaborative

In 2001, Cape Wind became the first offshore wind energy project proposed for development on the U.S. Outer Continental Shelf. This proposal attracted both ardent support and strong opposition, along with vigorous public debate about the permitting process.

Cape Wind LLC originally selected General Electric (GE) to supply wind turbines for the proposed Cape Wind project. In the summer of 2003, GE representatives approached the Massachusetts Technology Collaborative (MTC—a quasi-state agency that manages the Massachusetts Renewable Energy Trust) and DOE with the idea of establishing a collaborative process to explore opportunities for developing next-generation offshore wind energy systems. GE was specifically interested in technologies that could tap wind resources in deep water off the New England coast, and the company had already been working on a research agenda with academics from the University of Massachusetts, the Massachusetts Institute of Technology (MIT), and the Woods Hole Oceanographic Institution. However, GE was looking for a more comprehensive and anticipatory approach that would engage regulatory agencies, policy makers, environmental advocacy groups, and other industry partners as well.

Following a series of meetings, MTC, GE, and DOE agreed to commit funds and staff time to pursue design of a collaborative process. These three partners formed the initial Offshore Wind Collaborative. They convened a broad group of stakeholders in Washington, DC, to consider the universe of challenges and opportunities associated with generating electricity from marine-based wind energy systems. The result was *A Framework for Offshore Wind Energy Development in the United States* (September 2005)—a comprehensive agenda for developing a sustainable offshore wind

---

[1] MMS April 22, 2009 press release: http://www.mms.gov/ooc/press/2009/press0422.htm

industry. The *Framework* anticipates environmental and socioeconomic concerns and calls for a robust partnership among government, industry, academia, and the NGO community. This partnership would be able to address key issues and take advantage of every opportunity to *mitigate by design*.

To illustrate potential activities for an offshore wind collaborative, MTC, GE, and DOE jointly funded five pilot research projects. These projects were completed in 2005 and covered topics including the policy framework, technical considerations, and economic and environmental performance expectations for offshore wind development.[ii]

In the ensuing years both GE and DOE shifted focus away from offshore wind. This prompted the Offshore Wind Collaborative to regroup with emphasis on a new, vacant niche—offshore wind advocacy that engages all sectors and transcends political time frames.

A volunteer, ad-hoc Steering Committee for the Offshore Wind Collaborative came together in 2008 with the intent to build on the original success of the collaborative concept. This new committee comprised representatives from state agencies, industry, academia, and environmental organizations. The Steering Committee's diverse membership reflected both the changing levels of participation among the original partners and the expanding number of states engaged in planning and promoting offshore wind energy development.

Also in 2008, the Steering Committee officially launched the U.S. Offshore Wind Collaborative (USOWC) at the American Wind Energy Association's Offshore Wind Workshop in Wilmington, Delaware. At this workshop, USOWC convened state representatives from across the U.S. to engage in conversation about state roles in advancing offshore wind development. The event drew representatives from states, federal agencies, industry, academia, and non-governmental organizations, and it highlighted the need for further interdisciplinary dialogue.

Since this initial forum, USOWC has been pursuing state/federal coordination between Northeast, Mid-Atlantic, and Great Lakes states and federal agencies including the Minerals Management Service (MMS), the National Oceanic and Atmospheric Administration (NOAA), the Army Corps of Engineers and the Environmental Protection Agency (EPA). USOWC is currently exploring opportunities for collaboration with DOE, in addition to continuing its central role as a catalyst and facilitator.

In this context, the USOWC mission statement is defined as follows: *The mission of the USOWC is to address the technical, environmental, economic, and regulatory issues necessary to catalyze the sustainable development of offshore wind energy in the waters of the United States.* USOWC intends to fulfill this mission by serving as a focal point, convener, and information clearinghouse, in order to promote successful collaboration among U.S. offshore wind stakeholders.

## Purpose of this Working Paper

In the years since the Framework was published in 2005, the U.S. has achieved many advances in policy and technology relating to offshore wind development. However, these successes have been limited by additional financial, technical, policy, and public support factors. Only recently has a confluence of political will, public interest, and contextual circumstances created a new environment for advancing the U.S. offshore wind industry.

The future looks bright for offshore wind power, but even this confluence of opportunities does not ensure success. The U.S. offshore wind energy universe involves a complex network of stakeholders, including multiple federal agencies, state governments, diverse industry stakeholders

---

[ii] http://www.usowc.org/init.html#owc

(such as manufacturers, developers, and construction firms), academic researchers, and nongovernmental energy and environmental organizations. The public will play an important role, since the ocean is one of America's most valuable public trust resources. Successful offshore wind development in the U.S. will require meaningful engagement with all these stakeholders.

Long-term success will also require addressing a number of interrelated political, technical, economic, financial, and environmental issues. Developing viable solutions to these complex issues will require coordinated cross-sector engagement. Offshore wind projects may be located in ecologically-sensitive marine environments where significant threats from pollution to climate change are already being felt. As a result, the offshore wind activities must be compatible both with aquatic ecosystems and with other human uses.

The changing regulatory and policy structure presents an additional challenge for the offshore wind industry. The structure is evolving not only for this industry specifically, but also for related areas including renewable energy standards, climate change policy, and comprehensive ocean management planning. The offshore wind industry must be able to adapt to, influence, and evolve within these changing regulatory environments.

Given the opportunities and complexities facing the offshore wind industry today, the USOWC Steering Committee decided to develop this document as an update to the 2005 *Framework*. Its purpose is to foster discussion by highlighting opportunities and challenges influencing development of a U.S. offshore wind industry, with focus on five key areas: a) state and federal policy, including regulatory structures, b) technology development, c) economics, d) environmental/marine use compatibility, and e) coordinating leadership. The information that follows is the product of extensive research and interviews with selected experts.

We present this document as a snapshot of the 2009 context for the U.S. offshore wind industry. It will be updated periodically as a part of USOWC's effort to serve as an information clearinghouse for offshore wind. The document also defines USOWC's strategies for mobilizing new and existing partners in order to help guide the nation on a path toward realizing its offshore wind energy potential.

# 1. Regulation and Government Policies

## Overview

While U.S. policies for offshore oil and gas extraction are well established, policies and regulations for offshore wind energy development are still in preliminary stages. Since *A Framework for Offshore Wind Energy Development in the United States* was published in 2005, there have been notable advances in wind energy policies, particularly those related to project siting. Government policies and regulations set the stage for the research, investment, and development needed to create a sustainable offshore wind industry and send signals about the viability of the sector.

In the past few years, federal and state agencies have been exploring policies that would advance offshore wind energy development in the U.S. The Minerals Management Service (MMS), a federal agency within the U.S. Department of the Interior, issued draft and final rules for offshore renewable energy facilities, but the U.S. has not yet fully developed a regulatory process for offshore wind. The established models used to manage oil and gas extraction can provide some policy guidance, but these models do not sufficiently address the different economic, environmental, and technical conditions associated with offshore wind energy generation.

It will undoubtedly take time to develop comprehensive regulatory and policy support structures for offshore wind energy development in the U.S., but these challenges are not insurmountable. Government support for offshore wind energy, if made equal to the support given to other, non-renewable energy technologies, will go a long way in advancing the U.S. offshore wind industry.

This document section explores elements of government policy and regulation that relate to the U.S. offshore wind industry, including an overview of current trends and forces driving government regulation and policy; an overview of ongoing federal and regional policy developments; a snapshot of current state-level offshore wind activities; and offshore wind policy developments outside the U.S. that might serve as models for domestic initiatives.

## Trends and Drivers

Since the *Framework* document was published in 2005, several trends have emerged as key drivers of regulation and policy development, in the U.S. and abroad. These trends will only increase in importance as the U.S. offshore wind industry develops. They include:

### Climate Change

Concerns regarding climate change have brought renewable energy options, such as wind power, to the forefront of modern energy production strategies. Generating electricity from wind does not produce air pollutants or greenhouse gases, and has the potential to offset emissions from other energy sources. A 1-MW land-based wind turbine can offset 1,800 tons of carbon dioxide per year in relation to the current utility mix in the U.S.[1] Offshore wind power developments have the potential to offset even greater amounts of carbon dioxide than land-based projects since a 1-MW offshore turbine can realize greater capacity factors (The ratio of the actual output of a power plant over a period of time compared to what would have been produced had the plant been operating at full capacity). This increase in electricity production is due to the greater strength and consistency of offshore winds, which can be 25% stronger than nearby onshore winds.[2]

In 2007, the E.U. agreed to reduce carbon emissions 20% by 2020,[3] and as recently as October 2008 reiterated its intention to meet this target.[4] The U.S. has not yet agreed on specific carbon emissions reductions; however, legislation to address climate change policy is under discussion in the current Congress and in the Obama Administration.[5]

### Growing Electricity Demand

In its *Annual Energy Outlook 2008*,[6] the U.S. Energy Information Administration (EIA) projects annual electricity consumption to grow at a rate of 1.1% in its “reference case.”  In this scenario, U.S. electricity demand would increase 29%, or 1,046 terawatt-hours (TWh), by 2030. Such growth in consumption would require new generation capacity. Energy efficiency can and should be used to offset demand growth, but new clean energy capacity will still be needed to replace existing fossil-fuel plants. At an increasing rate, wind energy is providing added capacity to domestic electricity generation: in 2007, new wind power represented 35% of U.S. capacity growth. DOE's *20% Wind Energy by 2030* report outlines a scenario that could lead to wind energy meeting 20% of the nation's electricity needs in 2030.[7] This scenario projects that more than 54,000 MW of wind energy will come from offshore sources. The majority of this offshore wind development will likely occur along the U.S. eastern seaboard, close to large electricity demand centers.

## State Renewable Electricity Standards

The Renewable Electricity Standard (RES), also referred to as the Renewable Portfolio Standard (RPS), is a market-based mechanism that requires electric utilities either to generate a certain percentage of their electricity from clean, renewable sources, or to purchase renewable energy credits. Currently, an RES is one of the most cost-effective and politically viable measures for reducing greenhouse gas emissions while meeting growing electricity demand. States have found that to be successful in advancing a diverse portfolio of renewable energy beyond the least cost resource (typically onshore wind), an RES must provide differential support for higher-cost renewable technologies through multipliers or technology set-asides.

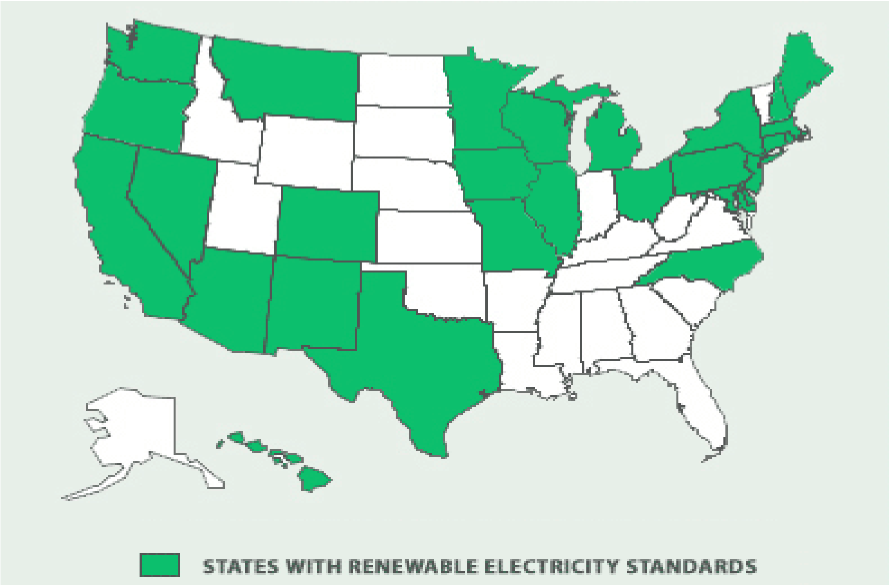


Figure 1: States with Renewable Electricity Standards

*Source: Union of Concerned Scientists*

Twenty-nine states and the District of Columbia have either goals or laws requiring that a certain percentage of their electricity be generated by renewable energy. For many states, these standards may be difficult to meet using only land-based renewable energy sources, either because local renewable resources are insufficient or because of land-use constraints. Offshore wind energy development may be the only way for some coastal states to comply with their policies.

Many states, particularly in the Northeast have found it necessary to include Alternative Compliance Payment (ACP) mechanisms in their RES programs. Through an ACP, utilities have the option of making a payment in lieu of procuring either renewable generation capacity or Renewable Energy Certificates (RECs). Most states dedicate ACP revenues to support renewable energy project development. Offshore wind projects may be eligible for financial incentives from ACP funding in coastal states with RES programs.

The U.S. Congress is considering enactment of a federal RES that could have major implications for the future of offshore wind development in the U.S., depending on the legislation's final design. Versions of this national standard have already passed the U.S. Senate three times and the House of Representatives once.

Table 1: State RES

| State | Percentage / Installed Capacity | Yr[iii] |
|---|---|---|
| Arizona | 15% | 2025 |
| California | 20% | 2010 |
| Colorado | 20% | 2020 |
| Connecticut | 23% | 2020 |
| District of Columbia | 11% | 2022 |
| Delaware | 20% | 2019 |
| Hawaii | 20% | 2020 |
| Iowa | 105 MW | |
| Illinois | 25% | 2025 |
| Kansas | 20% | 2020 |
| Massachusetts | 20%+ | 2025 |
| Maryland | 9.5% | 2022 |
| Maine | 10% | 2017 |
| Minnesota | 25% | 2025 |
| Missouri | 11% | 2020 |
| Montana | 15% | 2015 |
| New Hampshire | 16% | 2025 |
| New Jersey | 22.5% | 2021 |
| New Mexico | 20% | 2020 |
| Nevada | 20% | 2015 |
| New York | 24% | 2013 |
| North Carolina | 12.5% | 2021 |
| Ohio | 12.5% | 2024 |
| Oregon | 25% | 2025 |
| Pennsylvania | 18% | 2020 |
| Rhode Island | 15% | 2020 |
| Texas | 5,880 MW | 2015 |
| Utah | 20% | 2025 |
| Washington | 15% | 2020 |
| Wisconsin | 10% | 2015 |

### *Regional Greenhouse Gas Initiative*

The Regional Greenhouse Gas Initiative (RGGI) is a 10-state "cap-and-trade" system to regulate the electricity sector 's carbon dioxide emissions —the first such system in the U.S. Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont are involved in this initiative designed to address power plant emissions of $CO_2$. Representatives from the Eastern Canadian Provinces Secretariat, the Province of New Brunswick, as well as representatives from Pennsylvania, have been observing the process.[8]

The first RGGI auction of pollution took place in September 2008.[9]

Many participating states use RGGI auction revenues to provide financial incentives to renewable energy projects; offshore wind projects may be eligible for this type of funding.

## U.S. Federal Policy Developments

To date, the most significant step forward in clarifying the regulatory context for U.S. offshore wind development occurred on Earth Day, April 22, 2009, when MMS issued final regulations governing all renewable energy projects on the Outer Continental Shelf (OCS). The issuance of this Final Rule followed a recent Memorandum of Agreement between MMS and the Federal Energy Regulatory Commission clarifying jurisdictional ambiguities.[10]

The Energy Policy Act of 2005 gave MMS lead agency authority over offshore alternative energy and alternate use activities on the OCS. Prior to this explicit authorization, the regulatory approval pathway for offshore wind development in federal waters was undefined.

In November 2007, MMS released a final Programmatic Environmental Impact Statement (PEIS) that examines the potential environmental

---

[iii] **Note**: Some of the RES states listed here count existing renewable energy capacity toward their RES targets, while other states only allow new renewable energy capacity (installed after the RES was established) to count toward their goals.

effects of OCS renewable energy uses over the next five to seven years. The PEIS assesses potential impacts from development, operation, and decommissioning of alternative energy facilities. It also identifies key issues and mitigation measures that should be considered by subsequent site-specific reviews. The PEIS includes policy guidelines and 52 Best Management Practices which have been incorporated into the new regulations.

Also in 2007, MMS announced an interim policy for authorizing installation of offshore data collection and technology testing facilities in federal waters. In June 2009, MMS announced that it would issue five limited leases authorizing wind resource data collection on the OCS offshore New Jersey and Delaware. Five OCS blocks will be leased for a term of 5 years. Leases have been issued for four OCS blocks off the coast of New Jersey and one off the coast of Delaware to four companies: Bluewater Wind Delaware, LLC; Bluewater Wind New Jersey Energy LLC; Fishermen's Energy of New Jersey, LLC, and Deepwater Wind, LLC.

Two offshore wind energy projects were treated separately under the Energy Policy Act of 2005 because their applications were already being processed at that time: the Cape Wind project and the Long Island Offshore Wind Project (LIOWP). LIOWP was suspended in August 2007, due to the Long Island Power Authority's change in management and concerns about costs.[11] The Cape Wind project continues to move through the MMS National Environmental Policy Act (NEPA) and leasing processes. On January 16, 2009, MMS released the Cape Wind Final Environmental Impact Statement. A Record of Decision is expected in 2009.[12]

The Army Corps of Engineers is the lead federal permitting agency for offshore projects in the Great Lakes.

## State Offshore Wind Development Activities, by Region

Individual states are also taking a variety of approaches toward offshore wind regulation and policy. These initiatives are moving forward at a rapid pace, and this section provides a review and summarized status of activities through June 2009.[iv]

### Northeast Region

*Maine*

On February 14, 2008, Maine Governor John Baldacci's Task Force on Wind Power Development made numerous recommendations to encourage offshore wind development in the state's waters, including:

- Aggressively pursue development of Maine's offshore wind resource.
- Establish comprehensive rules for large-scale offshore leasing.
- Evaluate the potential for other wind power-related improvements to the state's submerged lands leasing program.[13]

The Maine state legislature passed a bill in April 2008 that endorsed the Task Force's recommendations. The state's overall targets for wind energy are 2,000 MW by 2015 and 3,000 MW by 2020, with at least 300 MW developed offshore.[14]

In late 2008 the Governor appointed a 21-member Ocean Energy Task Force to develop strategies for offshore wind, wave, and tidal development, as well as oil and gas extraction.

In June 2009, Governor Baldacci signed a bill that streamlined the permitting process for offshore wind projects and directed the Ocean Energy Task Force to identify up to five deep-water test areas by December 15, 2009.

---

[iv] This status is current and complete through April 2009, to the best of USOWC's knowledge.

### *Massachusetts*

As the site of the first proposed offshore wind farm in the U.S., the Commonwealth of Massachusetts gained early, significant experience with siting issues for offshore wind development. In October 2002, the Massachusetts Renewable Energy Trust (MRET), administered by the Massachusetts Technology Collaborative, convened the Cape and Islands Stakeholder Process to examine potential impacts and benefits from offshore wind development in New England waters. The USOWC concept of facilitating multi-sector dialogue and collaboration emerged from this original stakeholder process; MRET has continued to provide financial support for the USOWC since that time.

Additional activities in Massachusetts include:

- Hull Offshore Wind Energy Project: the Town of Hull Municipal Light Plant was awarded a $1.7 million forgivable loan from MRET to conduct pre-development studies for a proposed four-turbine project 1.5 miles from shore. Hull recently received an additional $951,000 in federal stimulus funding to support ongoing environmental studies and economic analysis.
- MRET commissioned an analysis of Massachusetts ports and harbors that identifies appropriate locations for offshore wind project deployment; another study analyses transmission and other issues and processes s related to offshore wind siting and development.

DOE announced in June 2007 that Massachusetts would host one of two new wind turbine testing facilities under a Cooperative Research and Development Agreement. The Massachusetts-NREL Wind Technology Testing Center will be constructed in the Charlestown neighborhood of Boston and will be supported by a consortium including the Commonwealth of Massachusetts, MRET, the National Renewable Energy Laboratory (NREL), the University of Massachusetts Amherst Wind Energy Center,, and the Massachusetts Port Authority. In its first phase, the facility will serve as a blade testing facility; however, this facility might be expanded in the future to support other areas of wind turbine research and development (R&D).[15]

In May 2008, Governor Deval Patrick signed the Massachusetts Oceans Act into law. This new law directed a 17-member commission to develop a state ocean management plan. The plan, to be completed by the end of 2009, will guide development in Massachusetts state waters, including "appropriate scale" renewable energy development. The *Draft Massachusetts Ocean Management Plan,* published in June 2009, allows for community-scale offshore wind projects (up to 10 turbines) in state waters , and identifies specific Renewable Energy Areas for commercial-scale development (more than 10 turbines).

In January 2009, Governor Patrick set a Massachusetts goal of developing 2,000 megawatts of wind power capacity—enough to power 800,000 Massachusetts homes—by 2020.

### *Rhode Island*

In 2006, Rhode Island commissioned a study that determined offshore wind energy could meet as much as 15% of the state's electricity demand. This study, delivered to Governor Donald Carcieri in 2007, also identified ten appropriate sites for offshore wind projects. The state conducted four stakeholder meetings in the summer and fall of 2007. Meeting participants examined potential issues that could affect each site, with an eye toward an eventual environmental impact assessment that would compare and contrast relative merits of alternative sites. The report that emerged from this process, *RIWINDS, Phase 1: Wind Energy Siting Study*, found two preferred locations near Block Island for offshore wind projects.[16]

Based on this work, the state decided to pursue offshore wind development, and in April 2008, it issued a Request for Proposals (RFP) for an offshore wind project near Block Island. The state set a requirement that this project must produce 1.3 million megawatt-hours of electricity annually, the projected 15% of state electricity cited in RIWINDS Phase I.

Following review of the seven bids received, the state selected the company Deepwater Wind to develop the project. The state of Rhode Island and the developer signed a Joint Development Agreement in January 2009.

In a parallel effort, the Rhode Island Coastal Resources Management Center partnered with a 60-member multi-disciplinary team from the University of Rhode Island to create a Special Area Management Plan (SAMP) for Rhode Island's offshore waters.[17] This plan will define use zones, including "wind energy zones," through a research and planning process that integrates the best available science and coastal/ocean management experience with open public input and involvement.

The SAMP effort is funded through a two-year, $3.2 million commitment from the state's energy office. An additional $666,050 in federal stimulus funds was recently allocated to support necessary fieldwork. Final siting of the Deepwater Wind project will be based on the SAMP conclusions.

### *New York*

In September 2008, Long Island Power Authority (LIPA) and Consolidated Edison, Inc. (two New York-based utilities) initiated a joint study to determine suitable locations, wind energy resources, and transmission and interconnection requirements for a large wind project off Long Island. Analysis concluded that 700 MW of wind power capacity would be feasible, provided appropriate upgrades are made to the existing transmission system.

LIPA and Consolidated Edison then formed a collaborative with several other entities interested in supporting or purchasing power from a potential 350-MW wind farm 13 miles off Rockaway, possibly expandable to the full 700 MW target. Partners included the New York State Energy Research and Development Authority, the New York Power Authority, the New York City Economic Development Corporation, the Metropolitan Transit Authority, and the New York-New Jersey Port Authority.

This collaborative issued a Request for Information in July 2009, seeking input on the proposed project from the wind industry and other stakeholders on the proposed project.[18]

### *New Jersey*

In December 2004, then-acting New Jersey Governor Richard Codey signed an executive order placing a 15-month moratorium on offshore wind energy permitting and funding, following proposals for several large, unanticipated projects in the region. A panel was created to assess the economic and environmental effects of offshore wind energy on the state. *The Blue Ribbon Panel on Development of Wind Turbine Facilities in Coastal Waters* delivered a final report in May 2006 that recommended the state to move ahead with a test project of no more than 350 MW capacity, accompanied by a rigorous study of environmental and economic impacts and benefits.[19]

The Blue Ribbon Panel's findings prompted two subsequent actions to advance prospects for offshore wind development along New Jersey's coastline. First, the state's Department of Environmental Protection issued a competitive solicitation to Geo-Marine, Inc. for an 18-month Ocean/Wind Power Ecological Baseline Study.[20] Then, in March 2008, the Board of Public Utilities (BPU) issued a RFP for an offshore wind project no larger than 350 MW capacity. BPU offered a five-year production credit valued at $19 million for the proposed facility. In September 2008, New Jersey announced its intention to move forward with Garden State Offshore Energy, a venture between Deepwater Wind and Public Service Electric & Gas. This offshore wind farm is projected to be operational in 2012.[21]

In December 2008, Governor Corzine rolled out New Jersey's Energy Master Plan. This extensive document calls for New Jersey to have at least 1,000 MW of offshore wind energy by 2012 and at least 3,000 MW by 2020. In furtherance of this new goal, the BPU initiated a rebate program for construction of offshore meteorological towers. The program provides applicants with a rebate of $4 million per meteorological tower, for towers constructed in 2009.[22] In addition to Garden State Offshore Energy, the BPU approved Fishermen's Energy of New Jersey and Bluewater Wind to participate in this program.

To further stimulate offshore wind development in New Jersey, the BPU is considering applying an offshore wind "carve out" within the state's RPS. This would require all electricity suppliers to obtain a certain number of Offshore Wind Renewable Energy Certificates (ORECs) based on the company's market share in New Jersey. Pricing and management details for this incentive process are under development. Offshore wind developers and other stakeholders are involved in designing this incentive structure, and hearings on a proposed rule are anticipated in fall 2009.

## Mid-Atlantic Region

### *Delaware*

In the fall of 2006, Delmarva Power and Light, the state's largest investor-owned utility, released a RFP for development of new clean energy generation facilities. Among the responses was a proposal for an offshore wind farm. After six months of review and debate by elected officials and the Delaware Public Service Commission, plus thousands of pages of citizen testimony, four state agencies directed Delmarva to negotiate a power purchase agreement with Bluewater Wind. The proposed project includes construction of a 200-MW to 300-MW capacity offshore wind facility with a back-up natural gas plant.

Initial negotiations between Delmarva and Bluewater Wind occurred over a three-to-four month period. The resulting contract was then tabled by the same four state agencies for another three months. Negotiations for a revised contract between the two companies were brokered by the Senate Majority Leader, and they concluded in June 2008 with the first-ever Power Purchase Agreement (PPA) for a U.S. offshore wind energy project. Delmarva agreed to buy the wind farm output—up to 200 MW—without the natural gas plant back-up. Delaware's Governor Ruth Ann Minner signed into law a provision allowing Renewable Energy Credits produced by the offshore project to count 3.5 times toward the utility's renewable energy purchase requirements._

### *Virginia*

The Virginia Energy Plan, passed in August 2006, created the Virginia Coastal Energy Research Consortium (VCERC). VCERC, which includes eight universities, five government agencies, and three industry partners, will consult and coordinate with a variety of stakeholders involved in offshore renewable energy. This consortium will also conduct and publicize research to facilitate the development and use of new coastal energy technologies. VCERC conducted preliminary mapping for potential offshore wind facilities in the region and commissioned a feasibility and economic impact baseline study for offshore wind development.

## Southeast Region

### *Georgia*

The Southern Company funded a project with Georgia Institute of Technology to determine what locations off the Georgia coast would be suitable for an offshore wind farm. Specific areas off Tybee Island and Jekyll Island were identified as potential wind farm sites, and a feasibility study will be conducted to further consider offshore wind projects in the area.[23] Under MMS's interim policy (which authorized offshore renewable energy data-gather activities), the Southern Company is pursuing three limited leases off the Georgia coast.

### *South Carolina*

Santee Cooper, South Carolina's state-owned power and water authority, is working with Coastal Carolina University and the South Carolina Energy Office to assess the feasibility of offshore wind development along the state's coast. This partnership announced the launch of weather buoys off Georgetown and Little River to measure wind speed, direction, and frequency up to six miles offshore. The six buoys and two land-based stations will collect data for six months in order to help identify the best location for installing an offshore platform that would measure upper-level winds at turbine hub-height for 18 months.

Funded through a DOE grant, separate task forces were organized to analyze permitting and transmission issues. Santee Cooper has established a goal of 40% energy from non-greenhouse gas resources by 2020.

## Gulf of Mexico Region

### *Texas*

The Texas General Land Office (GLO) obtained wind resource maps for the Gulf of Mexico coastline. In 2005 this office granted leases to Wind Energy Systems Technology, Inc. (W.E.S.T.) and Superior Wind Energy for projects off the coasts of Galveston and South Padre Island, respectively. Superior Wind Energy later withdrew its project proposal due to economic concerns and preference for onshore wind development opportunities in the state. The W.E.S.T. project continues to move forward, assessing local wind resources and conducting avian studies on the Galveston tract. The company has since applied for a general construction permit.[24]

In October 2007, the GLO awarded four additional leases for offshore wind projects to W.E.S.T., allowing the company to install meteorological towers in these offshore areas. W.E.S.T. is also conducting wind resource assessments and avian monitoring on these four more-recently-leased tracts.[25]

In June 2008, the Lone Star Wind Alliance and DOE announced completion of an agreement for a wind turbine blade testing facility, the Texas-NREL Large Blade Research and Test Facility, to be located in Ingleside, Texas (originally announced in June 2007 along with the Massachusetts-NREL Wind Technology Testing Center). This facility will test blades up to 70 meters (230 feet)—expected blade sizes for future offshore turbines. The University of Houston will own and operate the testing structures, which are expected to be completed by 2010.[26]

## Great Lakes Region

The Great Lakes Wind Collaborative (GLWC) *offshore wind working group* is working to clarify regulatory issues and siting strategies for offshore wind energy facilities in fresh water.[v] While MMS has lead authority in ocean waters, the lead federal permitting agency for offshore development in the Great Lakes is the Army Corps of Engineers (ACOE). The ACOE will apply existing regulatory authorities under Section 10 of the Rivers and Harbors Act, and Section 404 of the Clean Water Act. It will also coordinate other federal and state agency reviews of offshore wind development proposals through the NEPA process.

In addition to collective efforts through the GLWC, individual Great Lakes states are pursuing initiatives focused on data collection, environmental compatibility issues, and feasibility studies relating to specific offshore wind project concepts.

### *New York*

To carry out an initiative known as the Great Lakes Offshore Wind Project, the New York Power Authority gathered support from wind power proponents including National Grid, the New York State Energy Research and Development Authority, the New York State Department of Environmental Conservation, the University of Buffalo, wind power developers, and state and local environmental organizations. This combined effort is gathering a wide range of technical, financial, economic development, and environmental information that would be a basis for large-scale (capacity greater than 120 MW) private wind power development in the state's future.

### *Ohio*

Cuyahoga County Regional Energy Development Task Force issued a Request for Qualifications (RFQ) for a feasibility study involving development of 5 to 20 MW of offshore wind capacity in Lake Erie. This task force awarded JW Great Lakes Wind more than $1 million for the study, which is expected to be completed in 2009. A primary purpose of this initiative is to serve as a template for permitting future offshore wind projects in the Great Lakes.[27]

The Great Lakes Energy Development Task Force recently released findings from a one-year analysis of a proposed pilot wind project in waters off Cleveland. The final report presents a summary of results from the project's feasibility study across a variety of technical and economic disciplines. The findings indicate that a pilot project of between two and ten turbines is technically and environmentally feasible. Any such project would pend further studies of selected issues, approvals by regulatory agencies, and solutions to make the development more economically viable.

The pilot project area is approximately three to five miles from the downtown Cleveland shore. The study identifies nine potential turbine configurations at different locations in this area, and recommends an area east of the Cleveland water intake crib.

The study estimates pilot project capital costs to be $77 to $92 million. Cost variations would include turbine size, wind farm design, construction methods, onshore facilities, and associated infrastructure. The study also recommends investigating alternative funding sources, including grants from DOE and NREL, federal stimulus money, and other resources through national, regional, and local organizations.

---

[v] The GLWC is a multi-sector coalition of wind energy stakeholders working to facilitate the sustainable development of wind power in the bi-national Great Lakes region.

### *Wisconsin*

The Wisconsin Public Service Commission voted in April 2008 to assess whether offshore wind turbines could be installed in Lake Superior and Lake Michigan as part of initiatives from Governor Jim Doyle's Task Force on Global Warming.[28]

The resulting feasibility study issued by the Commission on January 15, 2009, is titled *Harnessing Wisconsin's Energy Resources: An Initial Investigation into Great Lakes Wind Development.* Wind energy is expected to be a large component of the state's strategy for meeting a proposed RPS of 25% renewable energy by 2025, with 10% mandated from sources within the state. The study found a number of advantages associated with offshore wind development (compared with land-based), but it also identifies challenges and information gaps. It concluded that Great Lakes offshore wind projects are technologically feasible, but would currently face a number of economic, environmental, and legal issues.[29]

### *Michigan*

The *Michigan Great Lakes Offshore Wind Permitting Dry Run Final Report* was submitted to the Michigan Economic Development Corporation in May 2008. Compiled by a consultant and an extension specialist from Michigan State University, the report looks at two scenarios: first, a 100-turbine deep-water project in Lake Michigan 30 miles from shore, and second, a corresponding project in more shallow water.[30]

### West Coast Region

In the U.S., the East Coast currently hosts the majority of offshore wind activity; however, commercial-scale wind resources exist on the West Coast as well. The most suitable areas for offshore wind development in California are in the northern part of the state, where shallow waters and strong wind resources coincide. Future deep-water turbine technologies may make more areas off California's coast viable for wind development.

In November 2008, Principle Power Inc. and the Tillamook Intergovernmental Development Agency proposed an early-stage phased demonstration project in Oregon. These two entities have signed a Memorandum of Agreement to demonstrate a floating foundation design.

## International Policy Developments

Europe has had operational offshore wind power facilities since the first offshore turbines were installed in Denmark in 1990. To achieve expanded offshore wind development, European governments have set political targets accompanied by government support mechanisms. By 2007, offshore wind capacity in Europe had grown to 1,100 MW. By the end of 2008, European Union (E.U.) nations had installed more than 1,470 MW of offshore wind capacity, representing 28 projects in five countries. The European Wind Energy Association estimates that the European offshore wind industry could reach 10 to 15 GW of cumulative capacity by 2015. The United Kingdom and Germany, respectively, are expected to lead this growth.[31]

Known European offshore wind activities that were ongoing prior to January 1, 2009 include:

### *United Kingdom*

The United Kingdom (U.K.) issued offshore leases beginning in 2001 under the first round of its leasing program. At that time, the government awarded 18 lease agreements.[32] Round 2 of the leasing program occurred in 2003 and yielded 15 additional agreements for leases. Second-round applicants were encouraged to consider the results of the Offshore Wind Farm Development Strategic Environmental Assessment—an analysis which determined specific areas for offshore wind farms based on wind resources, marine uses, and environmental factors. The approved lease areas from the first two rounds of the leasing program have the potential to produce 8 GW of offshore wind energy in the United Kingdom.[33] Round 3, launched on June 4, 2008, will award leases corresponding to an additional 25 GW of potential offshore wind capacity.[34]

The U.K. enacted a policy similar to a RES called the Renewables Obligation, which requires electricity suppliers to get an increasing percentage of their electricity from renewable energy sources, reaching 10% in 2010. Additionally, financial support through capital grants, Renewable Obligation Certificates, and a Climate Change Levy are all available to offshore wind developers.[35]

In contrast to Rounds 1 and 2, the Crown Estate will fund up to 50% of Round 3 development costs through co-investment. As the seabed landowner out to the 12nm territorial limit (and with vested rights for renewable energy generation out to 200nm), the Crown Estate views co-investment as a mechanism to accelerate and to appropriately direct offshore wind development. This will allow the Crown Estate to take a strategic lead on planning issues, including shipping and military interests. The Crown Estate will not be involved in the construction or operation of wind farm sites.

The U.K. intends to create an Infrastructure Planning Commission (IPC)—a new Non Departmental Public Body—as one component of a series of measures to reform the way that planning decisions are made for nationally-significant infrastructure projects in England and Wales.[36] It is expected that the IPC will begin accepting applications in 2010. Working within a framework of government-generated National Policy Statements, the IPC will have a statutory duty to evaluate planning applications for Round 3 offshore wind projects within 12 months of a proposal's submission. It is anticipated that the IPC could effectively provide a single consent for both offshore and onshore components of a wind project, reducing the risk of the application being deferred to Public Inquiry.[37]

### *Germany*

The German government set a goal of 25 GW of offshore wind capacity by 2030. A recent overhaul of the German Renewable Energy law increased the rate paid for renewable energy from the equivalent of approximately 9 cents per kilowatt-hour to 15 cents per kilowatt-hour, improving the incentive for offshore wind developers. Developers also benefit from a requirement that utilities must provide the funding and infrastructure for connecting offshore wind farms to the electrical grid. Germany's first offshore wind project, Alpha Ventus, began construction in August 2008. This project will consist of twelve 5-MW turbines, for a total capacity of 60 MW. The turbines will be in 30- to 40-meter-deep water, approximately 45 kilometers off the coast of Borkum.[38] The Alpha Ventus development is considered a research project and will not seek to sell its electricity commercially. However, as many as 30 commercial offshore projects are in planning stages in Germany.[39] Offshore wind developments in Germany will be located in government-designated areas farther from shore and in deeper water than most current European projects.

### *Denmark*

Eighteen years after its first offshore wind project, Denmark in 2008 had just over 400 MW of installed offshore wind energy capacity. The country's offshore wind industry continues to grow, largely due to a government goal for 30% of gross energy consumption to come from renewable sources by 2025. Recent approval of the country's largest offshore project (400 MW capacity) will help meet this goal.[40]

The first offshore developments resulted from Danish government demands that electric utilities build offshore wind projects to investigate relevant benefits, impacts, and technology. In 1999, private entities were allowed to apply to build offshore wind projects, and in 2004 a call for bids was announced. The government named the Danish Energy Authority the lead agency for permitting offshore wind projects.[41]

Denmark provides additional financial support to offshore wind projects through tax exemptions and green certificates, similar to renewable energy credits in other markets. These exemptions and certificates can have very significant economic value.[42]

### *The Netherlands*

The Netherlands completed its first major offshore wind project in 2007, following adoption of new offshore regulations.[43] This project, called Q7, is the first offshore wind project with non-recourse financing that relies solely on project revenues to cover interest and principal payments. The government is depending on offshore wind to reach its goal of 9% renewable electricity by 2010, and it has designated areas for 65 future offshore wind developments. However, stop-and-go policies toward project licensing have hindered development.[44]

### *Spain*

In 2007, Spain passed regulations for offshore wind farms which will allow projects 50 MW or larger to be built in designated offshore areas. It is expected that offshore wind capacity in Spain could reach 2,000 to 3,000 MW by 2020.[45]

### *Belgium*

Belgium began construction on its first offshore wind farm, Thornton Bank, in July 2008. The completed wind farm will consist of 5-MW turbines, with a total capacity of 300 MW. Non-recourse financing, modeled after the Q7 project in the Netherlands, was also used for this project.[46]

### *Ireland*

Ireland created a renewable energy feed-in tariff in 2006 that set a 15-year guaranteed purchase price of 5.7 euro cents per kilowatt-hour for wind energy projects greater than 5 MW.[47] The first phase of the Arklow Offshore Wind Park, Ireland's first offshore wind project, was completed in 2004 and has a capacity of 25.2 MW, comprised of seven 3.6-MW GE turbines.[48]

## Implications for Offshore Wind Energy Regulation and Government Policies

The future of the U.S. offshore wind industry will be heavily influenced by economic, environmental, and energy policy developments—at both state and federal levels. Decisions to invest public funds in planning and R&D will also play important roles in determining industry growth. Innovation and leadership from states interested in meeting RES, environmental, and economic development objectives through offshore wind development led to diverse planning approaches and financial incentives. However, an integrated federal support structure (like those catalyzing development in the E.U.) has not yet emerged in the U.S. Unified federal support will be necessary to accelerate offshore wind industry growth, since the most significant opportunities for offshore development exist in federal waters. As the Obama Administration moves to create a national framework for offshore renewable energy development, there is an opportunity to create a unified offshore wind strategy. To be successful, this strategy must link multiple federal and state public policy objectives, in order to create a dynamic context for private sector innovation and investment.

### Key Themes

*Growing Interest:* Although the U.S. does not yet have any installed offshore wind projects, there is significant interest (especially at the state level) to pursue offshore wind development. With individual states moving forward at a rapid pace, federal government regulation and policies will need to coordinate with ongoing state policies in order to accelerate the development process. While today only a few states are focused on specific offshore wind projects, more proposals are expected in the near future. This rapid industry growth will create a demand for effective regulatory structures.

*Diverse Approaches*: Currently, U.S. states take a variety of regulatory and policy approaches, and no single, unified model has emerged to best support offshore wind energy projects. Again, as states move forward with offshore development, federal policy-makers will need to address this dynamic regulatory and policy environment. States must share resources, consider regional approaches, and create procedures to manage the complexity of offshore wind development.

*Costs and Government Policy as a Driver*: In European wind development experience, supportive energy and environmental policy is the key to promoting renewable energy. This is particularly true for offshore wind development. Clear government mandates for renewable energy production drive public investment in addressing siting challenges and in maximizing regulatory efficiencies. Some experts suggest that setting a market floor, through a RES and a carbon policy, would recognize externalities not otherwise included in market prices. These experts note that while this approach has been effective in Europe, it may or may not be appropriate in the U.S. . However, it is essential to determine what kind of economic policy should be enacted to most effectively foster offshore wind development.

# 2. Technology Development

## Overview

Technology is a driving force behind the viability and proliferation of offshore wind energy development. While some lessons may be drawn from offshore oil and gas extraction industries and from the onshore wind energy sector, offshore wind energy generation faces unique technological challenges. These include electrical transmission, environmental compatibility, and construction in the marine environment. Significant R&D efforts in the E.U. have led to important advances in offshore wind energy technology, but there are still significant challenges to overcome. Some of these challenges will involve adapting current offshore wind energy technology to U.S.-specific marine environments.

This document section explores the technical factors that will affect and support a sustainable U.S. offshore wind energy industry, including current trends in offshore wind technology, proposed modifications and novel R&D solutions for future development, and current standards and considerations for future policy-makers and researchers.

## The E.U. and Offshore Wind Energy Technology Developments

Given the significant level of E.U. experience with offshore wind energy technology, the European perspective is used to inform possibilities for future U.S. offshore wind technology. As suggested in the previous document section on policy, European countries have advanced offshore wind development with supportive regulations and government policies. On the technology side, European manufacturers, developers, and engineering firms continue to lead the field in offshore wind technology development. Beginning in 1990 with a test turbine installed on a shallow-water offshore platform at Norgersund,[49] the cumulative installed capacity in Europe has grown to over 1 GW.[50] In Germany and elsewhere in Europe, future growth for wind installation is expected to be almost entirely offshore.[51]

Using European technology as a baseline, the following discussion will show that in transitioning from onshore to offshore wind technology, different subsystem modifications range from minimal to complete system overhaul. Many research challenges still exist for offshore wind energy technology, and there is a significant opportunity for the U.S. to contribute to and lead in the technology's development.

## Siting and Technical Design of Offshore Wind Farms

Siting issues continue to pose technological challenges for offshore wind development. These include issues related to resource assessments, design environments, and technical design considerations such as foundations, turbines, drive trains, control systems, and blades. In addition to driving research, these challenges also have wider policy and investment implications. The trends and advances in siting technologies include:

### Resource Assessment

Improvements in remote-sensing measurement technologies, such as LiDAR (Light Detection and Ranging) and SODAR, (Sonic Detection and Ranging) satellite-based meteorological systems, and mesoscale climate models, promise to improve the accuracy of offshore wind characterization. However, there is still much room for continued improvement of these technologies for specific offshore applications.[52] Offshore wind maps have been developed by NREL, in conjunction with AWS TrueWind.[53] But as with onshore wind, specific measurements and analysis at proposed project sites are still an important part of the development process. Offshore resource assessment studies and forecasting are complicated by accessibility and reliability issues for instrumentation mounted on offshore platforms. North of Germany, a dedicated research platform for offshore meteorological and environmental measurement is one notable example of an extensive data collection effort to characterize the marine environment for offshore wind applications.[54]

In the U.S., several projects have shown considerable success with data collection. The most comprehensive characterization of offshore wind resources has been in Nantucket Sound, where Cape Wind installed a meteorological tower at its proposed project site and has collected data for six years.[55]

Long Island, New York's Ambrose Light and Cleveland, Ohio's Lake Erie Crib represent efforts to characterize offshore wind resources using meteorological towers (with anemometers, directional vanes, and other sensors) that were installed on top of previously existing offshore structures. In Hull, Massachusetts, a shore-based LiDAR was used in addition to other instruments for measuring wind, wave, and geotechnical information.

More extensive research and testing are needed to increase understanding of offshore wind resources and to predict future resource behavior. In particular, data quality and predictive site measurement methods for energy production must improve before they are fully accepted by the technical and financial communities.

## Design Environment

For offshore applications, characterization of the design environment is especially critical. For instance, information on water depth, current, seabed migration level depth, maximum wind speed, and wave heights is used to study mechanical and structural loading on potential turbine configurations under various site-specific environmental conditions.[56] This analysis includes impacts of external conditions on the wind turbine, in terms of both survival during extreme loading and long-term fatigue damage and degradation. In the U.S., extreme external conditions are driven by infrequent tropical and extra-tropical storms. These events are difficult to extrapolate, and they are non-existent in European waters. Other aspects of the design environment include marine-growth, tidal forces, corrosion, and icing, as well as composition and morphology of the marine floor.

Fortunately, study of offshore design environments has been a subject of ocean engineering focus for decades. This is especially true for the oil and gas industry, which has been building offshore platforms since 1947.[57] Research of the design environment for offshore wind development should leverage the existing knowledge base of ocean engineering, particularly from the offshore oil and gas industry. However, most detailed oil and gas research has focused on the Gulf of Mexico. Increased understanding of the broader offshore design environment will require extensive research and testing. This research will be necessary to optimize wind turbine structures to withstand all foreseeable conditions, including those that stem from regional differences.

## Technical Design

The table on the following page provides an overview of the different wind turbine subsystems, along with a brief outline of design challenges presented by each.

Table 2: Offshore Wind Energy Technology Drivers and Challenges

| Offshore Challenge | Possible Technology Solutions |
|---|---|
| Higher Costs | Large turbine and project sizes<br>Minimal large vessel dependence<br>Lower O&M costs<br>Integrated offshore grid system |
| Corrosion Protection | Nacelle pressurization<br>Advanced materials and coatings |
| Wind/Wave Structural Design for Hurricanes | Codes and Standards<br>MET ocean characterization<br>Remote wind sensing |
| Reliability | Condition monitoring and predictive maintenance<br>Designs optimized for offshore<br>Direct drive generators |
| Personnel Access, shelter, and safety | Improved access vessels<br>Weather window forecasting<br>Training |
| Environmental Assessment | New data integration platforms<br>Cost-effective real-time wildlife monitoring methods |
| Grids and electrical infrastructure | DC power distribution<br>Offshore grid systems |
| Decommissioning | Easy to remove substructures and foundations<br>Long life foundations |

While some technologies have been proven through commercialization or by use in the oil and gas sector, others are still at the prototype stage or have yet to be tested in any capacity. Regardless, potential improvements through R&D are possible for all of the above subsystems. The following sections discuss each of these subsystems in greater detail and describe the current research challenges facing each.

## Towers and Foundations

The design environment has a direct impact on foundation/support structure design. Land-based support structures have moved away from truss towers, toward cylindrical, self-supporting tube towers. For offshore environments, gravity foundation/tube tower and monopile designs are considered appropriate for water depths up to 30 m. Stiffer, multi-pile configurations with broader bases suitable for development, including tripods, jackets, mono-towers and jackets, and suction bucket support structures are envisioned for water depths up to 60 m or greater.[58] Talisman Energy's Beatrice Wind Farm Demonstrator Project off the east coast of Scotland, in water depths up to 45 m,[59] uses a mono-tower with a jacket foundation (cylindrical tower above water installed on a truss tower base). The transition between the truss and the mono-tower occurs several meters above the waterline.[60] Mono-tower-and-jacket technology has been used by the oil and gas industry in depths up to 450 m.[61]

Foundation design is one specific area where the opportunity to leverage existing expertise from ocean engineering, specifically from the oil and gas industry should be taken advantage of. Although multi-pile foundations may be viable in water depths up to and above 60 m, floating turbine structures may become necessary in much deeper waters. These structures would be secured to the ocean floor via catenary guy wires, mooring lines, or taut tension legs, which in turn would be fastened to anchors or gravity-based platforms.[62] Several floating turbine configurations are being explored in Europe, including the Hywind, SwayWAY, BlueH, and WindSea concepts. The Hywind, a full-scale 2.5-MW spar buoy floating turbine, was deployed in Norwegian waters by StatoilHydro in June of 2009.[63] Floating turbines have several potentially-attractive attributes, including: a) access to much higher wind classes farther from shore, b) potentially lower environmental impacts on wildlife and their habitats, c) little to no visual impact (out of sight from shore), and d) mass production of the platform with the potential for full assembly near shore.[64]

The challenges of floating wind turbines extend far beyond developing an efficient, cost-effective floating platform design. The technology for floating systems is a substantial departure from the proven offshore wind turbines that exist today. Floating designs must be engineered as a complete turbine-platform system to withstand the coupled aerodynamic/hydrodynamic loading of more severe sea states and higher tower-top accelerations. Deploying wind turbines on floating platforms will likely require complete re-engineering to account for the different loading conditions. Design tools to engineer such structures are still being developed. Also, compared to fixed-bottom offshore designs, the loads on floating turbines may be much more difficult to model accurately.

## Turbines

Most offshore installations use large-scale versions of the same architecture as onshore turbine designs. This basic offshore configuration includes a three-bladed, pitch-controlled, upwind horizontal-axis turbine with a rotor, drivetrain, and other systems that are larger than their typical onshore counterparts. Offshore installations generally use very large turbines, ranging from the Vestas V-80 2 MW turbine to GE Wind's 3.6-MW turbine to REpower's 126 m diameter, 5-MW turbine.[65] As offshore turbine technology develops, it is expected that turbine capacity will continue to increase.

Large turbines currently under development include Clipper Wind's 10-MW turbine and the 8- to 10-MW turbine from American Superconductor working in cooperation with TECO Westinghouse and their Austrian subsidiary Windtec.

Generally, the trend has been to focus on scaling current technology. This can present many challenges, including blade and control system design (as discussed below). However, more radical design changes have been suggested that would tailor wind turbine technology to the offshore design environment. One such design is for a novel, two-bladed downwind turbine. The principal advantage of downwind turbines is that the blades deflect away from the tower under normal operation. As a result, the blades would not have to be as stiff, which would potentially prolong blade lifetime, reduce maintenance needs, and diminish loads transferred to the rest of the turbine system.[66] Historically, downwind rotors were avoided except in the most remote locations, because this configuration can create unacceptable levels of infra-sonic noise which bothers nearby residents. For offshore applications, minimizing infra-sonic noise may not be as serious a design constraint. A two-blade system also lowers turbine cost in comparison to a standard three-blade configuration—decreasing cost directly by reducing the number of blades, and indirectly by reducing the overall system weight needed to support the rotor.[67] Overall, novel configurations may introduce their own set of design challenges by increasing complexity and validation needs. R&D funding to reduce development risk and inspire new innovation would potentially accelerate new ideas for harnessing offshore wind energy.

### Drivetrains

Gearboxes continue to cause significant problems for the entire wind industry. Gearbox-related issues are responsible for 20% of turbine downtime, and as such, gearbox reliability continues to be an important discussion point within the industry.[68] However, due to the technology's maturity and wide availability, gearbox-based drivetrains are the most common. One alternative is a direct drive generator, where the rotor and mainshaft are connected directly to the generator. A problem with this approach is that the size of a conventional wound-rotor induction generator (of appropriate scale for offshore applications) would be extremely large—10 m in diameter—and therefore difficult to transport and install.[69] Certain companies are developing large hybrid superconducting permanent magnet generators that, compared to standard wound generators for the same rotor dimension, are expected to produce as much as twice the power at one-third the weight. The cost and reliability of such systems are still unknown.[70] Reducing gearbox and drivetrain failures for offshore installations is a particularly important subject for R&D efforts, due to the increased expense, time, and difficulty of maintaining turbines in offshore environments.

### Control Systems

Wind turbine control systems include constant speed pitch regulated and variable speed pitch regulated.[71] Such systems are used to start and stop the turbine and to control power output, especially at above-rated wind speeds. Some design strategies use blade pitch regulation (rotating the blade about its long axis), while passive stall systems use the steep angles of attack on the blade during high winds to aerodynamically reduce lift and increase drag. The extreme weather conditions for offshore environments, as could be seen in hurricane areas, impose additional constraints on turbine control systems. However, lower wind turbulence in offshore environments (compared with land-based) may ease some of the requirements for pitch control. Cyclic blade pitch strategies are under development, which would provide a variety of methods for reducing fatigue loading and controlling the turbine under extreme load cases. In addition to pitch considerations, all upwind turbines must have a yaw control system that orients the rotor into the wind. New strategies are under development that would allow mechanical control systems to provide more system benefits.

### Turbine Blades

The harsh conditions of the marine environment, including high moisture and salt, will create many challenges for blade design. Additional challenges come with the massive size expected for offshore turbines. One difficulty with large rotors is that as blade length increases, stiffness considerations begin to dominate blade design. This issue is especially relevant for blades longer than 60 m, in order to prevent the blades from striking the turbine tower. Extra material to provide stiffness in longer blades increases rotor weight, which is a progressive course toward sub-optimal design. Even if very long blades meet provisions for adequate stiffness in normal operation, occasional extreme loading conditions may cause the blade tips to exceed deflection limit standards set by the International Electrotechnical Commission (IEC).[72]

There are currently many blade innovations under development for land-based wind turbines that may be directly applicable to their offshore counterparts, such as active aerodynamic control devices, passive bend-twist coupling, smart composites, carbon fiber, and advanced manufacturing methods.

## Pre- and Post-Installation Technologies

In addition to siting considerations, pre- and post-installation issues also pose technological challenges for offshore wind energy development. These challenges drive research and have broad implications for policy and investment. The trends and advances in pre-and post-installation technologies include:

### Installation and Maintenance

Turbine installation is another area where offshore wind development will benefit from experience from the offshore oil and gas industry. Installation fleets include various vessels such as barges with compensated cranes, leg stabilized feeder fleets, oil and gas dynamic positioning vessels, and floating heavy lift cranes.[73] However, unlike oil and gas projects, wind projects seek faster and less-expensive installations that can be replicated easily for modular wind farms. These demands will require modifications to existing approaches. Also, the Jones Act mandates that only U.S.-based vessels work in U.S. waters. This imposes a limitation on American offshore wind development, since all vessels used for construction and operations and maintenance (O&M) on existing offshore wind farms have been European. To realize the potential of offshore wind energy in U.S. waters (especially the 54-GW of offshore wind power outlined in the DOE's *20% Wind Energy by 2030* scenario), many new, customized, U.S.-flagged vessels will be needed. To reduce O&M costs, wind farm operators must pay special attention to preventative maintenance strategies, in order to limit the need for expensive, reactive maintenance in response to failures.[74] More active condition monitoring of the rotor and drive train are suggested in order to schedule maintenance predicatively.[75]

## Technology Standards

As with the technology itself, some standards for offshore wind technology can be adapted from their onshore counterparts. However, these standards must also be extended to encompass circumstances specific to the offshore marine environment. There are currently two documents that contain relevant standards for offshore wind turbine design. The first document, the IEC 61400-3, extends the IEC design standard 61400-1 for onshore turbines to include offshore turbines. The API RP-2A applies to offshore structures in general. Both documents address in detail the unique aspects of offshore marine environments. For an offshore wind project to achieve final approval from MMS, the turbine design will have to demonstrate a minimum level of structural reliability based on the best application of available standards, which could include IEC, API, or other applicable standards. MMS is still in the process of determining these rules, and further clarification is expected as the first projects progress through the regulatory process.

Standard design criteria for offshore wind turbine structures will differ substantially from standards used for offshore oil and gas platforms. The IEC 61400-3 aimed for an impartial, broad perspective by recruiting an authoring group of wind industry representatives and oil and gas experts. The resulting standards explicitly bring together the worlds of wind, oil and gas.[76] However, application of such standards to the U.S. marine environment may present difficulties if the extreme weather characteristics of a proposed U.S. site differ substantially from those in Europe. In addition, the IEC standards do not encompass floating turbines, due to the early stage of the technology.[77]

## Transmission and Grid Interconnection

For near-shore wind farms, HVAC (High-Voltage Alternating Current) transmission is still possible. Yet the long cable lengths needed for applications farther offshore will likely require use of high-voltage direct current (HVDC) undersea cables.[78] Some novel solutions have been proposed, such as six-phase bipolar AC cable systems, but HVDC is largely seen as the solution of choice for offshore wind applications.[79] Studies comparing the different types of transmission technologies are still immature and arguably inconclusive.[80]

Grid interconnection is another area of significant technical interest for offshore wind. Although offshore winds are generally more consistent than onshore winds, wind resource variability is still an important issue. Fluctuations in wind power output will place strains on electric grid system design in terms of managing both short-term (seconds to hours) and long-term (days to years) operational needs. Especially for wind farms located far from shore, the difficulty of grid tie-in will require careful design of the wind farms and their grid connections. Good design will minimize grid stability impacts from potential outages or operational difficulties.

## Implications for Offshore Wind Energy Technology Advancement

In recent years, the offshore wind energy industry has made many significant technological advances. However, cost reduction, improved reliability, and greater environmental compatibility continue to be areas in need of continued technology innovation. Lessons can be drawn from many sources, including experiences with European offshore wind development, land-based wind development worldwide, and other energy technologies such as those used for offshore oil and gas extraction. However, the technological innovation necessary to drive a sustainable offshore wind industry in the U.S. will require significant targeted R&D investment. Below are some general conclusions regarding U.S. offshore wind energy technology:

### Learning from Other Contexts

European countries have been conducting research on and developing offshore wind technology for more than 15 years. This learning should be leveraged to the fullest extent possible. However, differences between European and U.S. offshore environments will require careful consideration. The effects of tropical storms in U.S. waters, for instance, are difficult to model and will have significant impacts on the structural reliability of offshore wind turbines.

### Project Scale

The lack of installed projects in the U.S. currently limits technology development and offshore wind industry advancement. Given the dynamic investment, political, and environmental contexts in the U.S., there are several options for near-term offshore wind projects in U.S. waters, including:

- Large-scale commercial projects that use technology already in practice in Europe. Large projects can achieve lower per-unit costs through economies of scale.
- Small-scale pilot projects that use proven technologies to gain experience with construction and operation of offshore wind systems in the U.S.; however, these projects would likely be of less interest to major offshore wind turbine suppliers.
- Small-scale pilot projects to demonstrate novel technologies and advance R&D in critical areas. These efforts will help improve reliability and reduce costs for future offshore wind projects.

### Investment in Research and Development

Even after 15 years of European experience with offshore wind development, the need still exists for significant technology advancements. Government, research communities, and developers would benefit from increased coordination to advance efficient R&D efforts, with specific focus on areas such as:

- Cost Reduction—Improvements in foundation design and materials; consideration of alternative and advanced strategies for offshore wind project construction and O&M activities.
- Reliability—Improvement in diagnostics and preventative maintenance for turbines and sub-systems; consideration of alternative design concepts that could avoid traditional problems with gearbox and/or blade failure. Reliability improvements are particularly important for offshore applications due to limited accessibility.
- Deeper-Water Technology—Floating platform technology is still in the conceptual stage, and further design development will be costly. Extensive research and funding are needed to engage entrepreneurs and technologists, rigorously test various designs, and identify the best floating concepts. Accumulated test data will be required to validate design tools and assumptions.

# 3. Economic and Financial Viability

## Overview

Offshore wind farms are more expensive to build and maintain than onshore systems. According to the U.S. DOE *20% Wind Energy by 2030* report, the capital costs for offshore wind farms are estimated at $2,400/kW (in 2006 dollars) compared with $1,650/kW for land-based wind projects. *Windpower Monthly* notes that information on the cost of offshore wind power facilities continues to be sparse.[81] Based on limited data available from completed offshore projects, this publication estimates that a fully-installed offshore wind system will cost as much as €3,300/kW ($4,600/kW) compared with €1,700/kW ($2,400/kW) for land-based. These figures include the cost of the turbines, as well as installation and maintenance.

Despite the increased costs associated with building and operating turbines in ocean and lake environments, there are several factors that make offshore wind development extremely attractive. Benefits include a more robust and consistent wind resource, and the ability to host ever-larger turbines (approaching 10 MW) and more expansive multi-turbine projects (with installed capacities of 1,000-3,000 MW). Economies of scale can offset, at least partially, the higher initial capital costs. Also, one of the most important economic benefits of wind power (both land-based and offshore) is that it reduces energy price risk. Once wind farms are operational, the fuel cost is zero (in contrast to the high price volatility of fossil fuels). Finally, for a number of states along the East Coast and Great Lakes, offshore wind offers the best—or only—opportunity to develop utility-scale renewable energy projects. The great potential benefits of offshore wind energy warrant its serious economic analysis.

## Offshore Wind Resources

U.S. offshore wind resources offer a vast, untapped source of renewable energy potential. Wind energy has been the world's fastest growing source of electricity during the past decade, with over 20% annual growth, and more than 121 GW installed globally.[82] According to the DOE report *20% Wind Energy by 2030*, offshore wind (utilizing current technology) could provide 54 GW of the nation's electricity by 2030; other estimates cite the possibility of up to 89 GW of offshore capacity by this date.[83] As suggested in the previous sections of this document, the thoughtful coordination of government policy, technology advancement, and investment strategies will be necessary to fully develop this valuable domestic resource.

Offshore wind resources are especially valuable because they have several distinct advantages over onshore wind. These benefits include greater energy potential, proximity to load centers, and, if sited far enough away from the coast, fewer noise and visual impacts.

Stronger and steadier winds found offshore result in higher energy capacity factors than for onshore wind.

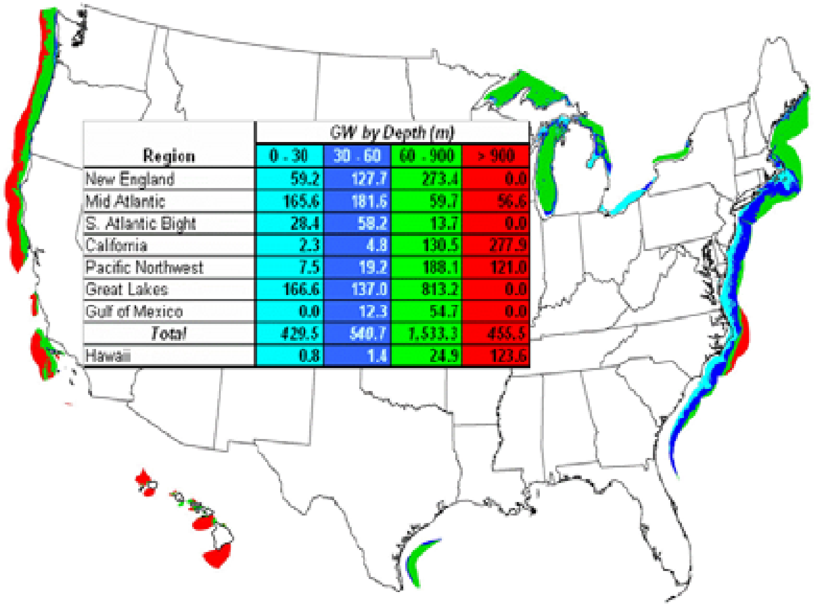


Figure 2: Bathymetry showing offshore wind resources (wind classes 5 and greater) by depth

| Region | GW by Depth (m) | | | |
|---|---|---|---|---|
| | 0 - 30 | 30 - 60 | 60 - 900 | > 900 |
| New England | 59.2 | 127.7 | 273.4 | 0.0 |
| Mid Atlantic | 165.6 | 181.6 | 59.7 | 56.6 |
| S. Atlantic Bight | 28.4 | 58.2 | 13.7 | 0.0 |
| California | 2.3 | 4.8 | 130.5 | 277.9 |
| Pacific Northwest | 7.5 | 19.2 | 188.1 | 121.0 |
| Great Lakes | 166.6 | 137.0 | 813.2 | 0.0 |
| Gulf of Mexico | 0.0 | 12.3 | 54.7 | 0.0 |
| *Total* | 429.5 | 540.7 | 1,533.3 | 455.5 |
| Hawaii | 0.8 | 1.4 | 24.9 | 123.6 |

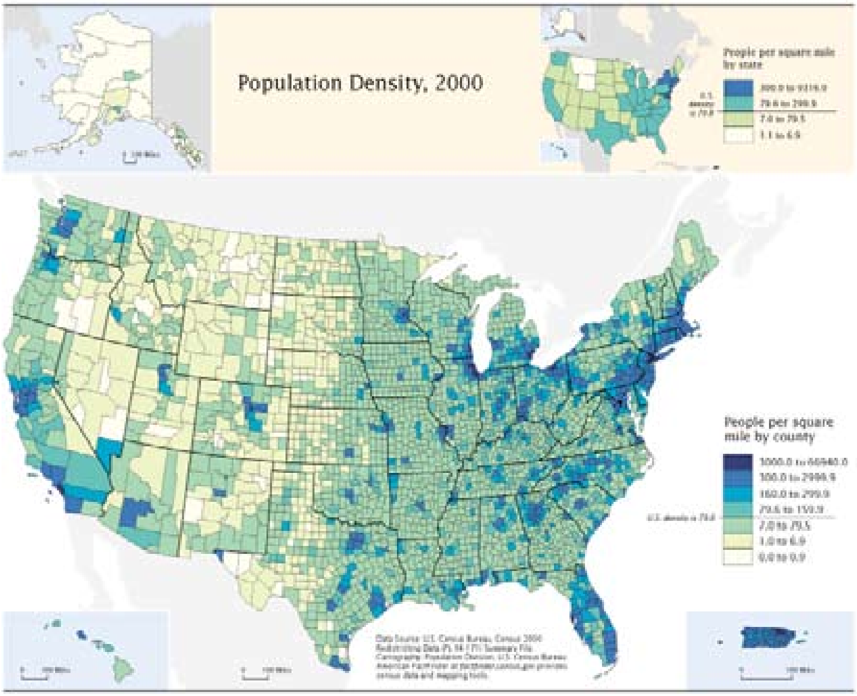


Figure 3: U.S. Population Density
*Source: U.S. Census Bureau, Mapping Census 2000: The Geography of U.S. Diversity*

Offshore winds are generally stronger, less turbulent, and more consistent due to the relatively flat surface of the ocean.[84] The amount of energy contained in wind (wind power density) is related to the cube of the wind speed, so slight increases in wind velocity lead to significant increases in energy production.[85] Average annual wind speeds tend to increase with distance from shore, which would correspond to a higher capacity factor, more energy production, and greater revenue for wind farms offshore.

### Proximity to load centers

Of the 48 contiguous U.S. states, the 28 that have coastal boundaries consume 78% of the nation's electricity.[86] Many of the best offshore wind sites are near states with large electricity demand, while most onshore wind projects are located far from load centers. As a result, offshore wind developments located close to coastal load centers would not require as large a transmission network as onshore wind projects.

Especially in coastal states with high population densities, offshore wind projects are opportunities for utility-scale renewable energy development with minimum human impacts. Compared with land-based wind farms, wind projects sited offshore, far away from communities, will not have to deal with as many visual-impact considerations. Additionally, due to distance from shore and ambient noise of the ocean, offshore wind farms generally do not have noise impacts on human populations. Increasing the distance between wind projects and populated areas should reduce the need for costly mitigation measures related to human impacts.

The best winds are over "deep waters"—water depths of 30 m (98.4 ft) or greater. However, severity of site conditions also increases with water depth due to larger extreme waves and higher peak gusts. While many desirable deep-water wind sites are just beyond the reach of current technology, coordinated research efforts have the potential to change this situation rapidly. In all areas of the offshore wind industry, investment in a focused R&D agenda will be necessary to successfully and sustainably exploit offshore wind resources.

## Project Costs

Several primary components account for the majority of an offshore wind project's costs (and cost variations). These include capital costs related to turbines, installation, O&M, support structures, electrical infrastructure, and engineering and management. Foundations represent a greater proportion of the cost of offshore projects (compared with land-based wind farms), due to the increased amounts of steel, concrete, and copper.

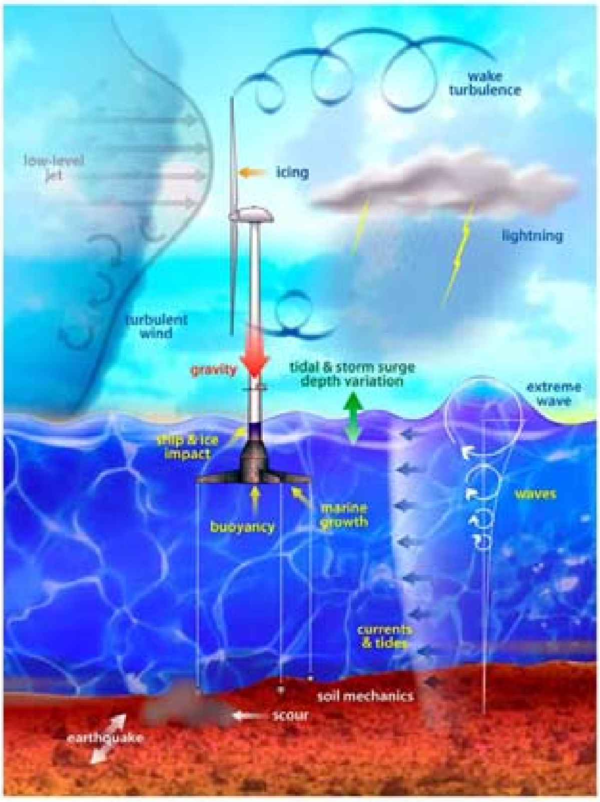
Table 3: Offshore Wind Project Cost Breakdown

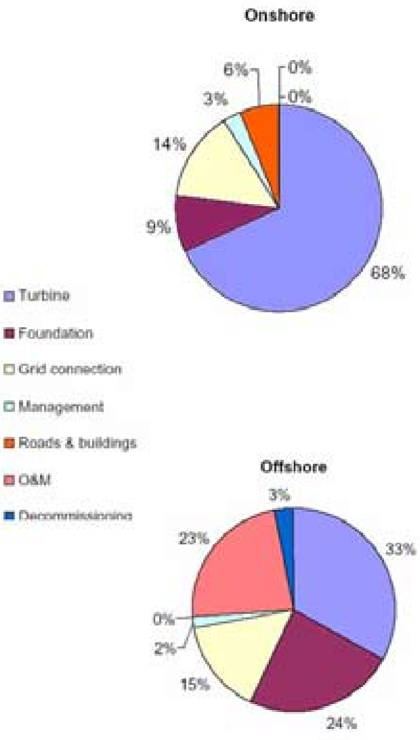
| Component | Percent of Total Project Cost |
|---|---|
| Turbines | 33% |
| Operations & Maintenance | 25% |
| Support Structures | 24% |
| Electrical Infrastructure | 15% |
| Engineering/Management | 3% |

There are several major factors that contribute to the high capital costs associated with offshore wind farm construction and O&M. First, engineers face difficult challenges when designing offshore wind systems to withstand the combined stresses of high winds and waves. Particularly for foundations, making engineering solutions cost-effective presents an additional set of challenges. Monopile foundations—the standard for land-based turbines—can become prohibitively expensive in offshore environments, due to the increased need for expensive materials like steel. Monopile foundations are impractical at depths greater than 30 meters.

The complexity of offshore wind projects (compared to onshore installations) currently translates into 30% to 60% greater initial capital costs and up to 33% higher construction costs.[87] Turbines themselves are the majority of the cost for land-based wind farms, while facility components (foundations, towers, transmission, and installation) are the bulk of the cost for offshore wind farms. A turbine manufacturer quoted in a recent publication by the U.K.'s Carbon Trust asserts, "One of the biggest benefits the industry could award itself would be the ability to build economic foundations at a water depth of more than 30 meters."[88]

Although wind speeds generally increase with distance from shore, construction costs increase as well. Offshore wind projects must be larger (both in terms of turbine size and overall project scale) in order to offset the additional costs of turbine support structures and cabling required for marine





installation.[89] Projects in deep water may require turbines of at least 5 MW to maximize economies of scale, in order to offset high construction and capital costs.[90]

Water depth has a significant effect on construction and project costs, since one additional meter of tower height adds approximately $2,000 to each turbine's capital cost.[91] Depth limitations for conventional foundations increase the appeal of alternative foundation technologies, such as floating structures. Also, a variety of meteorological and seabed conditions contribute to construction costs, including tidal currents, wind-driven currents, storm surges, extreme and breaking ocean waves, and soil conditions.

However, future project costs are not fixed and will depend heavily on advances in technology, electrical infrastructure, and construction practices. Sustained and predictable investment in R&D will likely lower costs across all phases of offshore wind development.

## Finance

The combination of market forces (supply and demand) and governmental incentives (both state and federal) will determine the financial viability of wind projects in the U.S. Offshore wind energy must compete on a cost-per-kilowatt-hour basis in order to emerge as a viable and sustainable domestic industry.

European offshore wind projects benefit from significant government financial incentives. E.U. markets employ mechanisms such as feed-in tariffs and tax credits to make offshore wind development more attractive to investors. The U.K.'s Crown Estate recently announced that it is extending leases for offshore wind projects to 50 years in order to provide investment certainty.

Despite this foreign support for offshore wind power abroad, the U.S. currently does not offer similar incentives to offshore wind developers.

Consequently, long-term (15-20 year) power purchase agreements (PPAs) are a vital means to secure financing for offshore wind energy projects in the U.S. Utilities might seek equity in offshore wind projects that have long-term PPAs in order to prevent them from showing up as liabilities on their books.

The cost of other sources of electricity (including natural gas, hydropower, and coal) affect the market penetration and consequently the financial attractiveness of offshore wind power. As a general rule, wind energy prices track with those of other electricity sources. The development of the electricity generation sector has been cyclical, with periods of high growth for one electricity source, followed by periods of slower growth as another energy source becomes more attractive. Factors influencing these growth patterns include government incentives, current and projected global resource prices, capital costs, and installation of new facilities. Coal appears to be poised for another growth period, with 9 GW of new coal-burning power plants under construction and another 40 GW at various stages of development.[92] The natural gas sector experienced capacity additions of 5 GW in 1998, 75 GW in 2002, and 20 GW in 2005.[93] While renewable energy currently makes up only 2.3% of U.S. electricity supply, there is growing interest in all forms of renewable energy, specifically including offshore wind development. Reasons for the increased appeal of offshore wind energy include: a) concerns about the recent price volatility of natural gas (ranging from $3/MMBtu to $10/MMBtu), b) fossil fuel resource constraints, and c) growing demand for renewable energy sources due to concerns about climate change and public health.[94]

## Cap and Trade

Wind energy has been the fastest-growing source of electricity over the last decade, primarily due to significant decreases in cost per kilowatt-hour (kWh) realized over the past 20 years. The cost per kWh of land-based wind energy has dropped from $0.40/kWh to as low as $0.04/kWh.[95] While $0.04/kWh is competitive with natural gas, it is more expensive than hydropower and coal. Currently, offshore wind energy is more expensive than that produced by land-based wind farms; in Europe today, land-based wind energy ranges from \$0.08/kWh to \$0.15/kWh, and offshore wind energy is about twice as expensive. However, most current estimates predict that capital costs for offshore wind projects will decrease. One source predicts \$2,520/kW through 2010, with costs decreasing 12.5% by 2030, largely due to technology advances.[96] This will have the effect of driving down wind-generated electricity costs to consumers.

## Implications for the Economic and Financial Viability of Offshore Wind Energy

Numerous factors contribute to the economic and financial viability of offshore wind development, including wind resources, project costs, and electricity markets. As previously indicated, the U.S. offshore wind industry is rapidly gaining attention, both domestically and abroad. However, the U.S. still does not have a national, consistent set of long-term financial guarantees available to investors in offshore wind development. To fully realize this energy potential, the U.S. must develop financial instruments/programs that complement state and federal incentives to provide long-term security and commitment. Additionally, it would be beneficial to design forums that would help developers, investors, and utilities understand each other's perspectives and concerns. Broadly-based, coordinated initiatives will be necessary to create to a sustainable and viable offshore wind industry in the U.S.

Government policies, coupled with advances in technology and environmental compatibility, will continue to improve the financial viability of the U.S. offshore wind industry. It is suggested that future U.S. economic policies should include:

*Long-term financial incentives*: Stable, guaranteed, long-term financial incentives would lead to significant growth in the offshore wind energy sector. As a prerequisite, government support for offshore wind energy should recognize this sector as distinct from the onshore wind energy sector. Long-term (10 year minimum) federal and state incentives for the offshore wind industry will foster project development and cost-reducing innovation. The U.S. can bolster existing incentives by providing long-term stability and additional funding, including:

- Production Tax Credits (PTCs)
- Loans and Loan Guarantees
- Power Purchase Agreements (PPAs)
- Renewable Energy Credits (RECs)

*More aggressive incentives:* More aggressive financial incentives would help the U.S. become a global leader in the offshore wind industry. These aggressive incentives might include a national renewable electricity standard (with set-asides or multipliers for offshore wind energy), or a stronger incentive structure that follows European models. Both approaches could decrease risk for offshore wind developers and broaden the customer base for offshore wind-generated electricity. For example, some European nations (Germany, Spain, Belgium, and others) adopted feed-in tariffs that have been successful in increasing demand for renewable energy.

*Increased R&D funding:* Funding to support R&D should be a priority, particularly for efforts aimed at reducing costs while increasing reliability and accessibility. In the near future, improvements and/or modifications to traditional monopile and jacket foundation designs will be necessary to take full advantage of transitional and deep-water wind development opportunities off U.S. coasts. For the longer term, investments in promising innovations like floating platforms should also be supported. Designs for turbines and foundations that use less steel (and other expensive materials) will help improve economic viability.

# 4. Environmental/Marine Use Compatibility

## Overview

The oceans and Great Lakes are highly valued public trust resources, subject to numerous uses and environmental stressors. In recent years, there has been increased emphasis on understanding marine and aquatic ecosystem functions and on improving ocean resource management. As a result, environmental compatibility and risk mitigation are significant priorities for the offshore wind industry. Greater compatibility with ecosystems and human uses, achieved by improving technology and best-siting practices, will be required to gain public acceptance for U.S. offshore wind development.

The following pages explore environmental and marine use compatibility trends, opportunities, and challenges that affect offshore wind development today. These factors include relative risk assessment, ocean management planning, investment in baseline data acquisition, collaborative planning and research, and adaptive management. This section also outlines experiences to date with offshore wind project monitoring and mitigation in the E.U., as well as U.S. progress in establishing standards for offshore wind review. As noted in the 2005 *Framework*, addressing environmental and marine use compatibility issues is essential for an offshore wind project's political viability.

## Trends and Drivers

Although offshore wind development is still an emerging industry, there is improved understanding in areas of environmental risk factors and use compatibility issues. These improvements are largely due to focused efforts in site selection, environmental assessment, monitoring, and mitigation. Ocean and Great Lakes environments are highly complex systems with both natural and human influences; thus new technological designs for offshore wind systems (e.g. deep-water installations) must consider environmental, socio-economic, and marine use factors. Addressing these issues at the design stage will help to identify the most promising development pathways.[97] Deep-water developments far from shore will avoid some issues facing near-shore sites (particularly aesthetic objections), but the deep-water environment will have its own set of new and different challenges. The European Wind Energy Association notes that while initial results are promising from a multi-year annual monitoring of existing wind farms, there is still limited understanding of wind farm effects on particular local environments.[98]

Environmental assessment, monitoring, and mitigation are also important cost factors for offshore wind development.[99] Consistent protocols and standards in these areas would reduce project risk, have financial/environmental benefits for developers, and improve regulatory decision-making. Regional consistency in baseline data collection procedures would contribute to an ecosystem-scale understanding of existing conditions. For future wind developments, standard protocols for monitoring project operation would promote cumulative learning about risk factors. Although there are currently no offshore wind projects installed in U.S. waters, new advances in assessment technologies and marine monitoring are contributing to a more thorough understanding of the offshore environment.

Development of efficient siting strategies will require baseline data as well as a general systems understanding of the marine environment.[100] While collecting baseline data is vital for the future success of the entire offshore wind industry, most individual developers are financially motivated to collect data only for project-specific environmental assessments. There is a sentiment that developers should not bear the financial burden for gathering general information beyond project-specific needs, and that this broader baseline data should be in the public domain.

## Relative Risk Assessment

Overwhelming scientific consensus holds that there are human-induced contributors to accelerated global warming—in particular the burning of fossil fuels.[101] Concern about climate change is one of the factors catalyzing expanded worldwide commitment to renewable energy development. Historically, any structure built in the marine environment was evaluated in terms of its own, isolated environmental and human impacts. More recently, greater understanding of risks associated with climate change is stimulating development of new, integrated approaches for evaluating the risks and benefits of specific renewable energy projects in *comparative* context with the risks and benefits of different energy options.[102]

Environmental risk analysis is not a new invention. Corporations and government agencies have applied it extensively; the U.S. Environmental Protection Agency (EPA) has used this process to make decisions involving toxic waste areas, water and air quality, nuclear energy options, and waste disposal.[103] A structured, analytical approach would facilitate a deeper understanding of the cumulative risks and benefits posed by offshore wind development.[104]

Scientists consider global warming to be an urgent ecosystem threat that requires immediate action to *decrease* greenhouse gas emissions and to *increase* renewable energy production.[105] Particularly in comparison to other energy sources, the environmental impacts of wind energy production are *minimal* and *local* when the facilities are properly-sited. For example, avian experts consider the effects of wind farms on bird populations to be much less harmful than those associated with fossil fuel extraction and use. Potential avian impacts of wind turbines include mortality from tower and rotor collisions, possible loss of winter foraging habitat, and/or increased migration distances. While there is currently no methodology for quantifying these risks associated with wind power development, fossil fuel extraction has known, measurable, and substantial negative impacts on bird populations.[106]

An *integrated risk analysis* identifies significant risks by assessing consequence probability and magnitude of impact. It provides a methodology for comparing risks across various sectors and locations, so that decision-makers better understand tradeoffs and impacts associated with a particular project, in relative terms to other options for achieving the same objective.[107] Moving away from sector-by-sector analysis, toward a more integrated approach, will be instrumental in building a sustainable offshore wind industry.

## Ocean Management Planning

Human use of the marine environment is ever-increasing and expanding farther offshore. Critical ocean uses will include commercial fishing, recreation, transportation, mineral extraction, aquaculture and new enterprises like offshore renewable energy. Coupled with a more thorough understanding of marine ecosystems, and concerns about ocean health, this expanding interest in ocean resource use has spawned a new push for ocean planning, both in the U.S. and globally.[108]

There are two seminal consensus reports that describe management priorities for the U.S. oceans: one published by the independent Pew Oceans Commission[109], the other by the federal-government-sponsored U.S. Ocean Commission[110]. Both highlight climate change as a major threat to marine health, due to sea-level rise, increasing water temperatures, loss of coral reefs through acidification, and ecosystem shifts, including changes in the geographic distribution of species.[111] Offshore wind development has great potential to contribute to climate change mitigation, energy security, and economic development. The ability to realize this potential creates a unique opportunity for partnership among industry, environmental interests, and government in promoting sustainable offshore wind development through ocean planning.

Currently, the central thrust of ocean planning is moving beyond traditional, fragmented regulatory schemes, toward a more integrated approach. Modern ocean planning incorporates two interrelated practices: *ecosystem-based planning* and *marine spatial planning.*

The "Scientific Consensus Statement on Marine Ecosystem-Based Management" states:

> *Ecosystem-based management is an integrated approach to management that considers the entire ecosystem, including humans. The goal of ecosystem-based management is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need. Ecosystem-based management differs from current approaches that usually focus on a single species, sector, activity or concern; it considers the cumulative impacts of different sectors.*[112]

The practice of *marine spatial planning* organizes uses, including conservation, in a spatially-explicit way that minimizes conflicts and encourages compatible multi-use. It utilizes technologies such as high-resolution seafloor mapping to understand the physical relationships between habitats and various marine uses. A finished plan for a marine area creates an overall vision, implemented through ocean zoning.[113] Offshore wind development has been one of the primary catalysts for recent ocean management initiatives, in states including Massachusetts and Rhode Island.

## Investment in Baseline Data Acquisition

Lack of baseline data on the marine environment—including marine mammal distribution and migration patterns, benthic habitats, and avian migration patterns—is a barrier to effective planning for offshore wind development. These information gaps also impair broader efforts involving ecosystem-based management and marine spatial planning. To address this problem, some East Coast states are conducting environmental analyses in both state and federal waters. As one example, the New Jersey Department of Environmental Protection commissioned a $4.5 million baseline planning study to support the siting of offshore wind farms, with information including avian and sea turtle surveys, acoustic surveys, and oceanographic work. This New Jersey study covered an area along the state's southern coast extending 20 miles offshore.[114]

In 2007, MMS published a Worldwide Synthesis of existing data on environmental and socio-economic factors related to offshore renewable energy development.[115] This report was the basis for a "Workshop to Identify Alternative Energy Environmental Information Needs," attended by 144 individuals representing federal and state agencies, NGOs, academic institutions, and industry, along with international experts.[116] The resulting *Alternative Energy Studies Development Plan for FY 2009-2011* identifies information needs in the areas of oceanography, airborne resources (birds and bats), aquatic biology, and the social sciences. It also presents profiles of the studies proposed for Fiscal Years 2009 and 2010, and provides study topic areas for Fiscal Year 2011 and beyond.

## Investment in Collaborative Planning and Research

Offshore wind development in the U.K. is supported by a unique public-private environmental research partnership, Collaborative Offshore Wind Research into the Environment (COWRIE). Initiated by the Crown Estate, the COWRIE steering committee includes natural resource and economic development agencies, the British Wind Energy Association (BWEA), the Royal Society for the Protection of Birds, and offshore wind developers designated in the initial round of leasing.[117] This collaborative's charge is to: a) develop and execute a coherent program of short-to-medium-term generic research to support offshore wind development, and b) manage and analyze the data collected throughout the lifecycle of each offshore wind farm. Focus areas include avian and benthos-related issues, such as marine bird survey methodology, remote sensing techniques, and underwater noise and vibration monitoring.

In addition to COWRIE (which is a non-governmental charitable organization), the U.K.'s Marine Renewable Energy Research Advisory Group coordinates an economic development/environmental agency-funded R&D program.[118] The U.K. government, working with BWEA, also established liaison groups to directly engage key stakeholders in efforts to address use compatibility issues. These issues, along with the targeted liaison group for each, include radar interference and other navigational difficulties (Navigation and Offshore Renewable Energy Liaison—NOREL), and conflicts with commercial fisheries (Fisheries Liaison with Offshore Wind—FLOW). These groups conduct research, promote best practice guidance, and provide outreach to their respective constituencies.[119]

In the U.S., land-based wind energy interests created similar structures for industry/stakeholder engagement, including the National Wind Coordinating Committee's Wildlife Workgroup.[120] Several coastal and Great Lakes states established initiatives to create research consortia directed toward offshore wind development and other marine renewable energy technologies. These efforts will engage universities, government agencies, industries, and other stakeholders in activities aimed at appropriately siting offshore wind developments.

## Adaptive Management

As described in U.S. Department of the Interior (DOI) Secretarial Order 3270, an adaptive management (AM) approach requires *moving forward through uncertainty to allow for learning and adjustment*. AM applies a series of scientifically-supported management actions, using monitoring and research to test and verify management decisions. For example, if an infrastructure project is constructed using an AM framework, information gathered in pre-construction assessments may guide design or siting changes for the final project plan. Preliminary data would also determine any need for post-construction studies.[121]

Offshore wind development will require an adaptive approach. Especially when evolving technologies are used in areas with complicated marine ecosystems, it is vitally important to be responsive to new information and circumstances. The MMS Alternative Energy/Alternate Use Programmatic Environmental Impact Statement (PEIS) includes Best Management Practices that embrace AM concepts when structuring leasing procedures for offshore renewable energy projects. AM is implemented through partnerships among ocean managers, scientists, and other stakeholders. These collaborative efforts work to analyze and adjust to lessons learned, based on robust analysis of existing projects' interactions with environmental parameters and marine users.

As suggested in Mass Audubon's *Challenge Proposal* to regulators and proponents of the Cape Wind project, the necessary centerpiece for AM is a comprehensive pre- and post-construction monitoring/impact assessment program. Clearly identified mitigation protocols must accompany this monitoring process in order to allow for response to unanticipated impacts.[122] Standardized monitoring regimes will help build a knowledge base and create efficient procedures that use lessons from past experience. When designing these standards, however, it is important not to burden private developers with data gathering responsibilities beyond what is necessary for project-specific risk assessments. Mitigation requirements should also be proportional to the scale of impacts.[123]

## Experience to Date: European Examples in Monitoring and Mitigation

As the U.S. offshore wind industry moves forward, it can learn from international experiences with monitoring and impact mitigation.

### Denmark

In 2006, the Danish Energy Authority released the first long-term, peer-reviewed monitoring study of environmental interactions with offshore wind farms. The report describes the results of a six-year monitoring program at Horns Rev and Nysted wind farms. The pre- and post-construction monitoring protocols were designed in a Before-After-Control-Impact (BACI) comparison framework which was vetted by the International Advisory Panel of Experts on Marine Ecology (IPEME). This panel was appointed by the Danish Energy Authority and included representatives from major universities in the U.K., Germany, and the Netherlands.[124] Studies included: a) impacts of introducing hard-bottom on benthic flora and fauna, b) fish distributions around wind farm structures, c) the effects of EMF on fish, d) studies of avian behavior, migration, and collision, e) impacts of construction and operational noise on marine mammals, f) coastal geomorphology, and g) socio-economic effects.

Overall, this analysis concluded that construction and operation of the two offshore wind farms had minimal environmental impacts.[125] The findings revealed localized and/or temporary impacts, and suggested important questions for further research. While the results from this study are site-specific and do not apply generally to all offshore wind farms, the monitoring program set the current standard for environmental impact assessment. The protocols for data collection demonstrated the value of applying consistent assessment strategies to support comparisons among different wind farms. Over time, this codified information could be used to build a comparative data base. As the offshore wind industry grows, environmental analysis must move beyond individual project assessment, toward evaluation of cumulative, regional impacts from multiple wind farms. The IPEME also emphasized the tremendous value of new monitoring technologies that were developed for its studies, including a Thermal Animal Detection System that measures collisions with birds, and a T-POD system (deployed data-loggers) for recording underwater sounds to measure local porpoise activity.[126]

### U.K.: Assessing and Mitigating Navigational Impacts

Studies of potential impacts of offshore wind energy structures on marine navigation and safety concluded that the most significant effect was on marine radar. These research efforts were conducted in 2004 within the U.K.'s North Hoyle Wind Farm, and in 2005 in the Kentish Flats Wind Farm. With funding from U.K. Round 2 developers, the BWEA conducted additional analysis to clarify the extent of the problem, consider practical solutions, and develop guidelines for navigating around offshore wind farms.[127] The BWEA's findings, endorsed by NOREL, determined that radar operators were aware of echo effects from turbines but were not overly concerned about the navigational impacts of isolated wind farms. However, they were concerned about potential cumulative impacts from multiple wind farms in close proximity to shipping lanes. The strong signal returns from wind farm structures also revealed vulnerabilities in existing ships' radar systems.[128]

Navigational issues around wind farms are highly site-specific. They will be influenced not only by proximity to marine vessels and air traffic, but also by factors including operator skill level, use of technologies such as Automated Identification Systems and Vessel Traffic Services, and potential for sea-icing.[129]

### Assessing and Mitigating Visual Impacts

Belgium, the Netherlands, and Germany are greatly reducing controversy over aesthetic issues by siting proposed offshore wind farms far from the coast. In these countries' waters, wind farms would be at least 20 to 30 km from shore. The U.K. is undertaking a seascape study as part of its Round 3 Strategic Environmental Assessment (SEA) to provide evidence-based guidance for determining appropriate buffer zones for offshore wind development.[130] This U.K. methodology considers *seascape unit sensitivity* and the anticipated *magnitude of the visual effect* for various wind farm siting options, in order to determine appropriate buffer zones. A variety of factors will influence the perception of offshore structures as *visual intrusions*, including: a) proportion of the horizon occupied, b) wind farm layout, c) the complexity of the scene into which the wind farm will be placed, d) remoteness, and e) scenic quality.

Public acceptance of the visual impacts from offshore wind farms seems to increase when opportunities for stakeholder engagement begin early in the siting process, and when there are clear local economic benefits of the proposed project.[131]

## U.S. Progress in Establishing Standards for Offshore Wind Review

### Cape Wind

On January 16, 2008, MMS released the Final Environmental Impact Statement (FEIS) for the Cape Wind energy project (the first offshore wind project proposed for U.S. waters).

First, the FEIS examines the existing physical, biological, and socio-economic resources at the proposed development site. It then analyzes impacts on each of these resources due to construction, O&M, decommissioning, and cumulative effects. Importantly, the document reflects the concept of adaptive management, requiring extensive monitoring and mitigation during each phase of development.[132] The FEIS is supported by numerous technical studies and by several years of monitoring key physical and biological parameters.

### The MMS Alternative Energy Program

As noted previously, the Cape Wind proposal predated the Energy Policy Act of 2005. This act initiated creation of a new policy and regulatory framework for renewable energy development on the U.S. OCS. The Cape Wind Environmental Impact Statement (EIS) process moved forward concurrently with MMS's development of a Programmatic Environmental Impact Statement (PEIS) that supported its regulations for leasing and managing OCS renewable energy sites.[133]

This PEIS outlined 52 Best Management Practices designed to protect environmental values and reduce conflict with other marine users. Site-specific experience with Cape Wind helped inform MMS in developing its overall regulatory program, and the Cape Wind project was evaluated in a manner consistent with the program's evolving standards. MMS's Final Rule was issued in April 2009.

## Technological Advances that Support Improved Siting, Environmental Assessment, Monitoring, and Impact Mitigation

As previously mentioned, one important outcome of the Danish monitoring study was success in applying new technologies for environmental assessment. These technologies helped to quantify bird collisions and detect marine mammal sounds, in order to track animal activity in the development site before, during, and after construction. Similarly, studies of potential wind farm impacts on marine navigation and safety reveal the possibility to mitigate these issues through technological improvements to radar systems.[134]

Offshore wind R&D initiatives often test new technologies designed to reduce environmental impacts. For example, COWRIE researched options for mitigating wind farm construction noise associated with pile driving—an important risk factor for marine mammals.[135] The results of this research favored the engineering solutions of an inflatable piling sleeve or a telescopic double-wall steel tube. For offshore areas with significant water depth and/or tidal current constraints, the COWRIE research determined that bubble curtains would not be feasible.

In addition, new methods for acquiring, managing, and integrating broad-scale environmental information are supporting current ocean planning initiatives and the appropriate siting of offshore wind developments. Examples from the U.S. include:

### Multi-Purpose Marine Cadastre

The Energy Policy Act of 2005 directed the U.S. DOI to develop a mapping initiative for the OCS to support leasing decisions for offshore alternative energy development. An interagency Marine Boundary Working Group developed an implementation plan that combines core marine cadastre information[vi] with supporting data, including human uses and natural resource information. The result is a single portal that assimilates these data layers in a seamless fashion. The implementation plan focuses on data compilation and standardization, ease of access and viewing, case studies, partnership development, and capacity building. Information is integrated for both state and federal waters, providing an accessible and consistent platform for marine spatial planning. NOAA's Coastal Services Center (CSC) is managing the portal's development, as well as training and working with partnering states, federal agencies, and others to increase functionality by adding new, highly-compatible data sets. For example, the Nature Conservancy is experimenting with use of the MMS lease blocks as standard mapping units for eco-regional assessment.

### Integrated Ocean Observing System

The U.S. Integrated Ocean Observing System (IOOS) is a multidisciplinary system designed to enhance the collection, delivery, and use of coastal ocean data. It does so through a national system of satellites, sensors (both in and above the water), shore-based radar, and other observation systems. These tools collect data and monitor changes in the conditions and health of the oceans and Great Lakes. Started in 1997, IOOS brings together many networks of disparate federal and non-federal observing systems, in order to provide information in accessible formats that facilitate good decision making. Eleven IOOS Regional Associations design and coordinate operation of regional coastal ocean observing systems. Also, these associations work with the many users of coastal information to identify data needs and develop new applications. The Alliance for Coastal Technologies (a NOAA funded partnership of research institutions, resource managers, and companies) supports development of reliable sensors and platforms, in addition to testing novel observing technologies. Currently, several regional associations are working with industry and state and federal agencies to address issues related to offshore wind development, including management of large data sets, advancing ocean technology expertise, and use of ocean information and modeling to guide wind farm siting strategies.

---

[vi] A *marine cadastre* enables the boundaries of maritime rights and interests to be recorded, physically defined, and spatially managed.

## Environmental/Marine Use Compatibility Implications for Offshore Wind Energy

In the E.U., growth of the offshore wind sector has been a cooperative endeavor between government and industry. This partnership has supported environmental assessment efforts and troubleshooting of use-conflict issues. In natural resource data collection (to support appropriate siting) and in post-construction monitoring and analysis, strategic public investment is advancing best practices for impact mitigation and adaptive management. This public-sector engagement is driven by clear policy directives to develop renewable energy resources. There is clear recognition of the long-term risks associated with continued dependence on fossil fuels, including climate change, environmental degradation, and energy security concerns.

In the U.S., the federal regulatory structure for permitting offshore wind facilities is still evolving. However, fostering a sustainable offshore wind industry in U.S. waters will require more than a careful review of individual project proposals. Some coastal states have taken a lead in conducting baseline environmental and ocean use assessments, in order to guide and partner with developers in identifying appropriate wind farm locations. To further facilitate offshore wind industry growth, the U.S. will require efficient, proactive approaches to environmental data collection, use-conflict resolution, and cumulative impact analysis. In this area, a focused partnership between government, industry, and academia will maximize efficiency in developing initial offshore wind projects and will allow for greater learning from experience.

Features of a comprehensive approach to address issues involving environmental and marine use compatibility may include:

*A Regional Approach:* Many natural systems and marine resources are better understood on a regional scale; examples include migratory birds and marine mammals. States must coordinate marine resource assessments both among themselves and with efforts to improve baseline ecosystem understanding in federal waters.

*Standardized Assessment and Monitoring Protocols:* Currently, there are multiple protocols for monitoring and evaluating the interactions between offshore wind projects and the marine environment. Standardizing assessment and monitoring protocols for offshore wind developments will facilitate comparative analysis across projects and regions, building a robust knowledge base to support an adaptive management approach.

*Data Integration:* Offshore wind energy development is a new ocean use that commonly targets areas only beginning to be mapped and catalogued. In this context, effective wind farm siting strategies will require baseline research that addresses *significant risks* and research gaps. Making marine and aquatic resource data readily accessible to developers and government regulators will promote good project decision-making, as well as broader ocean planning initiatives.

*New Technology Development:* R&D investment in new technologies for monitoring, assessment, and mitigation will support more sophisticated, cost-effective strategies for planning, analysis, and impact mitigation.

# 5. Leadership and Coordination

In the years since the *Framework* was published in 2005, the context for U.S. offshore wind development has improved considerably. Building on growing public enthusiasm for domestic renewable energy, an improving regulatory structure, increasing state-level activity, and industry innovation around the world, the U.S. offshore wind industry is at a crucial and opportune juncture.

As this document illustrates, leadership has emerged in all relevant sectors:

- Coastal and Great Lakes states have launched significant initiatives to attract, incentivize, and plan for offshore wind development.
- MMS has adopted a regulatory structure for leasing public OCS lands for ocean renewable energy development. The agency acknowledges the significant potential of offshore wind power to contribute to the U.S. energy future, particularly in New England and Mid-Atlantic regions.
- The private sector has increased R&D in deep-water technologies and investment in proposed projects.
- The Obama Administration is calling for rapid advances toward a clean energy economy.
- Colleges and universities are initiating new programs that focus on the technology, policy, and economics of offshore renewable energy.
- Energy development—renewable energy in particular—is emerging as a central issue in federal and state ocean planning agendas.

This important work at state and regional levels must be woven together into a national-level, coherent *U.S. offshore wind development strategy* that recognizes the urgency of the nation's energy and climate change challenge.

This document suggests a range of activities intended to support the efficient growth of a domestic offshore wind industry. Some of these actions may be taken independently by governments, industry, academia, or other stakeholders; *however, most require deliberate, coordinated effort among all these sectors.*

By taking strategic actions to move the whole offshore wind industry forward, the U.S. can maximize the benefits of collaboration in accelerating innovation and in leveraging both public and private investment.

This situation calls for an organization able to provide the resources, forums, and motivation necessary to address large-scale issues related to offshore wind development. Such an organization must draw from a pool of talented, knowledgeable, and diverse public and private-sector stakeholders. The USOWC is developing the infrastructure and capacity to address these needs.

In parallel to the U.S. offshore wind industry, the USOWC is also evolving and further defining its role as a catalyst for progress in the complex offshore wind energy context.[136] Interdisciplinary governance and strong relationships with diverse stakeholders position the USOWC to be a significant leader in helping the nation realize its offshore wind energy potential.

Through ongoing discussion with offshore wind stakeholders, the USOWC has identified key activities which will advance the themes of this document. These activities include:

- Initiating collaboration between government, universities, and developers to fund research in critical technology, policy, and environmental areas.
- Developing a web-based information clearinghouse for the U.S. offshore wind industry.
- Convening states to consider issues of regional interest in offshore wind development.
- Coordinating efforts with industry to commission a robust economic analysis of future financing and infrastructure requirements.
- Convening U.S. and European counterparts to promote learning and information sharing.
- Engaging new stakeholders who will contribute to advancing offshore wind energy development in the U.S.

The time is ripe for the U.S. to make significant advances in its offshore wind energy industry. With effective leadership, communication, and multi-sector coordination, the U.S. can create a supportive policy context that would foster the industry's sustainable growth. This context must establish opportunities to coordinate technological, economic, and environmental advances, along with the chance to build public trust and investor confidence in the potential that offshore wind energy holds for the nation. The potential is great, and so is the need. The U.S. must seize the opportunity to nurture and develop what the Obama Administration has identified as one of the technologies that can lead the nation to a clean energy future.

# Notes

## Section 1

1 American Wind Energy Association. "Wind Energy Basics." http://www.awea.org/newsroom/pdf/Wind_Energy_Basics.pdf.

2 AWS Scientific, Inc. *Long Island's Offshore Wind Energy Development Potential: A Preliminary Assessment*, 2002.

3 Traynor, Ian and David Gow. "EU promises 20% reduction in carbon emissions by 2020." *The Guardian*, February 21, 2007, http://www.guardian.co.uk/environment/2007/feb/21/climatechange.climatechangeenvironment.

4 "EU pledges to maintain emissions goals." *Australian Broadcasting Corporation*, October 17, 2008, http://www.abc.net.au/news/stories/2008/10/17/2393551.htm.

5 Gardner, Timothy. "Obama should compromise on carbon policy." *Reuters*, November 13, 2008, http://www.reuters.com/article/newsOne/idUSTRE4AC9B220081113.

6 U.S. Department of Energy. *Annual Energy Outlook 2008*. Washington: Energy Information Administration, 2008, http://www.eia.doe.gov/oiaf/aeo/.

7 U.S. Department of Energy. *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*. May 2008, http://www.20percentwind.org.

8 Regional Greenhouse Gas Initiative, Inc. http://www.rggi.org/home.

9 Schrag, Jonathan. "RGGI States' First $CO_2$ Auction Off to a Strong Start." Regional Greenhouse Gas Initiative, Inc., September 29, 2008, http://www.rggi.org/docs/rggi_press_9_29_2008.pdf.

10 Offshore Energy & Minerals Management. "Renewable Energy Program: Regulatory Development and Policy." U.S. Department of the Interior, http://www.mms.gov/offshore/AlternativeEnergy/RegulatoryInformation.htm.

11 Harrington, Mark. "LIPA chief kills wind farm project." *Newsday*, August 23, 2007, http://www.newsday.com/business/ny-bzwind0824,0,7647935.story.

12 Offshore Energy & Minerals Management. "Renewable Energy Program: Regulatory Authority." U.S. Department of the Interior, http://www.mms.gov/offshore/AlternativeEnergy/index.htm.

13 Governor's Task Force on Wind Power. *Report of the Governor's Task Force on Wind Power Development*. State of Maine, February, 14, 2008, http://www.maine.gov/doc/mfs/windpower/pubs/report/wind_power_task_force_rpt_final_021408.pdf.

14 "Wind Power Gets Big Boost in Maine." Natural Resources Council of Maine, April 11, 2008, http://www.nrcm.org/news_detail.asp?news=2331.

15 "Department of Energy to Invest up to $4 Million for Wind Turbine Blade Testing Facilities." U.S. Department of Energy, June 25, 2007, http://www.energy.gov/news/5163.htm.

16 Office of Energy Resources. "The Rhode Island Renewable Energy Fund." State of Rhode Island, http://www.energy.ri.gov/programs/renewable.php.

17 DiSavino, Scott. “Deepwater to build Rhode Island offshore wind farm.” *Reuters*, September 25, 2008, http://www.reuters.com/article/environmentNews/idUSTRE48O88U20080925.

18 Long Island- New York City Offshore Wind Project. “Request for Information.” http://www.linycoffshorewind-rfp.com/.

19 “Blue Ribbon Panel on Development of Wind Turbine Facilities in Coastal Waters.” State of New Jersey, http://www.state.nj.us/njwindpanel.

20 “GMI Awarded New Jersey Ocean/Wind Power Ecological Baseline Studies.” Geo-Marine, Inc., October 30, 2007, http://www.geo-marine.com/7_NJ_wind_power.htm.

21 Office of Energy Efficiency and Renewable Energy. “New Jersey to Develop a 345-Megawatt Offshore Wind Power Project.” U.S. Department of Energy, October 15, 2008, http://apps1.eere.energy.gov/news/news_detail.cfm/news_id=12038.

22 “Energy Master Plan.” State of New Jersey, October 2008, http://www.state.nj.us/emp/docs/pdf/081022_emp.pdf.

23 Southern Company. “Renewables.” http://www.southerncompany.com/commonsense/energy_renewables.aspx.

24 “Texas General Land Office Signs Historic Coastal Lease to Develop Offshore Wind Energy.” Texas General Land Office, October 24, 2005, http://www.glo.state.tx.us/news/archive/2005/events/offshorewind.html.

25 “Texas awards first competitive wind leases in the United States.” Texas General Land Office, October 2, 2007, http://www.glo.state.tx.us/news/docs/2007-Releases/10-02-07-wind-lease.pdf.

26 “Department of Energy to Invest up to $4 Million for Wind Turbine Blade Testing Facilities.” U.S. Department of Energy, June 25, 2007, http://www.energy.gov/news/5163.htm.

27 “Great Lakes Wind Energy Center Feasibility Study.” Cuyahoga County of Ohio, http://development.cuyahogacounty.us/en-US/Wind-Turbine-Feasibility-Study.aspx.

28 “Governor’s Task Force on Global Warming—Investigation to Assess Wisconsin’s Potential for the Development of Wind Energy Resources in Lake Michigan and Lake Superior.” Public Service Commission of Wisconsin, http://psc.wi.gov/globalWarming/05EI144/index-WindonWater.htm.

29 “PSC Issues Final Report on Great Lakes Wind Energy Study.” Public Service Commission of Wisconsin, January 15, 2009, http://psc.wi.gov/pdffiles%5CNews%20Releases%5C2009%5C01%20January%5Cwowfinalreportrelease.pdf.

30 Great Lakes IT Report. “MSU Report Studies Offshore Wind Power Regulation.” WWJ 950 News Radio, Detroit, August 25, 2008, http://www.wwj.com/pages/2848063.php?.

31 “Delivering Offshore Wind Power in Europe.” The European Wind Energy Association, 2007, http://www.ewea.org/fileadmin/ewea_documents/images/publications/offshore_report/ewea-offshore_report.pdf.

32 “Offshore Wind: Round 1,” U.K. Department for Business Innovation & Skills, http://www.berr.gov.uk/energy/sources/renewables/policy/offshore/round-1/page22510.html.

33 “Round 2: Offshore Wind Farm Leasing.” U.K. Department for Business Innovation & Skills, http://www.berr.gov.uk/energy/sources/renewables/policy/offshore/round-2/page22576.html.

34 “The Crown Estate Launches Round 3 of Offshore Windfarm Development.” The Crown Estate, June 4, 2008, http://www.thecrownestate.co.uk/newscontent/92-round3.htm.

35 Mast, EHM, Kuik, GAM van & Zaayer, MB. "Offshore wind energy policies and their effects: Experiences in Denmark and the UK and prospects for the Netherlands." In *Proceedings of the 2007 European Wind Energy Conference & Exhibition in Milan* edited by T Chaviaropoulos, 1-10. Brussels: EWEA, 2007.

36 http://www.nationalinfrastructureplanning.co.uk/about.aspx.

37 Ibid.

38 Waldermann, Anselm. "A Green Revolution off Germany's Coast." *Spiegel Online*, July 24, 2008, http://www.spiegel.de/international/germany/0,1518,567622,00.html.

39 "Germany Plans 30 Offshore Wind Farms." *Spiegel Online*, July 7, 2008, http://www.spiegel.de/international/germany/0,1518,564274,00.html.

40 Nielsen, Rune Birk. "Denmark's largest offshore wind farm approved." Danish Wind Industry Assoication, August 26, 2008, http://www.windpower.org/composite-2031.htm.

41 Mast, EHM, Kuik, GAM van & Zaayer, MB. "Offshore wind energy policies and their effects: Experiences in Denmark and the UK and prospects for the Netherlands." In *Proceedings of the 2007 European Wind Energy Conference & Exhibition in Milan* edited by T Chaviaropoulos, 1-10. Brussels: EWEA, 2007.

42 Ibid.

43 "Dutch Offshore Wind Project Sets Financing Precedent." *Renewable Energy World*, March 16, 2007, http://www.renewableenergyworld.com/rea/news/story?id=49530.

44 Mast, EHM, Kuik, GAM van & Zaayer, MB. "Offshore wind energy policies and their effects: Experiences in Denmark and the UK and prospects for the Netherlands." In *Proceedings of the 2007 European Wind Energy Conference & Exhibition in Milan* edited by T Chaviaropoulos, 1-10. Brussels: EWEA, 2007.

45 "Dutch Offshore Wind Project Sets Financing Precedent." *Renewable Energy World*, March 16, 2007, http://www.renewableenergyworld.com/rea/news/story?id=49530.

46 "World's Largest Wind Turbines Headed for Offshore of Belgium." *Engineering News Record*, June 19, 2007, http://enr.construction.com/news/powerIndus/archives/070619a.asp.

47 "Minister sets offshore wind energy prices." *RTÉ News*, February 8, 2008, http://www.rte.ie/news/2008/0208/environment.html?rss.

48 "Global Showcase for Offshore Wind Power Dedicated in Arklow, Ireland." *Business Wire*, May 26, 2005, http://www.allbusiness.com/energy-utilities/utilities-industry-electric-power-power/5142735-1.html.

## Section 2

49 Zaaijer, M.B. "Offshore windenergie." *Afdeling Voor Offshore Techniek*, Oct. 16, 2003. http://www.offshorewindenergy.org/.

50 "Delivering Offshore Wind Power in Europe." The European Wind Energy Association, 2007, http://www.ewea.org/fileadmin/ewea_documents/images/publications/offshore_report/ewea-offshore_report.pdf.

51 "The wind energy industry expects even more distinct growth within the next years than it had in 2004." *WindEnergy e-news*, March 2006, http://www.hamburg-messe.de/windenergy/we_en/e_news_03_06.htm.

52 Pena, A. et. al. “LiDAR observations of offshore winds at future wind turbine operating heights.” Presented at the European Offshore Wind Conference and Exhibition, Berlin, Germany, December 4-6, 2007.
Phillips, J. et. al. “Methods for assessing the spatial variation of wind resource in German waters: the role of Mesoscale Modeling and Earth Observation data.” Presented at the European Offshore Wind Conference and Exhibition, Berlin, Germany, December 4-6, 2007.

53 “Offshore.” AWS Truewind, http://www.awstruewind.com/maps/offshore.cfm.

54 FINO - Research Platforms in the North and Baltic Seas, http://www.fino-offshore.com.

55 *2008 Cleveland Crib Wind Report*. Green Energy Ohio, http://www.greenenergyohio.org/page.cfm?pageID=2197.

56 Fischer, G. “Experience from Four Years Operation of Research Platform FINO 1.” Presented at the European Offshore Wind Conference and Exhibition, Berlin, Germany, December 4-6, 2007.

57 Sorensen, P. “The Heritage from the Offshore Oil & Gas Industry.” Presented at the European Offshore Wind Conference and Exhibition, Berlin, Germany, December 4-6, 2007.

58 Musial, W. “Why Go Offshore and The Offshore Wind Power Potential of the United States.” Southeast Regional Offshore Wind Power Symposium Presentation, Feb 27, 2007, www.offshorewindenergy.org.

59 “Beatrice Wind Farm Demonstrator Project Overview.” Talisman Energy, http://www.beatricewind.co.uk/overview.

60 Musial, W. “Why Go Offshore and The Offshore Wind Power Potential of the United States.” Southeast Regional Offshore Wind Power Symposium Presentation, Feb 27, 2007, www.offshorewindenergy.org.

61 Ibid.

62 Ibid.

63 Moe, G. “The prospects for offshore wind energy in Norway in a 25 year perspective.” Presentation to the Chinese Academy of Engineering, 2008.

64 Paul Sclavounos (Massachusetts Institute of Technology). Interview by Katherine Dykes. September 22, 2008.
Dr. Larry Viterna (Nautica Windpower LLC). Interview by Katherine Dykes. September 22, 2008.

65 “First REpower 6-MW Turbines Assembled.” *Renewable Energy World*, December 22, 2008, http://www.renewableenergyworld.com/rea/news/story?id=54362&src=rss.

66 Ashuri, T. and M.B. Zaaijer. “Review of Design Concepts, Methods and Considerations of Offshore Wind Turbines.” Presented at the European Offshore Wind Conference and Exhibition, Berlin, Germany, December 4-6, 2007.

67 Butterfield, C.P. “Overview of Offshore Wind Technology.” Presentation at the Chinese Renewable Energy Industry Association WindPower Conference, Shanghai, China, October 2007.

68 Ribrant, J. and L. M. Bertling, “Survey of Failures in Wind Power Systems with focus on the Swedish Wind Power Plants During 1997-2005.” *IEEE Transactions on Energy Conversion*, Vol 22, No 1, March 2007.

69 Ashuri, T. and M.B. Zaaijer. “Review of Design Concepts, Methods and Considerations of Offshore Wind Turbines.” Presented at the European Offshore Wind Conference and Exhibition, Berlin, Germany, December 4-6, 2007.

70 Greg Yurek (American Superconductors). Interview by Katherine Dykes. October, 7, 2008.

71 Ashuri, T. and M.B. Zaaijer. “Review of Design Concepts, Methods and Considerations of Offshore Wind Turbines.” Presented at the European Offshore Wind Conference and Exhibition, Berlin, Germany, December 4-6, 2007.

72 Professor James Manwell, 2008. (University of Massachusetts). Interview by Katherine Dykes. September 23, 2008.

73 Prowse, M. “New Concepts for Installation of Turbines.” Presentation at the European Offshore Wind Conference and Exhibition, Berlin, Germany, December 4-6, 2007.

74 Giebhardt, J. et. aEt. l. “Requirements for Condition Based Operation and Maintenance in Offshore Wind Farms.” Presentation at the European Offshore Wind Conference and Exhibition, Berlin, Germany, December 4-6, 2007.

75 Rhead, P. “Combined Rotor and Drive Train Monitoring System for Predictive Maintenance Scheduling.” Presentation at the European Offshore Wind Conference and Exhibition, Berlin, Germany, December 4-6, 2007.

76 Professor James Manwell (University of Massachusetts). Interview by Katherine Dykes. September 23, 2008.

77 Ibid.

78 Burges, K. “Bipolar offshore networks of high capacity for collective wind farm connections.” Presentation at the European Offshore Wind Conference and Exhibition, Berlin, Germany, December 4-6, 2007.

79 Ibid.

80 Ahndorf, T. “The German offshore grid - A successful integration of offshore wind power.” Presentation at the European Offshore Wind Conference and Exhibition, Berlin, Germany, December 4-6, 2007.

## Section 3

81 Milborrow, David and Lynn Harrison. “Wind Rock Solid as Uncertainty Reigns.” *Windpower Monthly*, January 2009.

82 World Wind Energy Association. *World Wind Energy Report 2008*, 4. February 2009.

83 U.S. Department of Energy. *20% Wind Energy by 2030: Increasing Wind Energy’s Contribution to U.S. Electricity Supply*. May 2008, http://www.20percentwind.org.

84 Minerals Management Service *Technology White Paper on Wind Energy Potential on U.S. Outer Continental Shelf.* U.S Department of Interior. Washington, DC, May 2006.

85 Manwell, J.F., J.G. McGowan, and A.L. Rogers. *Wind Energy Explained: Theory, Design and Application*. Chichester, England, 31, 2002.

86 Energy Information Administration, http://www.eia.doe.gov/.

87 Blair, N., M. Hand, W. Short, and P. Sullivan. “Modeling Sensitivities to the 20% Wind Scenario Report with the WinDS Model,” Presentation at the American Wind Energy Association (AWEA) WindPower 2008 Conference, Houston, Texas, June 1–4, 2008, 9, http://www.nrel.gov/docs/fy08osti/43511.pdf.

88 “Offshore wind power: big challenge, big opportunity - Maximizing the environmental, economic and security benefits.” Carbon Trust, 2008.

89 Butterfield, C.P. and W. Musial. *Future for Offshore Wind Energy in the United States.* National Renewable Energy Laboratory, 5, 2004.

90 Minerals Management Service. *Technology White Paper on Wind Energy Potential on U.S. Outer Continental Shelf.* U.S Department of Interior. Washington, DC, May 2006.

91 Ibid.

92 Black & Veatch. *20 Percent Wind Energy Penetration in the United States: A Technical Analysis of the Energy Resource.* Walnut Creek, CA: Black & Veatch, 2007, 9, http://dnr.wi.gov/environmentprotect/gtfgw/documents/Black_Veatch_20_Percent_Report.pdf.

93 Ibid.

94 Ibid.

95 Minerals Management Service. *Technology White Paper on Wind Energy Potential on U.S. Outer Continental Shelf.* U.S Department of Interior. Washington, DC, May 2006.

96 Black & Veatch. *20 Percent Wind Energy Penetration in the United States: A Technical Analysis of the Energy Resource*. Walnut Creek, CA: Black & Veatch, 2007, 13. http://dnr.wi.gov/environmentprotect/gtfgw/documents/Black_Veatch_20_Percent_Report.pdf.

## Section 4

97 U.S. Offshore Wind Collaborative. *Offshore Wind: A Structural Framework*, 2005.

98 European Wind Energy Association (EWEA). *Delivering Offshore Wind in Europe: Policy Recommendations for Large Scale Deployment of Offshore Wind Power by 2020*. 2007.

99 Ibid.

100 Minerals Management Service. *Fiscal Years 2009-2011 Studies Development Plan: Alternative Energy*. U.S. Department of the Interior. Washington, DC, 2009.

101 International Panel on Climate Change. *Climate Change 2007: The Physical Science Basis*. http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm.

102 Ram, B. *Environmental Risks and Siting Challenges*. Presentation at the Global Marine Renewable Energy Conference, New York City, April 2008.

103 National Research Council. *Science and Decisions: Advancing Risk Assessment*. Washington, DC: National Academies Press. November 2008.

104 Ram, B. *An Integrated Risk Framework for Gigawatt-scale Deployments of Renewable Energy*. Draft White Paper, National Renewable Energy Laboratory. Forthcoming 2009.

105 Allison, T.D., E. Jedrey, and S. Perkins. "Avian Issues for Offshore Wind Development." *Marine Technology Society Journal*, vol. 42 no.2, Summer 2008.

106 Ibid.

107 Ram, B, *An Integrated Risk Framework for Gigawatt-scale Deployments of Renewable Energy*. Draft White Paper, National Renewable Energy Laboratory. Forthcoming 2009.

108 Pew Oceans Commission. *America's Living Oceans: Charting a Course for Sea Change*. 2003.

109 Ibid

110 U.S. Ocean Commission. *An Ocean Blueprint for the 21st Century: Final Report of the US Commission on Ocean Policy.* 2004.

111 National Center for Atmospheric Research. *Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers*. 2006.

112 McLeod, K. L., J. Lubchenco, S. R. Palumbi, and A. A. Rosenberg. 2005. *Scientific Consensus Statement on Marine Ecosystem-Based Management.* Signed by 221 academic scientists and policy experts with relevant expertise and published by the Communication Partnership for Science and the Sea at http://compassonline.org/?q=EBM.

113 UNESCO Ecosystem-based Marine Spatial Management Initiative. http://www.unesco-ioc-marinesp.be/.

114 New Jersey Dept. of Environmental Protection, Div. of Science, Research and Technology. *NJ Solicitation for Scientific Research Proposals: Ocean/Wind Power Ecological Baseline Studies*, April 2007.

115 Michel, J., H. Dunagan, C. Boring, E. Healy, W. Evans, J.M. Dean, A. McGillis. and J. Hain. *Worldwide Synthesis and Analysis of Existing Information Regarding Environmental Effects of Alternative Energy Uses on the Outer Continental Shelf.* U.S. Department of the Interior, Minerals Management Service, Herndon, VA, MMS OCS Report 2007-038. 2007.

116 Michel, J. and E. Burkhard. *Workshop to Identify Alternative Energy Environmental Information Needs: Workshop Summary.* U.S. Department of the Interior, Minerals Management Service. 2007.

117 Collaborative Offshore Wind Research Into the Environment (COWRIE), http://www.offshorewind.co.uk/Pages/COWRIE.

118 Marine Renewable Energy Research Advisory Group. *Environmental Research Portfolio - Status Report December 2007.* U.K. Department for Business Innovation and Skills, December 2007. http://www.berr.gov.uk/files/file42357.pdf.

119 Chris Jenner (Renewables, RPS Group PLc). Interview by Fara Courtney. 2008.

120 "Wildlife Workgroup." National Wind Coordinating Collaborative, http://www.nationalwind.org/workgroups/wildlife.

121 National Research Council. *Science and Decisions: Advancing Risk Assessment*. Washington, DC, November 2007.

122 Allison, Taber D. and Jack Clarke. "A Challenge Proposal Regarding the Cape Wind Energy Project." March 27, 2006, http://www.massaudubon.org/PDF/capewind/MAS-TheChallenge-3-06.pdf.

123 Chris Jenner (Renewables, RPS Group PLC). Interview by Fara Courtney. 2008.

124 *Danish Offshore Wind: Key Environmental Issues*. Published by Dong Energy, Vattenfall, Danish Energy Authority, Danish Forest and Nature Agency. November 2006. http://www.ens.dk/sw42535.asp.

125 Ibid.

126 Horns Rev website, http://www.hornsrev.dk/index.en.html.

127 British Wind Energy Association. *Investigation of Technical and Operational Effects on Marine Radar Close to the Kentish Flats Offshore Wind Farm*. 2007.

128 Ibid.

129 Rob Beck (Commander [dpw-s] First District, US Coast Guard). Personal communication. October 17, 2008.

130 White Consultants. *Offshore Energy SEA Seascape Study*. Draft working paper, January 2009.

131 Ibid.

132 "Cape Wind Final Environmental Impact Statement." Offshore Energy & Minerals Management, U.S. Department of the Interior, January 16, 2008, http://www.mms.gov/offshore/AlternativeEnergy/CapeWind.htm.

133 Minerals Management Service. *Record of Decision: Establishment of an OCS Alternative Energy and Alternate Use Program*. U.S. Department of the Interior. December 2007.

134 *Investigation of Technical and Operational Effects on Marine Radar Close to the Kentish Flats Offshore Wind Farm*. British Wind Energy Association. 2007.

135 Nehls, G., K. Betke, S. Eckelmann, and M. Ros. *Assessment and costs of potential engineering solutions for the mitigation of the impacts of underwater noise arising from the construction of offshore windfarms*. BioConsult SH report, Husum, Germany. On behalf of COWRIE Ltd. 2007.

136 See USOWC Prospectus 2009-2010.

US Offshore Wind Collaborative

**www.usowc.org**

Contact: Sonya Mitchell
mitchell@usowc.org
Tel: 508-737-0809
Fax: 508-898-9226