A FRESH LOOK AT OFFSHORE WIND OPPORTUNITIES IN MASSACHUSETTS

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The utilization of offshore winds for generating electricity was first proposed in the early 1970's, specifically in regards to Massachusetts, by Prof. William Heronemus, a naval architect at the University of Massachusetts. Subsequent studies commissioned by the federal government concluded that offshore wind development anywhere would be unlikely. More recently, a number of European countries have begun to devote substantial effort to the development of their offshore wind resource. Now, with support from the Massachusetts Division of Energy Resources, attention is being focused once again on the Massachusetts offshore. It is now apparent that significant opportunities exist for offshore wind in New England. In a region whose inland resource is concentrated on ridges, where access may be difficult or expensive, the offshore resource holds the potential to provide substantial amounts of renewable energy to the region. The offshore regions contain relatively large areas suitable for ocean floor mounted wind turbines, as well as even larger areas which could be suitable for (as yet undeveloped) floating turbines. On the other hand, the region is also the site of large marine sanctuaries, and there are many other competing uses for the coastal waters. This paper reviews the extent of present offshore resource estimates and other issues related to the development of the resource, including water depths, regulatory and environmental issues, weather related issues, and the existence of the support infrastructure for offshore wind development.

1. Introduction

Prof. William Heronemus of the University of Massachusetts first proposed offshore wind power in the early 1970s. Building on his naval architecture background, Heronemus proposed floating deep-water platforms with multiple rotors producing electricity or hydrogen, as illustrated in Figure 1[1]. Starting in the late 1980s the Europeans starting considering ocean floor mounted wind turbines in shallower waters. There have now been numerous offshore demonstration wind projects in Europe and many commercial projects have been started or are planned.

In the recent past, most of the focus on the possibilities for wind power in Massachusetts has been on the ridge top wind resource in the western part of the state[2]. That focus is broadening in the light of recent developments. Recent electricity restructuring legislation[3] established both a renewable portfolio standard and a fund to support the introduction of renewable power production in the state. The Commonwealth's Division of Energy Resources is also actively supporting renewable power project development including offshore wind power.

There are presently a number of demonstration wind projects off of European shores and plans for larger commercial projects. The oldest operating offshore wind farm, at Vindeby in Denmark, is composed of eleven 450 kW machines. The largest offshore installation, at Dronten in the Netherlands, has a 16.8 MW capacity[4]. These demonstration projects are supplying energy at costs of about 7.5 cents/ kWh. There are plans to install 40 MW of wind power in Copenhagen harbor in Denmark and 50 MW off of Rostock, Germany this summer[4]. These and other planned projects are driven by commitments of a number of European countries to substantially increase their supply of offshore wind generated electricity. All of these projects plan to use foundations that sit on the sea floor.

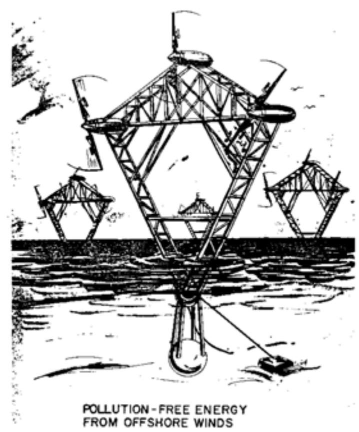

FIGURE 1. EARLY PROPOSED FLOATING OFFSHORE WIND POWER STATION

In deeper water, floating wind turbine support structures would be needed. This would represent a radical departure from current practice, but a number of possible designs have been proposed.[5,6,7] Floating wind farms would enable the harvesting of wind energy resources from areas far from shore and close to shore in regions where the water depth increases rapidly near the coast.

2. *Overview of the Wind Resource in Massachusetts*

The wind resource in Massachusetts in concentrated in the western hills, along the coasts and offshore. Figure 2 illustrates 1986 estimates of the local wind resource by wind power class[8]. The state's wind power projects have taken advantage of either the favorable ridge top wind resource in the state or the winds on the islands off of the coast. These projects have included the wind farm at Princeton, MA, the University of Massachusetts 250 kW wind turbine, and early wind turbine installations on the islands of Cuttyhunk (MA), Martha's Vineyard (MA). As indicated in Figure 2, the state also has a significant offshore wind power resource with class 4, 5, and 6 sites located along the coast or farther offshore.

The technically realizable onshore resource in Massachusetts has been estimated by the Department of Energy to be 70% of the state's electric consumption[9]. This estimate includes onshore areas with a wind resource of class 3 or higher and excludes land with urban development and environmentally sensitive areas. Based on these assumptions, the Department of Energy estimates that wind power could provide 33,000 GWh of energy per year.

The utilizable resource will depend on a number of technical and political constraints, including the site-specific nature of the resource and the many hurdles needed to develop it. Siting issues at ridge-top sites such as road access, visibility, proximity to power lines and the need to address local and state permitting processes make it difficult to develop the onshore resource. Nevertheless, there has been interest in the development of large-scale projects in a few locations in the state.

The state's offshore resource is large but not well characterized. In general, offshore winds are more energetic than the winds over the land and the geographic extent of these high-wind areas is larger than that of high-wind areas in western Massachusetts and along the coast. A more exact determination of the offshore resource as a function of distance from shore and water depth is required for large-scale development. As described below, those efforts are starting. The rest of this paper looks in more detail at the extent of the offshore resource and at the other issues which will affect the development of offshore wind in Massachusetts.

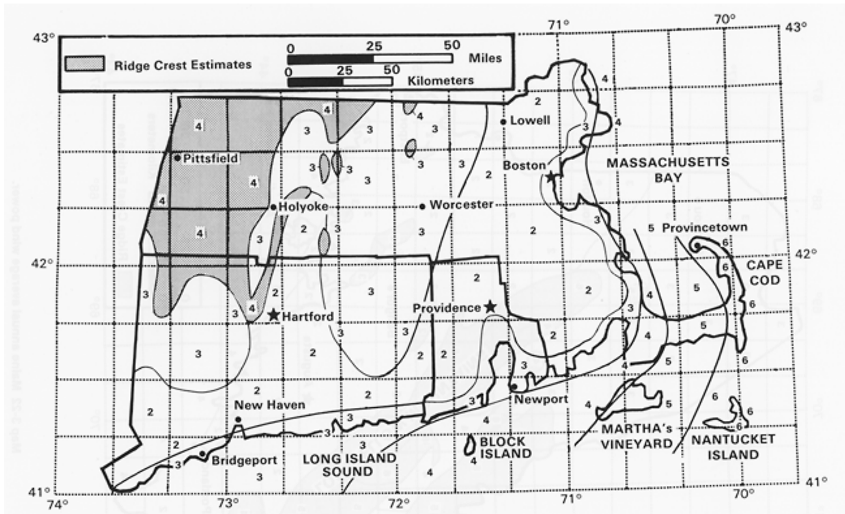

FIGURE 2. MAP OF WIND POWER CLASSES IN MASSACHUSETTS

3. The Coastal Waters of Massachusetts

The coastal waters of Massachusetts include Buzzards Bay (between southeastern Massachusetts and Cape Cod), Nantucket Sound (south of Cape Cod, between the islands of Nantucket and Martha's Vineyard and Cape Cod), Cape Cod Bay, the Boston Harbor area and ocean off of the coast (see Figure 2). These area are intersected by major shipping lanes into Boston harbor and through Buzzards Bay and the Cape Cod Canal (between the Cape and the rest of southeastern Massachusetts). All of the coastal waters within three miles of the coast are part of the Commonwealth's protected marine sanctuaries. Outside of these areas are additional federal marine sanctuaries such as Stellwagen Bank, north of Cape Cod, which is a feeding ground for whales. Numerous fishing activities and operations of the armed forces also occur off the coast.

A significant factor in the development of economic offshore wind farms is water depth. For ocean floor mounted turbines, the deeper the water, the more the foundation, and therefore the total system, costs. Existing offshore wind turbines are located in water no deeper than 8 m. The Danish Wind Turbine Manufacturer's Association suggests that cost effective turbines can be installed in waters up to 15m.[10] Research focusing on resource estimates have considered water as deep as 40 m.[11] Deeper water wind power would require floating supports anchored to the ocean floor. These may also, under various circumstances, be cost effective.

This study focuses on the shallow water resource. For this study it is assumed that water depths of up to 18.3 m (60 ft), an easily identifiable depth on navigation charts, would allow for cost-effective development using ocean floor mounted foundations. Figure 3 is a composite of navigation charts that cover all of the waters off Massachusetts. All areas shallower than 18.3 m in Figure 3 are bounded by a dark line. Except for the Cape Cod area and various harbors, water with depths of less than 18.3 m extends from 2 to 4 km (1.3 to 2.5 miles) from the shore. In Cape Cod Bay, areas with depths less than 18.3 m extend up to 15 km (9.3 miles) from the shore. Significantly, the almost the whole of Buzzards Bay and Nantucket Sound are shallower than 18.3 m.

4. Estimation of the New England Offshore Wind Resource

The most complete existing source for offshore wind data is a network of buoys and stations operated by the National Oceanic and Atmospheric Administration. Moored buoys and C-MAN (Coastal Marine Automated Network) stations record data on wind, waves, temperature and barometric pressure. It is possible to obtain data covering several years of measurements. One can also find wind data from islands, offshore platforms, lighthouses, and ships that is of some use in defining the offshore wind resource. Unfortunately this data is rarely collected at two heights or close to the hub height of turbines that would be considered for offshore operation.

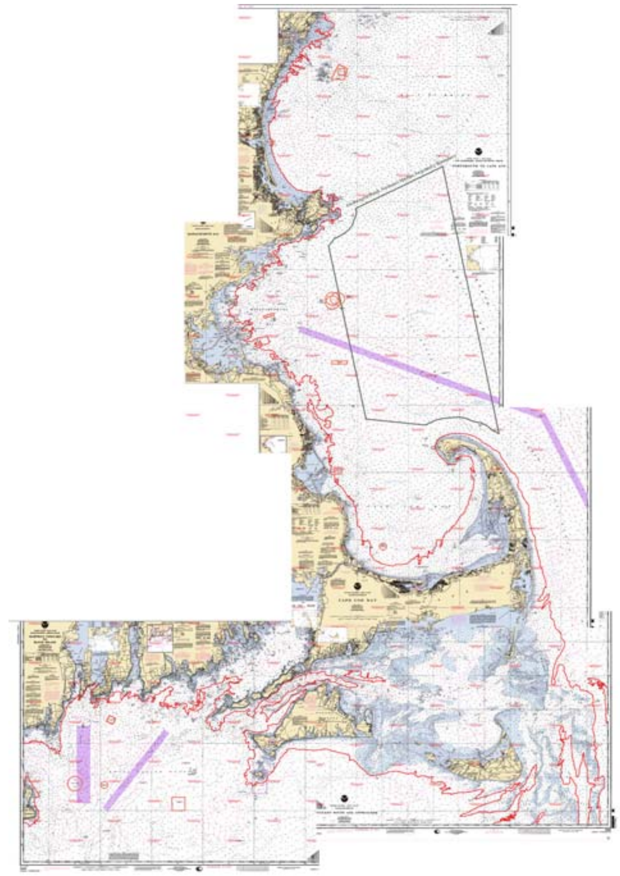

FIGURE 3. MAP OF MASSACHUSETTS COASTAL WATERS

Buoy data has been used in the preparation of this paper to estimate the wind resource off the shores of Massachusetts. Not all yearly data sets are complete and, because of inter-annual variation, not all complete yearly data sets are representative of the local wind resource. Data was chosen for each buoy for a year in which a complete data set was available and for which the mean wind speed at Logan Airport in Boston harbor was close to the 10 year Logan Airport average. Hub height wind speeds have been estimated using the well-known "log law" and assuming a surface roughness of 0.2 mm. The results yielded annual average wind speeds at 60 m of 8.4 m/s (18.8 mph) and 7.9 m/s (17.7 mph) in Buzzards Bay and Boston harbor, respectively.

Results of estimated mean 60 m wind speed for local buoys are shown near the buoy designation in Figure 4. It can be seen that the offshore wind environment consists of class 5 and 6 sites. This is an excellent wind resource. For comparison, the mean annual wind speed at Thompson Island is also shown. Thompson Island, in Boston harbor about 1 mile from shore, has a mean annual wind speed of 6.33 m/s.

The technically realizable shallow-water energy production from this offshore resource has been estimated assuming the use of a 1.65 MW turbine with a 66 m rotor diameter. Hub height wind speeds, represented by Weibull distributions, were calculated using the log law and the yearlong data sets. The calculations yielded capacity factors of 0.373 at Buzzards Bay and 0.332 at Boston harbor. Estimates for the total production potential of the shallow water resource assumed a capacity factor of 0.33 and that the turbines were located on a grid 10 rotor diameters apart over all coastal waters off of Massachusetts less than 18.3 m (60 ft) deep. The geographical area under consideration is 4780 square kiometers (1846 square miles), or about one quarter of the total land area in the state. Based on this analysis, shallow water projects off the coast of Massachusetts could supply 54,720 GWh, about 116% of Massachusetts' energy needs.

This estimate does not include the vast deep-water wind resource, which approaches within 2 kilometers of much of the eastern-facing shores of Massachusetts. Beyond a distance of three miles, where state jurisdiction ends, the jurisdiction of the Federal government extends to the 200 mile (320 km) national limit. The deep-water area within that 200 mile limit includes a huge energy potential that waits to be tapped.

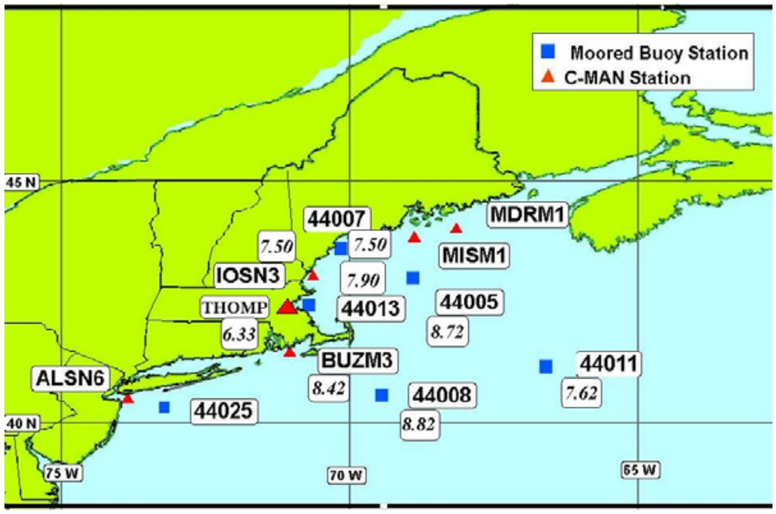

FIGURE 4. MEAN 60 M WIND SPEEDS AT BUOY LOCATIONS

Clearly further work is needed to thoroughly map the resource. The variation of the resource as function of distance from land would be very valuable in assessing the viability of projects in different areas.

5. Constraints Affecting the Utilizable Offshore Wind Resource

An accurate estimation of the state's utilizable offshore wind resource and detailed plans for siting offshore wind turbines require a thorough accounting of the constraints that affect the siting of possible turbines. These constraints can be separated into three categories: physical constraints, technical constraints, and public acceptance and conflicts with other activities. Physical constraints include those in the physical environment that affect the turbine design and thus costs. Technical constraints include those due to human activities that affect the turbine design and costs. Public acceptance and conflicts with other activities include a number of issues whose effect is played out in the political arena. Possibly the most important of all of these issues are the physical constraints of water depth and distance from shore and the public acceptance issue of visual impact.

A. Physical Constraints

Water depths. Water depths affect turbine foundation design and costs and installation methods and costs. Significant deep water exists off most of the coast with shallower water suitable for ocean floor mounted foundations in harbors, Cape Cod and Buzzards Bays and Nantucket Sound.

Distance from shore. The distance of a wind farm from shore affects the wind resource, interconnection, maintenance, and installation costs, electrical losses and the visual impact of offshore turbines. In addition, significant regulatory hurdles can be avoided by operating more than 3 miles from shore.

Sea bed morphology and slope. The composition and structure of the sea bed has a significant influence on the cost effectiveness of various foundation options. The geography of Cape Cod and the surrounding area is the result of glacial deposition. In general, the sea floor composition changes from sand to a sand-mud mixture and finally to mud in the deepest depths. Throughout the area there are scattered stones, boulders and rock outcrops. Waters in Nantucket Sound contain numerous shifting sandy shoals. Significant seabed slopes make turbine installation difficult, but the slope of the local seabed is yet to be determined.

Underwater currents. Currents in coastal areas of Massachusetts are caused by tides and winds. Both types of currents can cause scouring around foundations in sandy seabed. The drag caused by underwater currents increases roughly as the square of the speed. Tidal currents switch direction twice a day and, for example, achieve speeds of 1.3 m/s (2.5 knots) in some locations in Nantucket Sound. The magnitude of wind driven currents, on the other hand, are a function of wind speed.

Waves. Wave heights and periods and the probability of extreme wave occurrences affect turbine design and access for maintenance and installation. Wave loads, especially breaking wave loads[11], can have a significant effect on the foundation design. Data need to be assembled on expected wave heights. The maximum wave height measured at the buoy at the mouth of Boston harbor in 1991 was 9.1 m (30 ft). For comparison, the 50 year maximum expected wave at Vindeby is 4.75 m (16 ft)[11].

Weather Issues and Floating Ice. Obviously weather can be a significant factor in the maintenance and construction of wind farms offshore and extreme weather determines the design loads on the turbine. Hurricanes often cross Cape Cod and Nor'easters are famous for the loss of lives and ships that they cause. Floating ice can cause significant loads on turbine structures, but this is not expected to be a problem off of the coast of Massachusetts.

B. Technical Constraints

Grid connection Availability. The availability of interconnection to the local distribution system near the point where the power lines comes ashore affects costs.

Availability of harbors for maintenance craft and turbine assembly. The installation and operation of offshore wind farms involves support craft, heavy barge mounted cranes, cable laying vessels, staging areas, and possibly ship yards for building special-built vessels and floating turbine support structures. Massachusetts has significant dock, dry-dock and ship yard facilities in New Bedford (near Rhode Island) and in Quincy, just south of Boston, that would meet these needs.

Undersea cables. There are numerous undersea electrical cables in the waters off of the coast. Nantucket is powered by a 46 kV, 30 MW capacity cable running roughly due south from Harwich to Nantucket. This cable and others need to be avoided or protected from damage.

Unexploded ordinance and defense activities. The U. S. Navy and Coast Guard keep track of the location of any unexploded ordinance that may result from military exercises in the state's coastal waters. These locations need to be avoided or the ordinance needs to be properly removed before a wind farm can be located there.

C. Public Acceptance and Conflicts With Other Activities

Visual impact. Issues of visual impact seem be the primary factor underlying the public acceptance of wind power projects. Wind turbines are tall structures that can be seen for quite a distance on the open ocean. A 64 m (210 feet) high wind turbine would be visible above the horizon 36.6 km (22.8 miles) away. Additionally, if the total height of wind turbines exceeds 61 m (200 feet) then they are required by the FAA to have beacons to alert airplanes of their existence at night.

Shipwrecks and other underwater archeological sites. There are numerous shipwrecks in the coastal waters off of Massachusetts, many very old. The location of most of these is known and can be avoided.

For example, the highest density of shipwrecks in the area of Nantucket Sound is east of the coast of Cape Cod and on the shoals around Monomoy Island

<u>Shipping lanes</u>. There are major shipping lanes into Boston harbor, through Buzzards Bay and through Nantucket Sound. Each of these routes includes an inbound and an outbound lane. In addition there are numerous smaller channels and routes used by fishing boats, ships of smaller tonnage, seasonal ferries and pleasure craft. Shipping lanes in Nantucket Sound are illustrated in Figure 5.

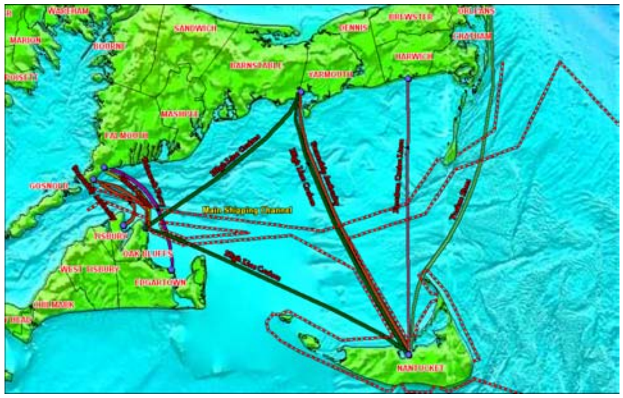

FIGURE 5. NAVIGATION CHANNELS IN NANTUCKET SOUND

<u>Fishing areas</u> – Fishing occurs throughout the waters off Massachusetts. Significant wind farm development would need to involve coordination with fishing interests.

<u>Habitat impact and Avian Issues</u>. The possible impact of wind energy on marine flora and fauna needs to be assessed. On the one hand, disruption needs to be avoided. On the other hand, the possible benefits need to be appreciated. For example, the foundations may prove beneficial for certain shellfish. Species that are of concern include the significant whale populations in the water off of Massachusetts, in addition to protected eel grass species. Many of them are protected under state or federal law. Avian-turbine interactions need to be minimized. Offshore migration routes and activity around nesting grounds close to shore need to be considered because Cape Cod is home to several species of protected birds. These include the piping plover and roseate tern and migratory birds such as the peregrine falcon and bald eagle.

<u>Civil Aviation issues</u>. Wind turbines and wind farms need to be located out of the path of aircraft. This is especially a consideration in Boston harbor where Logan International Airport is located. Avoidance of the glide path of aircraft arriving and leaving the airport limits turbine size close to the airport.

<u>Ocean sanctuaries</u>. Protected marine sanctuaries may limit wind power development or may require special permits.

6. Onshore Infrastructure

Offshore wind farm construction and operation requires an onshore infrastructure. This includes construction facilities for foundations or floating platforms, a harbor with staging areas for foundations, turbines, and cables, an appropriate barge with a crane for installation and cable laying vessels and equipment. For shallow water foundations, cable laying vessels and crane barges will need to be able to maneuver in shallow water. Wind farms a distance offshore will require cable laying vessels with significant cable capacity. Appropriate cable laying vessels and cranes with enough capacity and appropriate draught may need to be custom built. Maintenance activities will require smaller specially outfitted craft with a stock of turbine parts and the capability to handle some larger turbine parts.

As mentioned above, Massachusetts has significant dock, dry-dock and ship yard facilities in New Bedford and in Quincy. These ports and other nearby ports that have been central to the New England fishing industry have experienced economic declines recently due to increasing catch restrictions. The development of offshore wind farms would provide opportunities for economic development and employment for these port cities.

7. Economics

Offshore wind power plants cost more to install than comparable onshore plants. They also tend to have a greater energy yield due to the higher winds off shore. Both of these factors affect the cost of energy from offshore installations. The increase in installation cost is primarily due to higher foundation and power transmission (undersea cable) costs offshore. A detailed assessment of offshore energy costs has not been pursued for this paper, but a review of some of the published analyses of offshore wind energy costs indicates that the cost of energy should be in the range of 4 to 5 cents per kWh. Offshore wind energy costs are primarily a function of wind speeds, turbine and foundation design, wind farm size, and distance from shore.[12,13] A recent study found that a 7.5 MW wind farm of five 1.5 MW machines off of Denmark could produce energy at 4.9 cents/kWh if it were 5 km from the coast but only at 6.9 cents/kWh if it were 30 km from the coast. A much larger wind farm with a 200 MW capacity could produce electricity at 4.1 and 4.4 cents/kWh at distances of 5 and 30 km, respectively, from the coast. The first offshore project that has been proposed for Massachusetts is a 100 MW wind farm about 8 km from the coast.

8. Regulatory Issues

At the present moment there is no standardized procedure for permitting offshore wind farms. A number of local, state, and federal agencies have jurisdiction over offshore waters. Exactly who has jurisdiction depends primarily on the distance offshore.

The state and local towns have jurisdiction within three miles of the shore. Within the state government there are two cabinet level offices that have an interest in offshore development issues, the Executive Office of Environmental Affairs and the Executive Office of Consumer Affairs. The Executive Office of Environmental Affairs includes Coastal Zone Management, the Board of Underwater Archaeological Resources, the Department of Environmental Management, the Department of Environmental Protection and the Mass. Environmental Protection Act office which oversees projects over 100 MW. The Executive Office of Consumer Affairs includes the Division of Energy Resources, the Department of Telecommunications and Energy, and the Energy Facilities Siting Board. The later has jurisdiction for projects over 100 MW. At the state level, conflicts between regulatory agencies desires for coastal and marine protection and energy policies that call for low CO_2, renewable energy development are just starting to be resolved. Town agencies with jurisdiction over offshore projects include zoning boards and planing and inspection departments.

Within the three mile limit the state has also set up a series of Ocean Sanctuaries along the coast of Massachusetts in which offshore energy generation is prohibited [MGL Ch. 132A, Sections 13-18]. These provisions were aimed at generation from fossil fuels, but apply to all other generation technologies as well. Ambiguities in the Ocean Sanctuaries legislation will need to be resolved before development can occur in Nantucket Sound. The legislation appears to claim state jurisdiction over all of Nantucket Sound, including areas greater than three miles from any state shores, whereas Federal law seems to limit state jurisdiction to only three miles from its coasts. The possibilities for wind farms in state or federal marine sanctuaries may need to be resolved with amendments to legislation at either the state or federal level.

Outside of the three mile limit, the army Corps of Engineers appears to have primary jurisdiction. Other federal agencies such as the Coast Guard, Federal Aviation Administration, Department of the Interior and the Department of Agriculture (fisheries) may have concerns that will need to be addressed in any wind farm development.

9. Conclusions

A number of conclusions can be drawn from the overview presented here:

1. Although there is significant wind energy potential on the ridge tops in the western part of Massachusetts, there is a far greater potential off the coast. The technically exploitable wind resource found above the shallow waters off the coast could provide an amount of electricity greater than that used in the state.

2. The conditions in Massachusetts waters should be similar to those where wind farms are being installed in Europe, so the technology being applied in Europe should be adaptable to Massachusetts conditions. The cost of energy from offshore wind generation in Massachusetts would be expected to follow the trends in Europe, and should, in general, be lower than from land based turbines in the state (due to economies of scale and the lack of acceptable mainland sites for large wind farms).

3. The major constraint to offshore wind power development in Massachusetts is likely to be permitting and public acceptance, since the most promising areas from a technical point of view are also within sight of land and since there are many competing uses for the offshore waters. The amount of generation that will actually be installed, while possibly quite significant, is still likely to be substantially less than the technical maximum.

4. Most of the shallow waters off the coast of Massachusetts lie within three miles of land. Development of wind energy there would be subject to both state and local permitting. There is significant shallow water beyond the 3 mile limit, where wind power development would be subject to federal permitting.

5. A much larger resource exists in the deeper waters, further from the coast. Further developments in offshore wind energy technology are required before this resource can be economically utilized, however.

10. Recommended Future Activities

The potential for wind power off the shores of Massachusetts is receiving increased scrutiny and interest. A number of steps should be taken to support the future use of the offshore wind resource including:

1. Enhanced offshore wind and wave monitoring activities. These should include increased monitoring of wind and wave data for the purpose of looking at issues specific to wind power. This would require, most of all, data collection at multiple heights, approaching the hub height of existing turbines. The collection of wind and wave data needs to cover areas of likely interest such as in Nantucket Sound and Buzzards Bay, in addition to exploring the possibilities for future deep water offshore power production.

2. Attempt permitting. Permitting for the first offshore wind farm should be pursued in order to resolve just which agencies have jurisdiction over which activities and to push the resolution of ambiguities in jurisdictions and legal issues.

3. Install the first project. The installation of the first offshore Massachusetts wind farm will demonstrate the viability of the concept and provide valuable data on issues to be considered in future projects.

4. Work with other groups in the Commonwealth. The development of cooperative relationships between the Massachusetts maritime community (ship builders, fisherman, etc.) and wind power advocates will speed up the process of adapting wind turbines to New England offshore conditions.

5. Participate in European offshore activities. Active participation in European offshore activities will provide valuable information for the progress of U.S. offshore development.

6. Research and development for deeper water. Much of the waters off of the coast of Massachusetts is deeper than presently considered economically viable for ocean floor mounted foundations. Research into economical ocean floor mounted foundations for water deeper than 20 m and especially into the possibilities for future floating deep water wind farms is needed.

11. Acknowledgements

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