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Energy from Offshore Wind

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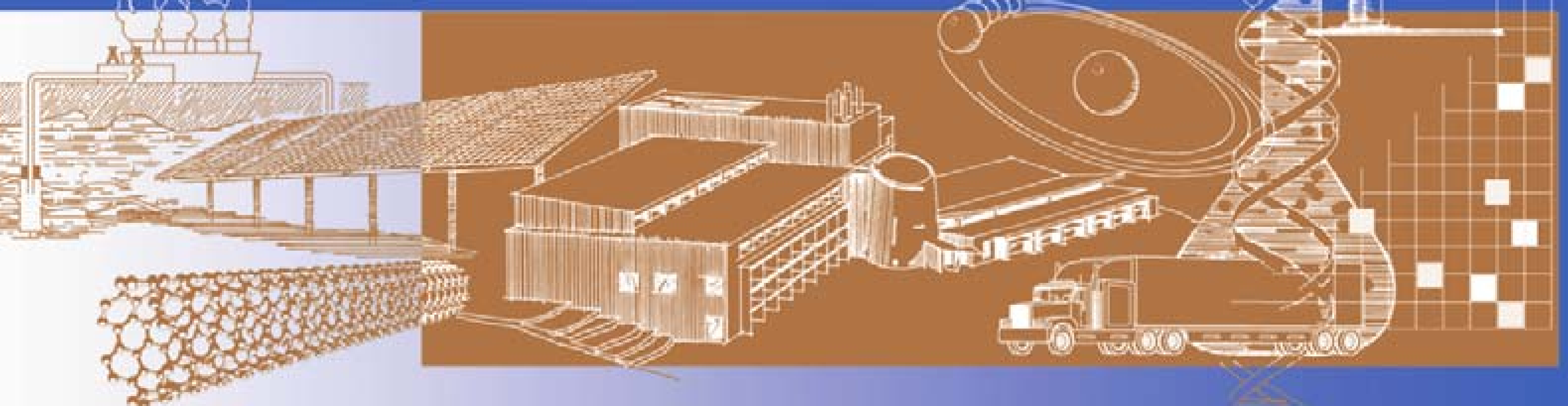

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Energy from Offshore Wind

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Abstract

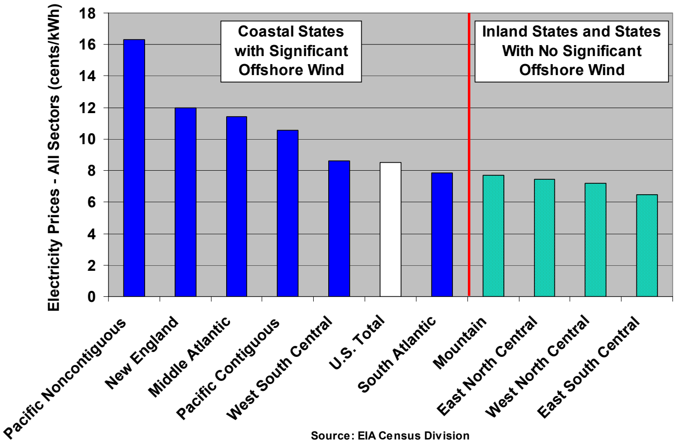
This paper provides an overview of the nascent offshore wind energy industry including a status of the commercial offshore industry and the technologies that will be needed for full market development. It provides a perspective on the status of the critical environmental and regulatory issues for offshore wind and how they are affecting the formation of the U.S. industry. The rationale provided describes why offshore wind has the potential to become a major component of the national electric energy supply. Future projections show this potential could result in over $100 billion of revenue to the offshore industry over the next 30 years in the construction and operation of offshore wind turbines and the infrastructure needed to support them. The paper covers technical issues and design challenges needed to achieve economic competitiveness for near term deployments in shallow water below 30-m depth. It also examines the requirements for future technologies needed to deploy systems in deeper water beyond the current depth limits. Although most studies to date indicate very low impacts to the environment, regulatory and environmental barriers have hindered the first offshore wind projects in the United States. A summary of these issues is given.

Introduction

Over the past two decades, on-shore wind energy technology has seen a ten-fold reduction in cost and is now competitive with fossil and nuclear fuels for electric power generation in many areas of the United States. Wind energy installations in the United States have grown from about 1,800 MW in 1990 to an estimated 9,200 MW at the end of 2005, and are expected to grow to 14,000 MW by the end of 2007 [1]. While onshore wind energy technology appears to be maturing rapidly by some measure, the need for further technology development still remains, as development booms have historically coincided with the existence of the 1.9-cent/kWh production energy tax credit for renewable energy sources. In addition, as wind energy penetrates a larger percentage of the grid, industry growth, dispatchability, and infrastructure, barriers will become critical long-term research issues.

Initial onshore wind development in the United States focused on the windiest sites (Class 6 that average 7.4 m/s at 10 m above surface annually), but these sites are generally in the more remote areas of the west, and on a few ridgelines in the east. The DOE Wind Program has led an initiative to drive the cost of wind energy down further through sustained technology innovations that have been identified, but have not yet been fully implemented under a Low Wind Speed Technology Program [2,3]. As lower costs are achieved, more sites are becoming economically viable in areas closer to energy constrained load centers, giving a higher value to the delivered electricity [4]. The full extent of the vast land-based resource is limited by transmission line access and capacity on the grid, which is making transport of electricity from the windiest areas more difficult [5]. Efforts to lower the onshore cost of energy (COE) and integrate wind energy into the electric utility grid are major technology areas that must continue for the United States to take advantage of its onshore domestic wind energy supply, but the full domestic wind electric potential cannot be realized in the United States without a broader perspective that includes the wind resources over the ocean.

Offshore wind generated electricity in the United States has the potential to become a major contributor to the domestic energy supply, on par with onshore wind, because it can compete in highly populated coastal energy markets where onshore wind energy is generally not available. Preliminary studies performed by the National Renewable Energy Laboratory (NREL) estimate the offshore resource to be greater than 1000 GW for the United States [6]. The wind blows faster and more uniformly at sea than on land. A faster, steadier wind means less wear on the turbine components and more electricity generated per turbine. The winds increase rapidly with distance from the coast, so excellent wind sites exist within reasonable distances from major urban load centers reducing the onshore concern of long distance power transmission. Figure 1 shows that in addition to the proximity to the load, the offshore resource tends to be geographically located nearest the states that already pay the highest electric utility rates in the United States.[1]



Source: EIA Census Division

Figure 1 – U.S. Electricity Rates by Region – 2005 (Source: EIA Census Division)

Offshore Wind Energy Economics

The estimated cost of offshore wind energy varies widely depending on the project, but some studies indicate that offshore projects cost significantly more than land-based turbine systems [7]. Much of the premium that is now being paid for offshore systems can be attributed to higher costs for foundations, installation, operation and maintenance.

As wind turbines are adapted for offshore, the process of achieving favorable economics depends less on reducing wind turbine costs and more on a full system life cycle cost approach. Figure 2 illustrates a typical breakdown of total system costs for an offshore wind farm in shallow water, from the wind turbine to the onshore utility connection, including the costs of operation and maintenance and decommissioning.

Although the exact proportions of each cost category in this chart will vary with the specifics of each project, the purpose is to show that the cost of offshore wind energy is increasingly dominated by balance-of-station (BOS) and operating expenses (OPEX). The electrical and grid infrastructure, foundations and support structures, offshore construction, and operations and maintenance now represent the major fraction of the total project cost. To be successful offshore, wind energy technologies must mature using the combined experiences and expertise of the cost-conscious wind industry and the sea-savvy offshore oil and gas and marine industries.

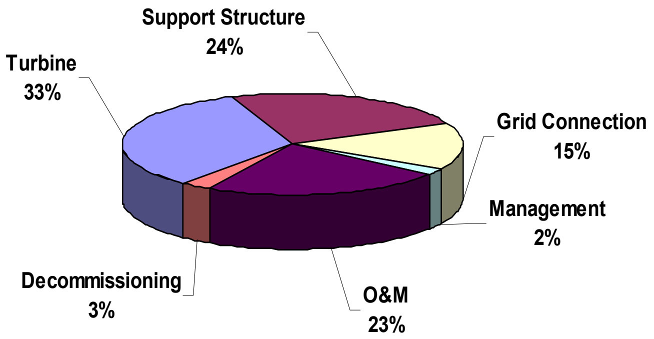


Figure 2 – Typical Cost Breakdown for an Offshore Wind Plant in Shallow Water [7]

Oil and Gas Synergy

Implicit in the large fraction of non-turbine system costs is the conclusion that the offshore oil and gas industry will have a dominant role in the implementation of offshore wind energy. The portion of the offshore turbine system below the waterline will largely be determined by experience and standards that were developed over the past four decades by the oil and gas industry. The design and installation of the electrical grid system, from interturbine cabling to laying the cable to shore, will be performed by the existing submarine cable industry. All offshore wind projects will employ the existing industry to perform site assessments and geotechnical engineering. Turbines will be installed and maintained using existing offshore vessels and equipment. Personnel access and service for turbines will use experienced offshore labor. In the United States where on-shore development has been largely unregulated, offshore turbines will have to undergo extensive structural evaluation and certification with an approval process under development at the Minerals Management Service (MMS) under the Energy Policy Act of 2005 [8]. This synergy between offshore wind and offshore oil is already underway in Europe where dozens of oil and gas and marine companies are already engaged in wind energy development. In the future, the partnerships between wind energy and offshore oil and gas will integrate further to maximize their mutual benefits resulting in sustainable commercial enterprises and the advancement of wind energy.

The economic potential resulting from this union requires some speculation, but for the purpose of illustrating the potential, a moderately aggressive development scenario based on preliminary analysis performed internally by the U.S. Department of Energy[2], indicates a concerted research and development effort to develop offshore wind energy would result in 50 GW of installed offshore wind energy capacity in

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[1] Some localized Great Lakes regions are included in the inland states regions but were difficult to separate.

[2] A white paper with the details of this study is in the publication process at this time.

the United States in the next 20 years. This represents approximately 5% of the nation's current electric generating capacity. At current pricing, this represents approximately $100 billion of capital investment with at least half of this revenue going to offshore design and construction contracts. Further expansion of the offshore wind industry is expected to double this capacity to 100 GW over the subsequent 10-year period. This revenue will flow directly to companies that have experience with offshore construction and that will benefit from the growth of offshore wind.

Offshore Wind: Current Situation 2006

Offshore wind energy began in shallow waters of the North Sea where the abundance of sites and higher wind resources are more favorable by comparison with Europe's land-based alternatives. The first installation was in Sweden with a single 300-kW turbine in 1990 and the industry has grown slowly over the past 15 years. There are now 18 operating projects with an installed capacity of 804 MW. Figure 3 shows a breakdown of where the installed capacity is located as a percentage of the total capacity and by country. The majority of the capacity is now located in Denmark and the United Kingdom, using mostly Danish turbine technology.

Over 11 GW of new offshore wind projects are planned before the year 2010 [9]. Most development will take place in Germany and the UK, but at least 600 MW of offshore wind is in the permitting process in the United States. All installations have been in water depths less than 18 m and distances from shore range from 1 km out to 14 km. The largest installations are operating off the coast of Demark with two 160-MW power plants; Horns Rev in the North Sea, and Nysted in the Baltic.

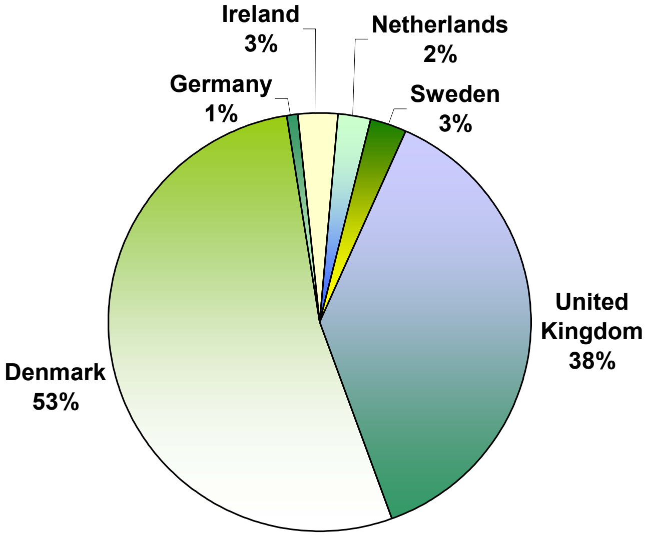

Figure 3 – Offshore Wind Projects Installed through 2005 Based on a Total of 804 MW

The largest offshore turbine installed to date is shown in Figure 4. This turbine sits in the Iris Sea at the 25.2-MW Arklow Banks wind farm. Each of the seven turbines has a rotor diameter of 104 m with a hub height of over 70 m. A single unit has an output capacity of 3.6 MW and can make as much as 15,000 MWh per year. The total turbine weight is about 290 tons. Current trends indicate that offshore turbines will grow much larger than this turbine in the future, as there are several 5-MW class turbines in the prototype stage.

Figure 4 – Typical Offshore Wind Turbine (courtesy of GE)

Offshore Wind Technology Development

The Path to Deeper Water. The offshore wind industry is likely to develop along the path illustrated in Figure 5.

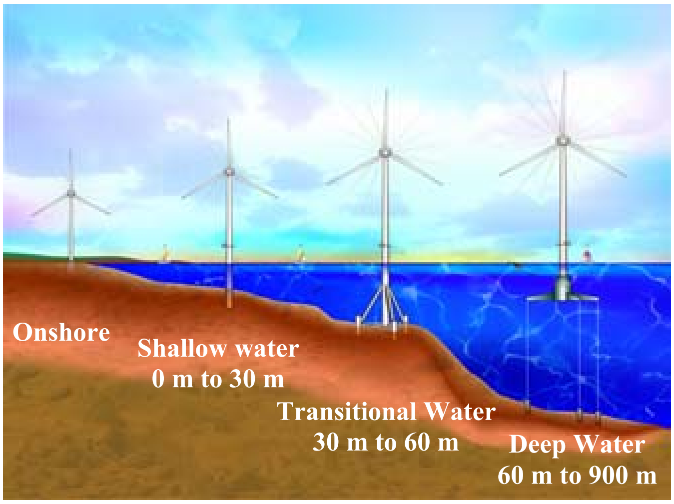

Figure 5 – Technology Progression for Offshore Wind Turbines

Preliminary mesoscale weather model assessments of the offshore wind indicate a sharp increase in wind speed with distance to shore. Siting options also improve with distance from shore, as there are more viable high wind sites with less visual impacts and competing uses for the seabed. These matters primarily, will gradually attract developers to deeper waters.

This progression to deeper water will make its way from experience gained from more sheltered projects in shallow water, similar to the petroleum industry's march into deep water during the twentieth century. As a result, much of the technology to do this has already been developed by the existing oil and gas industry, and a concerted effort to transfer that technology is already underway in the wind industry today. However, new technology is still needed to make wind energy economically competitive over a broad range of deeper water sites.

Offshore Substructures. The most critical aspect in the development and expansion of offshore wind energy lies with the substructures. As water depth increases, it is likely that the cost of offshore foundations will increase due to the added complexity and resources needed below the waterline. One of the goals of a new USDOE research and development program is to develop new substructure technologies and make them commercially available as the current designs reach their depth limits, and thereby minimize the water depth cost penalty. Figure 6 gives a conceptual view of how these technologies may evolve.

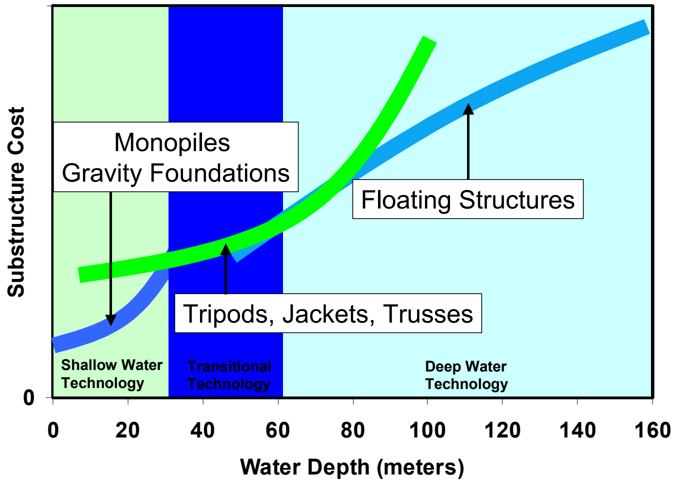

Figure 6 – Cost of Offshore Wind Turbine Substructures with Water Depth [10]

Tripods, jackets, and truss-type towers will replace monopiles and gravity bases, initially using conventional oil and gas offshore practices, but later implementing new strategies that can take advantage of the lower environmental and safety risks, and higher production volume associated with offshore wind turbines. At some depth, fixed bottom foundations will be replaced by floating systems that have a high potential for site independence, mass production, and wide-ranging wind turbine innovation.

Shallow Water Foundations. All offshore wind power plants thus far are in shallow waters between 5 m and 18 m. These projects use marinized versions of proven land-based turbine designs, with upgraded electrical systems and corrosion systems, placed on free standing concrete gravity bases or steel monopile foundations. The estimated 98 GW of shallow water wind energy potential in the United States (5 to 50 nm offshore) will provide the first step for the U.S. wind industry to develop the infrastructure, technical capabilities, and experience to advance into deeper waters [6].

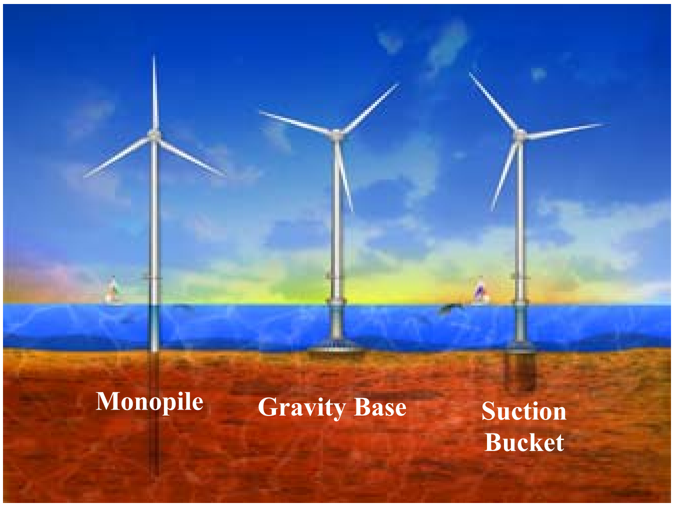

Figure 7 – Shallow Water Foundation Technology – Current Options

Figure 7 shows the range of shallow water foundations that are being deployed today. Monopiles are used in shallow depths because of their simplicity and minimal design developments required to transition from onshore to offshore, as well as their minimal footprint on the seabed. Monopiles are used in most offshore installations including the 160-MW wind farm at Horns Rev off the west coast of Denmark [11]. Monopiles are depth-limited due to their inherent flexibility. This limit occurs when the natural frequency of the turbine/support structure system is lowered into a range where coalescence with excitation sources such as waves and rotor frequencies becomes unavoidable. To maintain adequate monopile stiffness in deeper waters, a volumetric (cubic) increase in mass and therefore cost is required. This means the monopile length, diameter, and thickness are all growing to accommodate greater depths. At the same time, installation equipment such as pile hammers and jack-up vessels become more specialized and expensive, and eventually the required hammer capacities and jack-up depth limits cannot be reached. These limits are thought to be somewhere between 20 and 30m [12].

An alternative to the monopile is the gravity base foundation, also shown in Figure 7. These foundations have been successfully deployed at the 160-MW Nysted project in southeastern Zeeland in Denmark and at Samsoe in northeastern Jutland in Denmark to name a couple of examples. These foundations can overcome the flexibility issues of monopiles but will grow in cost very rapidly with water depth as well, although the use of concrete may provide some advantage in extending favorable economics [13]. Gravity base foundations require significant preparation of the seabed to assure a level substrate within 20 mm, however, installation effort is reduced once this preparation is complete [14]. Extensive site-specific soil analysis is required for each gravity base to assure homogeneous soil properties and compaction to minimize uneven settling.

Suction bucket foundations have not yet been used as an alternative to shallow water foundations but significant development research has been carried out and this new technology shows promise for some shallow water sites, especially in avoiding the limitation of large pile drivers presented by monopile type foundations [15].

Transitional Technology. The shallow water support structures will be replaced by fixed bottom systems that use a wider base with multiple anchor points like those frequently used in the oil and gas industry. Transitional substructure technology can be deployed up to depths 60 m or greater, as shown in Figure 8.

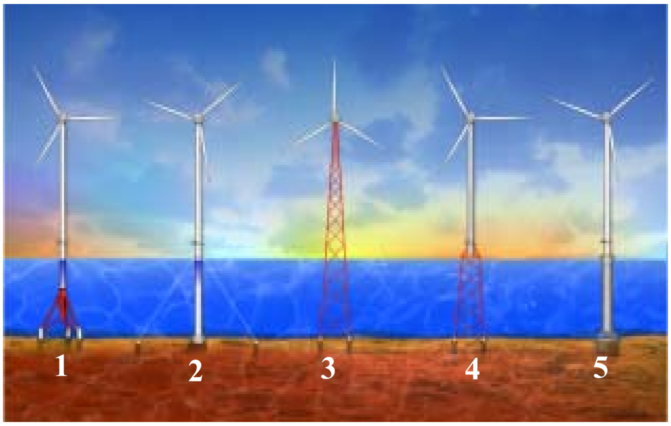

Figure 8 – Transitional Substructure Technology

Foundation types are identified numerically in the figure (from left to right): 1) tripod tower [16], 2) guyed monopole, 3) full-height jacket (truss), 4) submerged jacket with transition to tube tower [17], 5) enhanced suction bucket or gravity base. Transitional depth technology is an important step in the progression toward floating systems and access to the full offshore wind resource. Preliminary resource assessments for the United States have shown that the transitional depth resource (30-m to 60-m depth, and 5-nm to 50-nm distance from shore) for Class 5 wind and above exceeds 250 GW [18]. The first offshore wind turbines in transitional water depths are currently being deployed at a demonstration project consisting of two 5-MW wind turbines at 42-m depths in the North Sea [17].

Floating Technology. At some water depth, a floating substructure may be the best option. A floating structure must provide enough buoyancy to support the weight of the turbine and to restrain pitch, roll, and heave motions within acceptable limits. A primary difference between the load characteristics of a floating wind turbine and a floating oilrig is that, for a wind turbine, large wind-driven overturning moments dominate the design while an oilrig's design is payload and wave driven. System-wide interactions such as coupled turbine/platform dynamics could potentially impose additional inertial loading requiring more dynamically tolerant turbines. Any added complexities must be offset by higher offshore winds, and greater public acceptance due to lower visual and environmental impacts.

No full-scale floating systems have been deployed yet but some private groups in Norway claim to be working on full-scale prototypes [19,20].

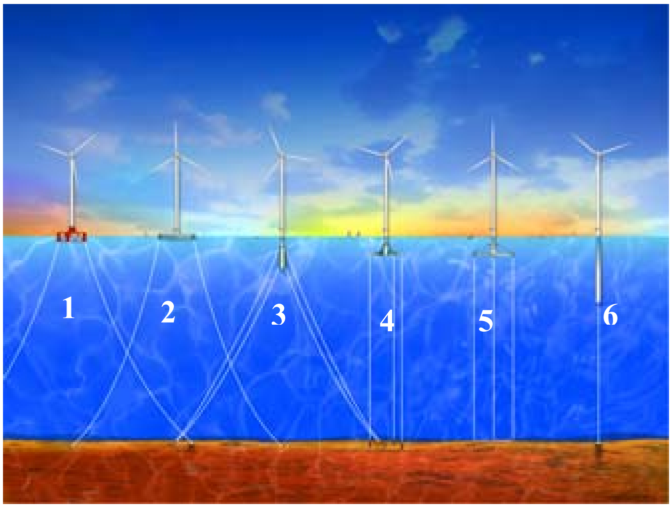

Figure 9 – Floating Deepwater Platform Concepts

Figure 9 shows a wide range of platform architectures that are being considered for floating offshore platforms. Platform types are labeled numerically in the figure (from left to right): 1) semi-submersible Dutch Tri-floater [21], 2) barge, 3) spar-buoy with two tiers of guy-wires [22], 4) three-arm mono-hull tension leg platform (TLP), 5) concrete TLP with gravity anchor [23], and 6) deep water spar [19,20].

Some preliminary studies have been done already to assess floating systems but none of the public studies to date have attempted to optimize the platform cost and geometry [21,24].

The wind turbine platform and mooring system should provide the most potential for system cost reduction because the application is new and the most significant cost saving design tradeoffs have not yet been explored. However, a solid basis from which to determine the optimum design has not yet been established.

Many of the same issues that govern oil and gas platforms will also be present in the design of wind platforms, but the importance of each variable will be weighted differently. There are a vast number of possible offshore wind turbine platform configuration permutations when one considers the variety of available anchors, moorings, buoyancy tanks, and ballast options in the offshore industry. Unfortunately, designers will find that most of the resulting topologies will have some undesirable aspects that could drive the system cost out of range for wind applications. The optimum platform probably does not exist due to real-world constraints, but there are many features that such a platform would embody that most designers could agree on. To narrow the range of options, a study is now underway at the National Renewable Energy Laboratory (NREL) to compare each platform design to features that an optimized platform should have. From this comparison, we can begin to determine the key issues that limit each platform type and that will direct future study in this area. Some of the variables to be assessed are identified by Butterfield et al [25] and are given below:

- Requirements for design tools and methods- controls complexity
- Buoyancy Tank Cost/Complexity/Material options
- Mooring Line System Cost/Complexity/Options
- Anchors Cost/Complexity/Options
- Load Out Cost/Complexity/Options/Requirements
- On-site installation requirements
- Decommissioning and maintainability
- Corrosion Resistance requirements – coatings, cathodic protection, etc.
- Depth Independence/ Specify depth range
- Sensitivity to Bottom Conditions / Specify limitations
- Required footprint (as a function of depth)
- System Weight Sensitivity/ CG sensitivity
- Induced Tower Top Motions - Wave Sensitivity- Allowable heal angle
- First Order Costs for Candidate Configurations

Butterfield also provided a framework for assessing various platform concepts on the basis of how a platform type achieves static stability. This approach argues that static stability and a range of associated operational and technical factors largely determine the first order economics of a floating platform. An optimization study to determine the lowest cost platform architechture will follow from these analyses.

Technologically, it is recognized that the commercial undertaking of floating wind turbines will be a bold step, but is necessary to unlock an additional 500-GW of offshore wind energy potential in the United States and become one of the major contributors to the world's electric grid [18]. However, it will require substantial experience in shallower water, with parallel and substantive research and development initiatives to realize this technology over the next 15 years.

Other Offshore Technology Challenges

Aside from the matter of substructures and foundations, a key area for development lies in the adaptation of the technology to the offshore environment. Current offshore wind installations in Europe are, ostensibly, extensions of land-based turbine technology and operating strategies that are functionally sound, but are not optimized for operation at sea. Offshore turbines must ultimately be re-engineered to accommodate multiple offshore environmental and logistical factors that address the effect of the offshore operating environment on the wind turbine, and the difficulty in working in it. Below, some of these areas are summarized.

Establish a Design Basis for Offshore Turbines. The best way to establish the requirements for an offshore turbine is to demonstrate the best technologies, down-selected from earlier optimizations at sea. This initiative should be done on a turbine test bed of representative scale to measure the true MET Ocean environment, loads, and actual permitting and environmental impacts. Ideally, this initiative should be conducted in the public domain to maximize its benefit to a wide industry base, including potential new entries from the offshore oil and gas industry. The output from such an effort would yield critical design methods and codes, uniform standards for structural reliability, design specification guidelines, industry accepted safety margins, and valuable data to validate design models, codes, and assumptions.

Offshore Design Codes and Methods. The development of accurate offshore computer codes to predict the dynamic forces and motions acting on turbines deployed at sea is essential before turbines can reliably be deployed. One of the immediate challenges common to all support structure designs is the ability to predict loads and resulting dynamic responses of the coupled wind turbine and support structure when subjected to combined stochastic wave and wind loading. Where the offshore oil industry primarily is concerned with wave loading when extrapolating to predict extreme events, offshore wind turbine designers must consider wind and wave load spectrums simultaneously [26, 27].

Additional offshore loads arise from impact of floating debris and ice and from marine growth buildup on the substructure. Offshore turbine structural analysis must also account for the dynamic coupling between the translational (surge, sway, and heave) and rotational (roll, pitch, and yaw) platform motions and turbine motions, as well as the dynamic characterization of mooring lines for compliant floating systems [28].

Minimize Work at Sea. Much of the success of land-based turbines can be attributed to the ability of designers to reduce the initial capital cost of turbine components while maintaining or improving overall reliability. The experience from on-shore wind development demonstrated good accessibility to turbines and therefore relative ease of maintenance. Therefore, added capital investment to reduce the long term O&M burden is not generally tolerated for on-shore systems due to the lack of a demonstrated life-cycle payback model and the desire to keep initial project costs low. However, work at sea is significantly more costly and time consuming and the on-shore O&M model will not provide the best economical option. New offshore strategies must be developed that minimize work done at sea, requiring a paradigm shift that takes into account all aspects of the project. Materials must be selected for durability and environmental tolerance. Designs, starting with the preliminary concepts, must rigorously place a higher premium on reliability, float-out deployments, and in-situ repair methods. Fabrication facilities must be strategically located for mass production, on-shore assembly, and rapid deployment with minimal large vessel dependence. Operators must be remotely equipped with intelligent turbine condition monitoring and self-diagnostics systems to manage O&M weather windows, minimize downtime, and reduce the equipment needed for up-tower repairs. Ultimately, a new balance between initial capital investment and long term operating costs will be established, which will have a broad impact on the COE for offshore wind technology.

Low Cost Anchors and Moorings. Cost-saving opportunities arise for wind power plants in deeper water with both fixed bottom and floating turbine foundations, as well as for existing shallow water designs where value engineering cost reductions can be achieved. Fixed bottom systems that favor rigid lightweight substructures, automated mass production fabrication facilities, and integrated mooring/piling deployments systems are envisioned as a possible low cost option. For floating systems, platforms that do not depend on mooring line tension as their primary means for achieving stability may be able to develop and capitalize on a new generation of drag embedment type anchors or vertical load anchors (VLA) to lower overall platform cost. Deployable gravity anchors show promise for all platform types. When multiple turbines are installed, economies-of-scale will allow developers to streamline repetitive installation procedures and look for innovative tooling that could not be justified under customized single installations.

Offshore Wind-Wave Measurements

Remote Measurement Systems. Unlike onshore data where extensive fixed-station continuously recorded anemometer data is available, the available measurements made for offshore wind are thinly distributed and more uncertain. The typical onshore method of making wind measurements from a MET mast is not feasible for a large number of sites due to the increased offshore cost. Anemometer based offshore windspeeds measurement systems consist of a sparsely distributed system of buoys and fixed C-MAN stations at the National Data Buoy Center (NDBC) operated by the National Oceanogrphic and Atmospheric Adminstration (NOAA). Buoy data is usually taken at 5 m above sea and is insufficient for regional mesoscale model validation, or to characterize the wind regime at a particular site. Alternative methods are needed to measure windspeed at multiple locations, and to determine wind shear profiles up to elevations where wind turbines operate. This will require adaptation of equipment such as SODAR, LIDAR, and coastal RADAR based systems combined with more stable buoy systems or fixed bases. Some systems are under development but have not fully been proven in these applications.

Hybrid Windspeed Database. Validation of offshore mesoscale models and site assessments to determine energy capture potential for a given site will require the use of a wide range of alternative databases [29]. Data from different agencies and entities can be compiled to characterize the coastal and offshore wind regime. Ultimately, the industry may depend on more accurate mesoscale models to make siting decisions and to assess wind project risk.

Wind Farm Turbulence and Array Effects. To achieve high penetrations of offshore wind, multiple wind power arrays will be installed over significant portions of the ocean. To supply 10% of the U.S. electric energy supply would influence an ocean area of approximately 20,000 km^2. Interference from one wind farm to another could introduce downstream turbulence and upset energy capture predictions. Flow models and measurements to determine the turbine-to-turbine influence and the aggregate influence of multiple turbines are needed to accurately determine the economic and structural consequences of wind large-scale offshore wind deployment.

Offshore Turbine Weight Reductions. Future offshore turbine designs may take advantage of several methods to reduce weight (and cost) that have been rejected for land-based systems because of acoustic emissions or aesthetics. For floating systems, the benefits of weight reduction are multiplied as a reduction in weight aloft also reduces the weight of the buoyancy and mooring systems. Offshore wind turbines will enable relaxed constraints on aerodynamic blade noise allowing higher tip-speeds, and resulting in lower nacelle weights. Higher rotational speeds allow smaller blade planform and lower blade weight for the same energy output. Higher speeds mean lower input torque and lower gear ratios, and hence, smaller shafts and gearboxes. Direct drive generators can be made smaller for higher rotational speeds and show promise for future turbines. The heaviest component above the water-line is by far the steel tower. Lower thrust loads and alternative lightweight materials and designs may significantly lower tower weight. Weight reductions may also be realized in the platform and foundation where, for example, lightweight concrete aggregates can reduce weight 40% below standard mixtures.

Electric Grid and Systems Integration. The offshore grid will have unique characteristics that will warrant in-depth studies and modeling including fault and stability analysis. A systems approach to wind farm turbulence, array stability, and array aggregation will be the focus of extensive research needed for wind plant optimization. Offshore wind forecasting and the reliable prediction of power fluctuations will also be critical. New grid code and security standards will be established for offshore wind. Control and communication systems of large offshore wind farms will need greater attention due to the inaccessibility of remote offshore turbines, which may lead to new grid architechures.

Ultra-large Turbines. No consensus exists yet on how large offshore wind turbines will become although most wind engineers agree that there is no hard physical limit preventing 10-MW turbines or greater. With turbine costs representing only one third of the life cycle cost of the wind project, and transportation and erection limits eased offshore, turbine growth will continue until overall system costs are minimized. The substructure and foundation costs appear to favor larger turbines, as mobilization of the installation and service equipment is a major cost driver. Fewer turbines means lower geotechnical costs, fewer electrical terminations, more generating capacity per ocean area, less interturbine cable length and trenching, and fewer service trips to and from towers.

As turbine size increases, new opportunities will become available and should be evaluated. For example, control systems and sensors that monitor and diagnose turbine status and health will not grow in cost as turbine size increases. But for the same cost fraction, larger turbines will enable a much higher level of controls and condition monitoring intelligence. In a similar way, larger turbines may also allow wind to move into other technologies such as light-weight super-conducting generators that become more cost effective with size.

Larger turbines will have significant implications for future research needs, test facilities, and infrastructure requirements. For example, no facilities currently exist anywhere that can perform the necessary testing for a 10-MW wind turbine blade, although the first 100-m blade test facility is under construction in Denmark at this time [30].

Environmental and Regulatory Issues

By comparison to other forms of electric power generation, offshore wind energy is considered to have relatively benign effects on the marine environment, according extensive analyses conducted by the European Community[3]. However, regulatory and environmental uncertainties have hindered the approvals for the first offshore wind projects in the United States and for the early years of development may have a greater influence over the pace of industry growth than the technical issues presented above.

Regulatory Framework for Wind Energy. Though the offshore wind industry has over a decade of experience in Europe, the United States did not have any project proposals until 2001 with the Cape Wind Associates project in Nantucket Sound [31]. Moreover, there were no firm national policies for offshore wind developments until the summer of 2005 with the passage of the Energy Policy Act of 2005. This is a case where projects were proposed before policies were in place.

On August 8, 2005, President Bush signed into law the Energy Policy Act (EPAct 2005, PL 109-58) granting the Minerals Management Service (MMS) within the Department of the Interior (DOI) new responsibilities over renewable energy and alternate uses of offshore public lands [8]. Prior to the passage of this legislation, the U.S. Army of Corp of Engineers (ACE) assumed the lead for coordinating the approval process for the first applications. For the last 40 years, MMS has regulated the offshore oil and gas industry and other mineral extraction activities in federal waters, also known as the Outer Continental Shelf (OCS). This new regulatory authority granted to MMS will evaluate compatible uses of the OCS, establish fair economic compensation for projects in federal waters, evaluate potential impacts to marine resources, and involve other federal and state agencies in the review and approval of future wind power permits.

The new authority does not supersede or modify existing authority of any other federal agency. It does not change any of the exclusions of the moratoria areas for oil and gas drilling. In addition, the regulatory regime will not apply to areas designated as National Marine Sanctuaries, National Parks, National Wildlife Refuges, Sanctuaries, National Parks, National Wildlife Refuges, or any National Monument. The project siting process will have to take into account these exclusion zones and a range of legal authorities affecting the OCS [32].

Given their experience in the oil and gas program and sand and gravel mining, MMS has a wealth of experience in siting and managing activities on the OCS. They do not, however, have a depth of understanding about wind resources or the wind energy industry. DOE and MMS will be signing a memorandum of understanding to facilitate cooperation between the two government entities for exchanging technical information relating to offshore wind energy R&D activities, engineering principles of wind turbines and their components, and certification procedures for the turbines and the entire structure.

In addition to the MMS and ACE, there are two other key federal agencies involved with ocean boundary jurisdictions, including the independent Federal Energy Regulatory Commission (FERC) and the National Oceanic and Atmospheric Administration (NOAA). FERC jurisdiction stems from their authority regarding electric transmission rights for approval of power supply contracts and connecting to the landfall cable. Most recently, FERC has assumed additional authority over ocean technology projects with a license requirement for wave power. NOAA, within the Department of Commerce, has jurisdictional authority to protect and manage marine sanctuaries. Any projects in or around a marine sanctuary or any protected area will be subject to NOAA review and approval.

There is a multitude of other federal and state agencies involved with ocean uses and management that have a role in the approval process for offshore wind projects. Generally, these roles and responsibilities are well defined, but there are numerous areas where these responsibilities overlap and even conflict. This could create a web of approvals and consultations that would delay projects and not necessarily contribute to better siting or management of offshore wind energy projects. Now MMS has the authority to strike a better balance between the development of the offshore wind resources and competing commercial and natural resource interests.

The new MMS authority to develop a new regulatory paradigm for offshore wind facilities, based upon Section 388 of the EPAct 2005, includes the following responsibilities:

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[3] For detailed analyses comparing the lifecycle costs of fossil, nuclear and wind power, see the EC reports at http://www.externe.info.

- Act as the lead agency for permitting offshore renewable energy projects, including wind.[4]
- Ensure consultation with states and other stakeholders.
- Grant easements, leases or rights-of-ways for uses of the OCS on a competitive basis.
- Pursue appropriate enforcement actions in the event that violations occur.
- Require financial surety to ensure that facilities constructed are properly removed at the end of their economic life (decommissioning).
- Regulate, monitor, and determine fair return to the nation with a reasonable payment for sharing revenue among coastal states within 15 miles of a project.

MMS is under a congressional mandate to develop new regulations by May 2006. The Advanced Notice of Proposed Regulation was just issued in December 2005 and public comments are being sought.

Potential Environmental and Socio-Economic Issues. The full range of potential environmental impacts from offshore wind is unknown today in the United States, since no projects have yet been installed. The only project evaluation thus far is the 3800-page Cape Wind draft environmental impact statement (DEIS) prepared by Cape Wind Associates, under the leadership of the ACE New England District. The document, released in November 2004, did not identify any significant impacts, but a range of specific mitigation measures and monitoring studies are proposed. The ACE held several public hearings, coordinated with 17 public agencies, and received over 5000 public comments. The extensive public involvement requirements along with the transfer of jurisdiction to MMS have slowed the permitting process significantly. Recently, MMS required that the Cape Wind DEIS be expanded to include construction and operational procedures, personnel safety, and decommissioning that fit a broader "cradle-to-grave" approach -- reflecting the new MMS program authority.

The only peer-reviewed information on potential environmental impacts from offshore wind is based upon lessons learned from land-based projects and European before-and-after-control-impact (BACI) studies for installed projects. Though there is over 15 years experience with offshore wind facilities in Europe, most of the projects were quite small (less than 10 turbines) and there were not scientifically credible siting criteria, study methodologies, and mitigation strategies established. Given the higher growth rate in Europe and significant deployment plans for the next 10 years, there is now a proliferation of studies and standards.

The most credible and broad-based environmental studies in Europe for commercial facilities are based upon the Horns Rev and Nysted projects in Denmark. These 2 sites have 80 and 72 turbines, respectively. Both sites have government-sponsored BACI studies with oversight from an international scientific panel reviewing the methods, design plans, and findings from three-year post-construction evaluations. The Danish studies did identify several significant temporal impacts during the construction phase. The pile driving and increased transportation requirements, for example, created noise and disturbance to the marine environment. Consequently, they documented short-term impacts to marine mammals as they dispersed away from the area when noise levels increased. In order to mitigate these temporal impacts, pingers were used before construction began to scare away any mammals in the area to reduce the impacts of the construction noise. Satellite tracking devices and porpoise detectors were attached to the seals and porpoises to verify their movements. Since the mammals returned to the area during the operational phase, these impacts were considered "insignificant." The actual impact to the mammals for feeding and molting is considered unknown since it is very difficult to ascertain the physical impacts on mammals in the wild and the subjects would have to be tracked for several seasons for a more definitive survey[5].

There are now thousands of pages of scientific material relating to the ecological effects of offshore wind sites in Europe and the United States. A discussion of the range of environmental effects and findings along with issues related to the competing uses of the ocean is beyond the scope of this paper. To give the reader a sense of community priorities, public opinion may shed some light. A recent survey of residents of Cape Cod, MA near the proposed Cape Wind project conducted by the University of Delaware identified the following as the most important concerns [33]: Impacts on marine life, aesthetics, fishing impacts, boating and yachting safety. Unfortunately, some of these public concerns have been heightened by poorly researched media anecdotes rather than documented factual information.

The installation of wind turbines also provides some beneficial effects to the local community and ecosystem. The turbine foundations placed onto or buried into the seabed create artificial reefs or breeding grounds that have a beneficial effect on local fish populations and benthic communities. Danish studies indicate that socio-economic impacts may be positive. Over 80% of the respondents in a recent Danish study have a "positive attitude towards the establishment of new offshore wind farms." There were, however, some concerns about the visual externalities of turbines when they can be seen from the shore (generally, less than 10 km). In the case of the Horns Rev wind site, over 1700 man-years of local jobs were created during the construction period and 2000 man-years created over the 20-year life of the projects. Approximately, one fourth of these jobs were locally based. The multiplier effects are associated with the construction activities and the manufacturing of materials as well as indirect effects from demands of inputs from goods and services.

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[4] The new authorization also includes jurisdictional authority over alternative energy, such as wave, solar, and current power as well as marine related uses of the existing infrastructure and a coastal assistance program that are not addressed in this paper.

[5] For details on these studies see the Horns Rev environmental reports at http://www.hornsrev.dk/Engelsk/default_ie.htm .

Realistically, there is no form of electric generation that can claim to be completely benign with respect to the environment. To provide a fair assessment of the alternatives, the environmental impact of a generating facility should be compared to the impact of an equivalent power plant using a competing fuel source with the same capacity. When this comparison is conducted, the potential impacts of offshore wind to the environment appear to very benign [34].

Summary

An overview of the present status offshore wind energy showed the industry in its infancy but with the potential to become a major contributor in the U.S. electric energy market. Since over half of the cost of an offshore wind energy power plant is outside the wind turbine itself, the offshore industry would be the primary beneficiary from this new energy source. If offshore energy predictions are achieved, offshore wind could result in over $100 billion of revenue to the domestic offshore industry over the next 30 years. The offshore would receive this revenue in the form of construction, site assessments, subsea electrical, inspections, service, and operation contracts. The technical issues and design challenges needed to achieve economic competitiveness for near term deployments in shallow water below 30-m depth were described, as well as the requirements for future technologies needed to deploy systems in deeper water beyond the current depth limits. New regulatory authority was granted to the Minerals Management Service in 2005 and this new regulatory system was discussed. Offshore wind shows very low impacts to the environment but regulatory and environmental barriers have hindered the first offshore wind projects in the United States.

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This paper provides an overview of the nascent offshore wind energy industry including a status of the commercial offshore industry and the technologies that will be needed for full market development. It provides a perspective on the status of the critical environmental and regulatory issues for offshore wind and how they are affecting the formation of the U.S. industry.

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