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A review of offshore wind technology and the development of the Virginia coastline and Outer Continental Shelf

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A Review of Offshore Wind Technology and the Development of the Virginia Coastline and Outer Continental Shelf

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Dedication:

I would like to dedicate this thesis to my parents who have always been there to support me and help me fulfill my dreams and goals.

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Abstract:

Offshore wind power is an increasingly viable resource that is being considered by many coastal States in the U.S for development. This thesis provides a recommendation concerning the foundations that will be needed for the construction of offshore wind farms off the coast of Virginia. To accomplish this I reviewed current and prototype underwater foundation technologies in order to establish viable options for developers to use. I was also able to analyze a case study that conducted "an analysis and survey of the experiences and lessons learned by developers of offshore wind farms" in Europe. This case study focuses mainly on early planning and construction lessons that were learned by European offshore wind developers on prior projects. It explains that most project costs and mistakes could be reduced or averted given sufficient and appropriate pre-project planning.

I have also reviewed the proposed offshore wind projects planned along the east coast of the United States. This review includes an analysis of the federal regulations that are involved in developing in offshore waters. This thesis also evaluates state and local laws in Virginia and reviews the state sponsored research program supported by the Virginia Coastal Energy Research Consortium. By compiling this information I am able to recommend that monopole and truss foundations with suction pillons be used for the development of offshore waters. Water depth and sediment type must be taken into account when choosing which foundation is best suited for a particular location. These two foundation types offer minimal seabed preparation and the lower cost per installation as compared to other foundations.

Chapter 1: Introduction

Rising energy prices, petroleum supply uncertainties, and protecting the environment are some of the biggest concerns the United States is currently facing. These concerns have generated an interest in alternative sources of electricity that can be used to develop power for the United States. As oil continually becomes a variable commodity, the U.S. will need to find alternative sources of energy to secure the economy and to meet the ever growing demands of the country and preserve price stability. One such source of energy that has a strong potential for use is offshore wind energy. Currently, offshore wind power is almost a completely untapped resource in the United States due to it being a relatively young and new technology. While Federal and State governments have recently started to support the growth of the offshore wind industry, there is still a lot of research that needs to be done.

As more knowledge is cultivated on offshore wind technology, European and U.S. wind developers have continually been innovative in the process of laying down the groundwork for the construction of new offshore wind farms. European wind farms have provided a large amount of data concerning offshore underwater wind foundations and the placement of offshore wind turbines. While information on wind turbine foundations and their placement in Europe is readily available, research concerning the development of the U.S. Outer Continental Shelf (OCS) and the Atlantic coastline of Virginia is still in the process of being collected. The development of the U.S. coasts is important because they will provide United States with clean renewable energy as well as create new jobs and opportunities.

A major challenge that should be noted for offshore wind farm development is the topography of the locations in which they are proposed to be built. When choosing a location, developers must take several factors into account when selecting the most effective and cost efficient foundation for use. This process includes collecting topographical and sediment information on a proposed site. This is due to different soil types, layers, and water depth greatly affecting the style and type of foundations that are capable of being installed at a certain location. While some of this data is readily available it must be confirmed before any site preparation or construction can take place.

By reviewing available offshore wind turbines and determining which offshore wind turbine foundations that would be best suited to Virginia's Atlantic coastline, Virginia will be able to lead the way in offshore development. If Virginia is able to install offshore wind farms it will reduce the state's CO_2 emissions from coal and oil fired power plants. With a reduction in CO_2 emissions, Virginia will be able to help lead the way in developing long term sustainable solutions to our ever growing energy needs. The Department of Energy, DOE, has set a goal that by 2030 20% of the U.S.'s energy will be from wind. Virginia can be a critical player in assisting the DOE in reaching this goal, if offshore wind farms are cultivated now. Along with providing clean and renewable energy offshore, wind farms will also provide jobs for Americans across the country.

The current foundations and prototypes that are being used and researched in the offshore wind industry will vary according to the changes in water depth off the coast of Virginia and the OCS. Wind developers are currently in the process of researching and developing new and inventive designs in order to push the boundaries of current day wind farm limits. With new designs and technologies continually being tested, the wind industry is constantly expanding and looking at new locations that can be developed in the future.

In order to learn from past mistakes American offshore wind developers have kept a close watch on the development and construction of wind farms in Europe. European developers have spent the last two decades developing multiple offshore wind farms and learning through trial and error. The lessons learned will be instrumental in the construction of new wind farms here in the United States. This will not only save States and individual investors money but will also decrease the amount of time it will take to implement their plans for new offshore sites.

With wind power and offshore wind farms now being actively pursued by states in the U.S., it has attracted the interest of European wind developers. Due to this interest, multiple states have engaged in contracts or are in negotiations with developers in order to develop the East coast of the U.S. If built, these wind farms could provide power to thousands of homes in each state with clean and renewable energy.

The growth of these new wind farms has also caused wind developers to become knowledgeable on federal and state policies regarding leasing and land rights. By becoming familiar with wind policies for waters controlled by the Federal government and States, developers are becoming well versed in the methods in which contractors must proceed. As these new wind farms are being planned, Virginia has taken steps in order to help with their growth. One of these steps was the formation of the Virginia Coastal Energy Research Consortium. This consortium is dedicated to the research and development of alternative resources for the State of Virginia and is extremely pro-active in helping to move the process forward.

The objective of this thesis is to compile the information reviewed above and provide a recommendation of which types of turbine foundations should be used in the development of the Virginia coastline and the OCS. This recommendation will include an analysis of the Virginia's offshore borders and jurisdictional rights off the coast. It will also offer a review of the bathymetry of Virginia waters and the OCS as well as examination of the sediment types that currently make up the seabed in these locations. With this data, developers will be able to determine what foundations should be examined for use in the development of Virginia's offshore waters.

Narrative Outline:

The objective of this thesis is to provide a recommendation of which types of foundations should be used for the development of wind farms in Virginia's offshore waters. This thesis will begin with the first chapter focusing on the introduction to offshore wind and how it can lead to cleaner and more efficient energy generation for the State of Virginia.

In chapter 2, this thesis will focus on reviewing available offshore wind turbines and determining which offshore wind turbine foundations would be best suited to Virginia's Atlantic coastline. This section of the thesis will analyze foundations that are currently in use and being researched by the offshore wind industry. By reviewing the technologies that are currently available and being prototyped, this chapter will give wind developers and idea of which types of turbines are available for Virginia's offshore waters.

The next chapter of this thesis is focused on the planning and construction of eight wind farms that have been built throughout various parts of Europe. This section will focus on the general planning and construction process that was undergone during the development of these wind farms. Chapter 3 will also review lessons that were learned during the completion of these wind farms and what future developers should pay close attention too during the planning and construction phases. By learning from the mistakes made in the past this will allow future developers to save time and money in the development of offshore wind farms.

Chapter 4 of this thesis will focus on the current day development of wind farms off the coast of the United States. With the successful development of wind farms offshore in Europe, States and private developers are becoming more interested in developing the waters off the U.S. coast. Chapter 4 will review the current wind projects and developers that are pursuing contracts through States for the development of offshore wind farms. This chapter will also focus on the federal policies and regulations that go into the development of Virginia's waters and the Outer Continental Shelf.

The 5th chapter covered in this thesis will evaluate the local and State government water sovereignty rights for the State of Virginia. It will also review the research consortium known as VCERC which is a research organization that is funded by the State of Virginia to advance the research and development of alternative resources for the State. This research group is extremely pro-active in advancing Virginia's goals of generating more clean and efficient energy.

The final chapter in this thesis will combine the information from the previous chapters in order to compile a recommendation for the State of Virginia. This recommendation will cover what types of foundations should be considered for use in the development of the Virginia coastline and Outer Continental Shelf. The 6th chapter will also discuss the different factors that will need to be considered when forming a recommendation on the type of foundations that could potentially be used for the development of Virginia's offshore waters.

Chapter 2: Current Turbines and Foundation Technology in Use by the Offshore Wind Industry

Offshore wind turbine foundations are one of the only real problems left with building wind farms offshore. The main problem that arises in this area is making a cost effective foundation that can support the weight of the turbines currently being used for offshore wind farms. In the past foundations have proven to be very expensive and have made offshore wind energy production a costly investment. With advances in technology, new turbines and foundations have been designed in order to cut cost and allow for the competitive development of offshore wind power. This chapter will examine turbines from four different offshore wind turbine manufacturers as well as the five foundations that are currently in use. These foundations are the gravity, monopole, suction caisson, tripod, and suction piles.[1] Along with these five foundations, this chapter will also discuss deepwater concept designs and prototypes.

Turbines Currently In Use:

The four most widely known manufactures of offshore wind turbines are Siemens, REpower, Vestas, and Areva-Multibrid. The turbines provided by these companies range in size producing between 2.0MW to 5MW of electricity per turbine and can have tower heights ranging from 59m to 100m high.[2] This section will briefly discuss the technical specifications of the turbines that are available from these manufactures in order give a reader a better idea of the stress's and loads that an offshore wind foundation must be capable of sustaining.

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1 Breton, S. P. and G. Moe, 2008: Status, plans and technologies for offshore wind turbines in Europe and North America. In press: Renewable Energy

2 REpower Systems AG: Wind Turbines [cited 11/4/2009 2009]. Available from http://www.repower.de/index.php?id=12&L=1.

Siemens:

Siemens Wind Power is a German based company that currently provides four different sizes of offshore wind turbines that can be purchased for use. The smallest wind turbine provided by Siemens is the SWT-2-3-82 VS. This wind turbine is capable of producing up to 2.3MW of electricity and is ideally suited for locations with noise restrictions. Once mounted on top of an offshore wind turbine foundation, this turbine can have a tower height of up to 80m high with the rotor having a total diameter of 82.4m. The mass of the rotor, nacelle, and tower that are used for this design weigh out to approximately 294 tons.[3]

The largest turbine that is offered by Siemens is the SWT-3.6-107. This turbine is capable of producing up to 3.6MW of electricity and is the most powerful turbine that is offered by Siemens for both offshore and onshore wind energy production. The SWT-3.6-107 wind turbine requires a tower height of 80m high, which can vary based on site specific information, and is designed to have a rotor diameter totaling 107m. Overall, the mass of the nacelle and blades for this design weigh out at 220 tons. In addition to this weight, an underwater foundation must also be able to take into account the mass of a tower that must be capable of holding up the nacelle and blades.[4]

REpower Systems:

REpower Systems currently offers only one turbine for offshore use. This turbine is known as the M5. The M5 offshore wind turbine is capable of producing up to 5MW of

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[3] Siemens AG - SWT-2-3-82-VS [cited 11/4/2009 2009]. Available from http://www.energy.siemens.com/hq/en/power-generation/renewables/wind-power/wind-turbines/swt-2-3-82-vs.htm.

[4] Siemens AG - SWT-3-6-107 [cited 11/4/2009 2009]. Available from http://www.energy.siemens.com/hq/en/power-generation/renewables/wind-power/wind-turbines/swt-3-6-107.htm.

electricity and utilizes a tower ranging between 90m and 100m high for offshore locations.[5] In order to produce this much energy the M5 offshore wind turbine has a rotor diameter of 126m and weighs 410 tonnes excluding the weight of the tower.[6]

Vestas:

Vestas is another manufacture in the wind industry that produces wind turbines. The V80-2.0MW wind turbine is currently one of the smallest sizes offered by Vestas for both onshore and offshore use and is capable of producing up to 2.0MW of electricity. This turbine requires a tower height between 67m and 80m in height, depending on the site location, and supports a rotor diameter of 80m in length. In order to support the mass of a fully assembled V80-2.0MW turbine an underwater foundation must be able to handle between 223.5 metric tonnes and 261.5 metric tonnes of weight depending on the tower height used.[7]

The largest turbine that is currently being manufactured by Vestas for offshore use is the V90-3.0MW turbine. This turbine is capable of producing up to 3.0MW of electricity and is built to be installed on tower heights of 80m, 90m, and 105m in height with a rotor diameter of 90m. Upon completion the total mass of the V90-3.0MW tower, nacelle, and rotor can weigh 257.5 metric tonnes for an 80m tower, 317.1 metric tonnes for a 90m tower, and 367.1 metric tonnes for a 105m high tower.[8]

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[5] REpower Systems AG: 5M [cited 11/4/2009 2009]. Available from http://www.repower.de/index.php?id=237&L=1.

[6] Hanke, Katherine. 2004. *5M: Proven Technology in New Dimensions.* Hamburg, Germany: REpower Systems Group.

[7] *V 80-2.0MW*.2009. Portland, Oregon: Vestas.

[8] *V 90-3.0MW*.2009. Denmark: Vestas.

<u>Areva-Multibrid:</u>

Areva-Multibrid is another wind turbine manufacturer that specializes in large offshore turbine production. This company currently offers one turbine for offshore wind farms titled the M5000. The M5000 offshore wind turbine is capable of producing 5.0MW of electricity and is designed to be mounted on top of a 100m tower. Excluding the tower weight, the turbines mass including the blades, hub, and nacelle can add up to 308.9 metric tonnes.[9]

Foundations Currently In Use:

Currently, there are five different foundations that are being used by the wind industry for the installation of wind turbines offshore.[10] In addition to these foundations there are also multiple foundations that are in the process of being developed, researched, and prototyped. The five most common and tested foundations can be seen below in figure 1:

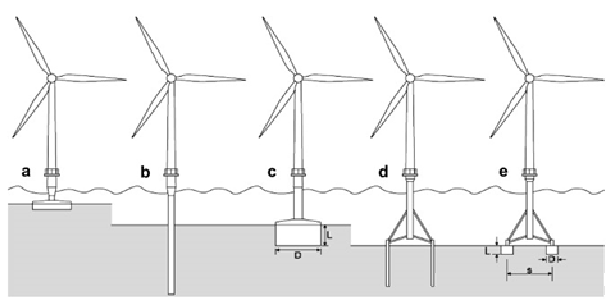

Figure 1 : Current foundations in use for offshore wind turbines.[11]

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9 Areva - Multibrid GmbH: Technical data [cited 11/4/2009 2009]. Available from http://www.multibrid.com/index.php?id=9&L=1.

10 Breton, S. P. and G. Moe, 2008: Status, plans and technologies for offshore wind turbines in Europe and North America. In press: Renewable Energy

11 [Ibid 10]

a) Gravity

b) Monopole

c) Suction caisson

d) Tripod

e) Suction piles[12]

<u>Gravity:</u>

Concrete Gravity:

Concrete gravity foundations were originally the first type of foundations that were used for the construction of offshore wind turbines. The first offshore wind pilot project was built in Denmark and used concrete gravity caisson foundations. These concrete caissons are built in dry docks onshore and floated to their final destination and then filled with gravel to achieve the necessary weight needed. The only real disadvantage to using concrete for gravity foundations is that the cost of using concrete is proportional with the water depth squared. According to the quadratic rule the concrete platforms tend to become prohibitively heavy and expensive to install at water depths above 10m.[13]

Steel Gravity:

An alternative to using concrete gravity foundations is to make them out of steel. Steel gravity foundations are lighter that concrete foundations and use a cylindrical steel tube placed on a flat steel box on the sea bed. Finished foundations must have a final weight of 1,000 metric tons. Of this weight the steel structure will only weight about 80-100 metric tons at water depths between 4 and 10m. Relatively low weights allow for barges to transport and install multiple foundations quickly. In this instance the same crane can be used to install

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12 Velkommen [database online]. Denmark, 2009 [cited 06/10 2009]. Available from http://www.windpower.org/en/tour/rd/concrete.html.

13 [ibid 12]

the foundations and the turbines. The base of a circular turbine, with a 65m rotor diameter, should have a foundation of 14m x 14m or a diameter of 15m for water depths between 4-10m. The advantage of a steel gravity foundation is that the foundation can be built onshore and may be used on all types of seabeds. For the installation of these foundations though some seabed preparation is required.[14] Silt must be removed and a smooth horizontal bed of shingles must be prepared by divers before the foundation can be placed at the site.[15]

<u>Monopole:</u>

Steel Monopole:

Steel monopole foundations are the most commonly and widely known foundation that is currently in use. Most foundations consist of a steel pile with a diameter between 3.5 and 4.5 meters. This pile is driven between 10 and 20 meters into the seabed depending on the type of soil they are being installed into. The mono pole foundation effectively extends the turbine tower underwater and into the seabed. One important fact to note about monopole foundations is that no preparation of the seabed is needed. The only downside is that heavy pile driving machinery will be necessary for the installation. These types of foundations should also not be installed in areas with large amounts of boulders in the seabed. In the case that boulders are encountered it is possible to drill down to them and use explosives in order to clear a path through them. The type of seabed and ocean conditions that the monopoles will be installed in can also affect the size of the monopole. These conditions can range from pack ice to the size of the waves that the foundation will

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[14] Velkommen [database online]. Denmark, 2009 [cited 06/10 2009]. Available from http://www.windpower.org/en/tour/rd/gravitat.html

[15] [Ibid 14]

encounter. Once these conditions are determined they can help decide how thick the foundation walls should be.[16]

Concrete Monopole:

Concrete has also begun to be used in the construction of monopole foundations. The reasons for this include the fact that concrete monopoles are inexpensive to build compared to steel monopoles and is much less vulnerable to price fluctuations than steel. Concrete also currently has an unlimited fabrication capacity along with a wide range of suppliers.[17] A few other advantages include that concrete monopoles have a reduced amount of underwater noise during their installation and can be used in various types of soil including area with boulders. Currently, designs for concrete monopoles include 3.6 and 5 MW wind turbines in waters of up to 30 meters.[18] The dimensions of these foundations can be seen below in table 1:

Table 1: Dimensions of 3.6 and 5 MW concrete monopole foundations.[19]

Dimensions	3.6 MW	5.0 MW
Outer diameter (mm)	6500	6900
Wall thickness (mm)	500	700
Pile length (m)	61	64
Weight (tons)	1450	2200

Concrete monopole foundations are fabricated using pre-cast reinforced concrete ring elements. Upon completion of monopole foundations they are then transported by floating them to the offshore site. During the installation process floating monopoles are upended using a Svanen crane and proven work methods. These foundations are then positioned on the seabed using the Svanen's guiding frame. Once the monopoles settle on

[16] Velkommen [database online]. Denmark, 2009 [cited 06/10 2009]. Available from http://www.windpower.org/en/tour/rd/monopile.htm
[17] [Ibid 16]
[18] The prefabricated concrete drilled monopile. in Ballast Nedam Offshore [database online]. Denmark, 2009 [cited 06/16 2009]. Available from http://www.offshore-energy.nl/page_10352.asp.
[19] [Ibid 18]

the ocean seabed they will sink in a couple meters due to their weight. From this point a drilling machine is installed inside the monopole which consists of a steel cutting shoe to cut through soil, creating an overcut. This overcut is filled with self hardening drill fluid. Once drilling starts the monopole will be continuously lowered until it reaches the appropriate depth. At that point the drill is removed and the drilling fluid hardens. Some advantages to using this method are that the drilling machine used during the installation process includes a cutter head and is designed to drill through various types of soil layers. The diameter of the cutting head is extendable and enables the machine to drill inside and under the monopole.[20] This enables it to excavate in two dimensions and allows for boulders in front of the cutter head to be destroyed. The installation of 128 foundations at the "Foundation Concepts Kriegers Flak Wind Farm" allowed for an average price of €500,000 for a 3.6 MW turbine and €400,000 for a5.0 MW turbine.[21]

<u>Suction Caissons:</u>

The suction caisson was discovered by the company "Senpere and Aubergne" who was using them for mooring anchors for large tankers off the coast of Denmark. With a renewed interest in offshore wind technology these foundations are being looked at very closely. These foundations are commonly used in shallower waters but have recently started being deployed in waters as deep as 1000 m by the offshore oil and natural gas industries.[22] This type of foundation has been described as an upside down bucket and is installed by lowering the suction caisson down to the seabed where the weight of the caisson is used to partially sink it in. Once the caisson has settled into the seabed a pump is attached to the

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[20] Velkommen [database online]. Denmark, 2009 [cited 06/10 2009]. Available from http://www.windpower.org/en/tour/rd/monopile.htm

[21] The prefabricated concrete drilled monopile. in Ballast Nedam Offshore [database online]. Denmark, 2009 [cited 06/16 2009]. Available from http://www.offshore-energy.nl/page_10352.asp.

[22] Sukumaran, B. *Suction Caisson Anchors - A Better Option For Deep Water Appliations.* Glassboro, New Jersey: Rowan University. Available from http://users.rowan.edu/~sukumaran/personal/publications/swe1.pdf

head. As suction is applied the caisson will slowly pull itself deeper into the seabed. These actions are shown below in figure 2. These foundations can also be easily removed by reattaching the pumps at the end of the foundations lifetime and applying pressure inside the caisson.[23] Suction caissons are currently thought to be a better alternative to using driven piles. The reason for this is the suction caissons durability and ease of manufacturing. Suction caissons reduce the need for heavy lift vessels allowing for reduced installation time and procedure. They also allow for a more controlled process than when driving piles during the installation process. The installation process allows for the anchors to be accurately placed in specific spots for wind turbine foundations. One other advantage to suction caissons is that they provide a greater resistance to vertical and lateral loads that driven piles and anchors due to their larger diameters.[24]

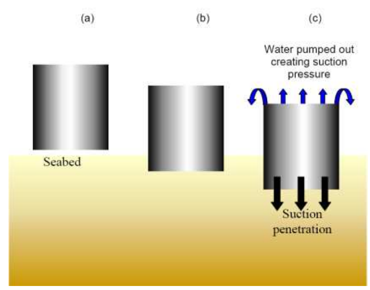

Figure 2: Installation sequence of suction caissons.[25]

<u>Tripod:</u>

The technology for tripod foundations is based off of that used in the oil and natural gas industries. During the installation process the turbine tower attaches to a steel frame and absorbs the forces being put on the tower and distrubutes them between three steel piles.

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23 Houlsby, Guy T., and Bryon W. Byrne. 2000. Suction Caisson Foundations for Offshore Wind Turbines and Anemometer Masts. *Wind Engineering* 24, no. 4:249. Available at http://www-civil.eng.ox.ac.uk/people/gth/j/j52.pdf

24 Sukumaran, B. *Suction Caisson Anchors - A Better Option For Deep Water Appliations.* Glassboro, New Jersey: Rowan University. Available from http://users.rowan.edu/~sukumaran/personal/publications/swe1.pdf

25 [Ibid 24]

These steel piles are driven 10-20 meters into the seabed depending on the soil conditions. This type of foundation is mainly only used in deeper waters and is not suitable for water shallower than 5-6 meters. The reason for this is that service vessels at low water depths will face problems on approaching the foundation due to the frame. One advantage other than being able to be used at deeper water depths is that the tripod foundation requires that only minimum site preparation is needed before installation. The only real disadvantage to using the tripod foundation is that the towers are anchored into the seabed with small steel piles. These piles make it so that that tripid foundation is not suitable to areas with large amounts of boulders in the seabed.[26]

Suction Piles:

Suction piles work along the same linse as suction caissons. Piles used in this type of installation are large and typically around 6 m in diamter and up to 30 m in length. They have steel walls between 20 mm and 30 mm and usually have cross pieces for stiffening at the end and across the lid.[27]

Once completed suction piles usually weigh between 60 and 100 tons. [28]

One of the main advantages to using suction piles is that they can be fabricated in relatively simple facilities and require a steel roller and welders. Depending on the situation in which the suction piles will be used different shapes can be made. An example of this would be making the piles into wedges in order to make for easier stacking on installation vessels or the addition of stubby winged cylinders on the sides which can be used to create additional lateral resistance in the ground. Suction piles can be used as almost any depth as

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26 Velkommen [database online]. Denmark, 2009 [cited 06/10 2009]. Available from http://www.windpower.org/en/tour/rd/tripod.htm

27 Greeman, Adrian. Seabed Sucker. in New Civil Engineer [database online]. 2006 [cited 06/18 2009]. Available from http://www.nce.co.uk/seabed-sucker/484196.article.

28 [Ibid 27]

acnhors for offshore wind farms. At installations of around 1000m currents have shown to be minimal. This allows for suction piles to be lowered down and positioned through GPS. Once the foundations reach the ocean floor the weight of the piles will usually push them about 5 m into the seabed. A detachable pump and monitoring skid are mounted on top of the pile in order to provide feedback and information on the installation process.[29] Suction piles can also be installed in clusters for more support. This can be seen below in figure 3:

Figure 3: Suction pile cluster.[30]

Deep Water Foundations and Designs:

Jacket:

Jacket foundations are commonly known as truss towers and are being explored as a new type of foundation for offshore wind. These towers, which are commonly seen on land, are shown below in figures 4 and 5:

[29] Suction Pile Cluster. in Specialized Offshore Contractor [database online]. 2009 [cited 06/19 2009]. Available from http://www.suctionpile.com/bin/ibp.jsp?ibpDispWhat=zone&ibpPage=S8_FocusPage&ibpDispWho=S8_Personnel&ibpZone=S8_Bedrijf&ibpDisplay=view&.

[30] [Ibid 29]

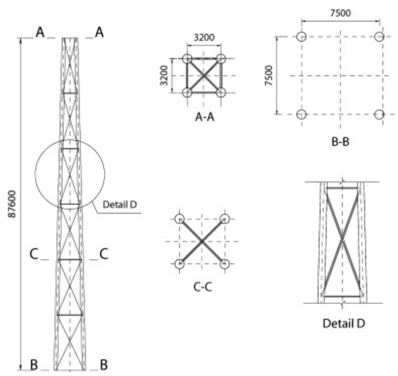

Figure 4: Layout of a truss tower.[31]

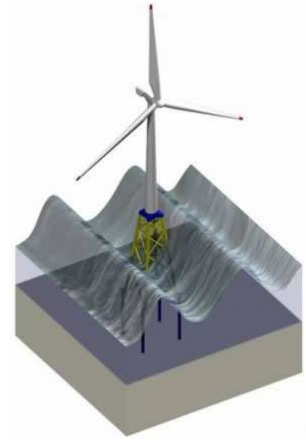

Figure 5: Jacket Foundation.[32]

These towers have already started undergoing intesive modeling and testing and so far can be installed in waters as deep as 60m. At this point natural frequencies, static stresses, and buckling have been tested and the results were satisfactory. Along with passing preliminary studies truss towers have also been shown to weigh half of what a monopile tower would. This decrease in weight can also play a large role in the reduction of cost in transportation and installation .[33] One other advantage to the jacket foundation is that minimal to no seabed preperation is needed.[34]

Mooring Line Stabilized:

Mooring line stabilized foundations are also known as "tension leg" stabilized foundations and are currently still being researched. These foundations are very similar to the ballast stabilzed foundations that are discussed below. The mooring line stabilized turbines are fixed in place with tension leg platforms and suction gale anchors. These

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31 Breton, Simon-Philippe, and Geir Moe. 2009. Status, plans and technologies for offshore wind turbines in Europe and North America. *Renewable Energy* 34, no. 3:646.
32 Jacket Foundation. in BlueHUSA [database online]. 2009 [cited 6/17 2009]. Available from http://www.bluehusa.com/.
33 [Ibid 31]
34 State of The Art Offshore Wind Technology. in Vestas [database online]. 2000 [cited 06/15 2009]. Available from http://www.offshorewind.de/page/fileadmin/offshore/documents/Vestas_presentation_State_of_the_Art_Offshore_Wind_Technology.pdf.

turbines are somewhat lighter than ballast stabilized wind turbines which allows for more motion of the tower. If the motions of the tower are not controlled they can lead to catostrophic impacts. Currently the mooring line stabilized foundation requires extremely expensive and heavy foundations in order to prevent motion.[35]

Bouyancy Stabilized:

Bouynacy turbines are one the lesser known foundations still being researched. This type of foundation uses a stabilized barge on the surface of the ocean in order to support the wind turbines. The barge itself is stabilized with cantenary mooring lines attached to anchors on the seabed. This type of foundation has not found wide practical use yet due to its susceptability to large waves and large motions due to waves. While some have tried to design these foundations based after oil and natural gas technologies the gyroscopic motion of the turbine side to side has made this difficult. In order for this design to work effectively developers have signaled that new designs for the foundations, towers, and turbines need to be found in order for them to work effectively.[36]

Ballast Stabilized:

Ballast stabilized foundations or spar bouys are one of the concept offshore foundations currently being researched. While this type of foundation is known to be very stable it is also known for its high cost.[37] In test being done in Europe a utitity sized wind turbine application can require

a ballast of up to 2,400 tons for stabilization. This large amount of ballast is used to create a center of gravity at the bottom of the turbine which adds increased cost from other types of foundations due to the heavy machinery that will be required to work with it. While the

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35 Challenges of Offshore Wind Energy. in Nautica WindPower [database online]. Olmsted Falls, OH, 2009 [cited 06/14 2009]. Available from http://nauticawindpower.com/index_files/Page668.htm.
36 [Ibid 35]
37 [Ibid 35]

ballast is what allows the wind turbine to stay upright and stable there are also two cantenary mooring lines that are used in order to hold the turbine in a particular spot out at sea.[38] Currently, there is a ballast stabilized concept being investigated by the company StatoiHydro. The foundation for this prototype will be using ballast below the center of the buoy as discussed above to provide balance. From there catenary mooring lines are used in order to keep the system in place. StatoiHydro is planning on using a 5 MW wind turbine with a 123 m blade diameter and placing it in 81.5 m of water. This prototype is being tested for water depths between 200 and 700 m and can be seen below in figure 6:[39]

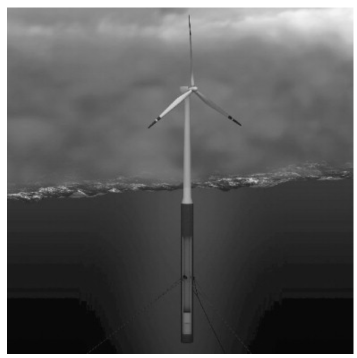

Figure 6: StatoiHydro Prototype Ballast Stabilized Foundation.[40]

[38] Challenges of Offshore Wind Energy. in Nautica WindPower [database online]. Olmsted Falls, OH, 2009 [cited 06/14 2009]. Available from http://nauticawindpower.com/index_files/Page668.htm.
[39] Breton, Simon-Philippe, and Geir Moe. 2009. Status, plans and technologies for offshore wind turbines in Europe and North America. *Renewable Energy* 34, no. 3:646.
[40] [Ibid 38]

Prototype Foundations:

Titan 200:

The Titan 200 offshore wind foundation was developed by Offshore Wind Power Systems of Texas. The foundation used for this design is a tripod foundation as seen below in figure 7:

Figure 7: Titan 200 prototype wind turbine.[41]

The Titan 200 offshore wind turbine foundation can be deployed in water up to 200 feet deep. What makes these turbines so unique is the fact that they are self installing and do not require any heavy cranes or lifting. The platforms are assembled on land and from there they are towed to their destination. Once they are located above the site they are to be installed at the platforms legs are lowered to the sea floor. As the legs hit the seabed they are ballasted down. This causes them to continue to sink into the seabed until they reach their proper depth. The vessel holding the turbine then begins to raise the turbine above the water line causing and air gap between the turbine and the water. This practice is used in the oil and natural gas industry and has proven reliable. Installation problems for the Titan are also easily taken care of. The jack up design used for the titan allows for use in uneven bottoms, different soil conditions, and obstructions below the surface. The titan legs can be rotated or

[41] Titan 200. in Offshore Wind Power Systems of Texas [database online]. Grapevine, Tx, 2009 [cited 06/18 2009]. Available from http://offshorewindpowersystemsoftexas.com/titan_200_deep_offshore_platform.

repositioned on the same centerline and reinstalled if an obstruction if found below the surface.[42]

Blue H Prototype:

The Blue H prototype was designed by the Blue H Group and can be installed in waters between 10 and 15 miles from shore in depths between 50m and 200m. This type of floating foundation uses a tension leg platform and was adapted from the oil and natural gas industries technology. The prototype, which is shown below in figure 8, uses a two blade rotor design.[43]

Figure 8: Blue H floating wind turbine.[44]

SWAY Prototype:

The SWAY prototype is currently being developed by the SWAY Corporation. This prototype is a cross between a ballast stabilized and a mooring line stabilized platform. This prototype foundation is currently being tested for a 5 MW wind turbine. This turbine is expected to be installed in waters between 80 and 300m deep. The tower for the SWAY turbine is set to extend 100 m underwater from the surface and will require a ballast of about 2,000 tons at the bottom in order to stabilize it. Attached to the bottom of the wind turbine

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42 Titan 200. in Offshore Wind Power Systems of Texas [database online]. Grapevine, Tx, 2009 [cited 06/18 2009]. Available from http://offshorewindpowersystemsoftexas.com/titan_200_deep_offshore_platform.

43 Offshore Wind Turbine Foundations - Current & Future Prototypes. in OffshoreWind.net [database online]. 2008 [cited 11/19 2008]. Available from http://offshorewind.net/Other_Pages/Turbine-Foundations.html.

44 Blue H Floating Turbine. in Blue H USA [database online]. 2009 [cited 06/18 2009]. Available from http://www.bluehusa.com/.

is a single tension leg line that holds the turbine in the correct position.[45] A picture of the SWAY prototype can be seen below in figure 9:

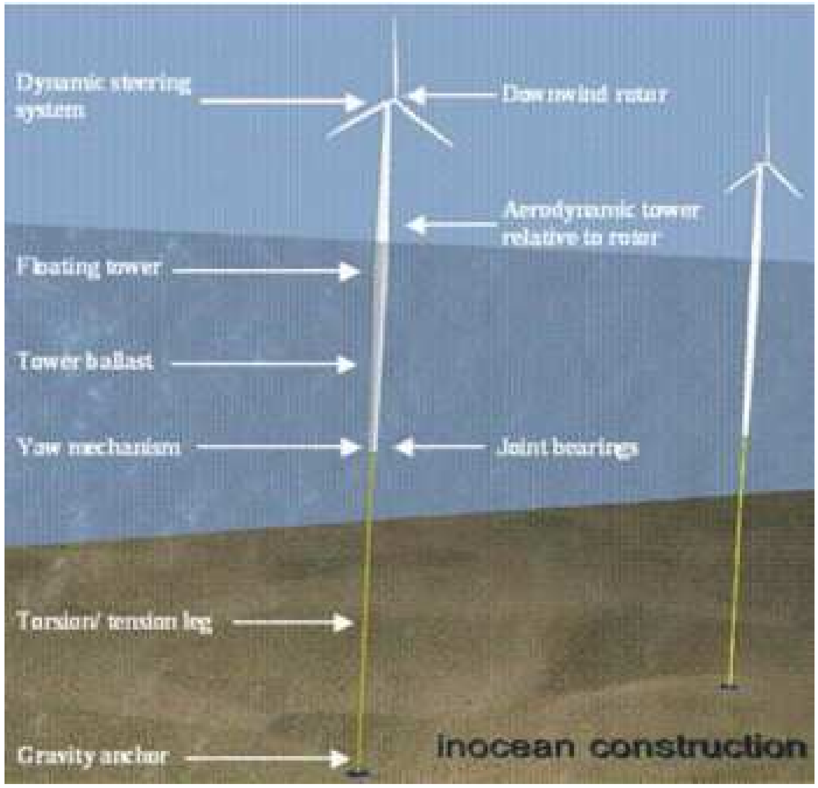

Figure 9: SWAY wind turbine prototype.[46]

[45] Breton, Simon-Philippe, and Geir Moe. 2009. Status, plans and technologies for offshore wind turbines in Europe and North America. *Renewable Energy* 34, no. 3:646.
[46] SWAY Changing the Future Of Wind Power. in SWAY [database online]. 2009 [cited 06/16 2009]. Available from http://www.sway.no/.

Chapter 3: European Wind A Review of Mistakes and Lessons Learned

The fast paced growth of the European wind industry has led to a number of offshore wind farms being planned and completed in a short period of time between 1990 and the early 2000's. With the fast pace of development of these wind farms there were problems and situations that occurred during their progress that could have been avoided earlier on due to increased studying and planning. This section of the thesis will review a case study of eight different wind farms located throughout Europe and provide the lessons learned and recommendations for future wind farm projects. By analyzing the mistakes and lessons learned from European developers the U.S. wind will be able to save time and money in the development of the United States coast. The wind farms analyzed in this section are located in Belgium, Denmark, Germany, Great Britain and the Netherlands. The wind farms being looked at will include:

- Egmond aan Zee - Netherlands
- Thornton Bank – Belgium
- Borkum West - Germany
- Butendiek – Privately owned but within Germany EEZ
- Greater Gabbard - UK
- Horns Rev - Denmark
- Nysted - Denmark
- Scroby Sands – UK[47]

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[47] Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

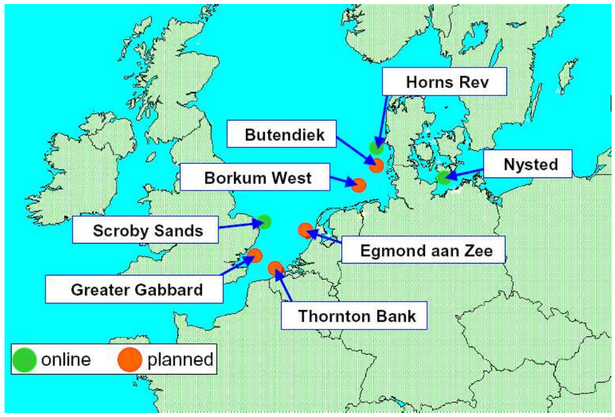

Figure 10: Location of wind farms being analyzed.[48]

Egmond aan Zee:

The offshore wind farm Egmond aan Zee, also known as OWEZ, was the first wind farm to be built in the North Dutch Sea. The wind farm is owned and financed by NoordzeeWind and was developed by Bouwcombinatie Egmond. These companies were brought together by Shell Wind Energy, Nuon Renewable Energy, Ballast Nedam Infra, and Vestas. The Egmond aan Zee wind farm was initially started in 1997 when the Dutch government decided that it needed to start a pilot Dutch offshore wind project. During that time and up till 2002 the project had to go through a rigorous policy and government approval process including an Environmental Impact Assessment (EIA) for the possible location of the farm and provide a Key Planning Decision (KPD) procedure. In 2002, NoordzeeWind was selected as the developer of the wind farm. Once this was done another EIA was conducted in order to study the spatial configuration of the wind farm. Construction of OWEZ was scheduled to begin in March of 2006 with final completion of

[48] Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

the project by the end of the year. As part of its contract NoordzeeWind is also required to dismantle OWEZ after a period of 20 years.[49]

During its different phases of planning and construction OWEZ provided important knowledge and lessons for the Netherlands. An important note to make is that OWEZ was a pilot project and in that sense was meant to be used in order to provide information to improve current policy, government, market, and public experience with the installation and use of offshore wind. A study done of OWEZ showed that government involvement in selecting sites for offshore wind farms and defining leasing conditions was crucial. The study also showed that it is within the interest of the government and developers to install some degree of freedom and flexibility in the decision making processes. Due to changes made later in the planning process with OWEZ developers were limited to 36 wind turbines for the site when more could have been installed using the same site dimensions. It was also noted that environmental conditions were not difficult to deal with during the project but that future research should be applied to expand the current knowledge of environmental consequences and the management of offshore wind farms. Overall, the case study of the Egmond aan Zee offshore wind farm showed that the Dutch are still in the early stages of developing their offshore wind resources and that government involvement can be very helpful in the realization of an offshore wind farm.[50]

Thornton Bank:

Thornton Bank wind farm was the first wind farm project to be built in Belgium. The site selection and project proposal for this wind farm was done by a private company

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[49] Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

[50] Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

known as C-Power. During the planning process the Thornton Bank wind farm was initially proposed to be built close to the shoreline.[51] Due to environmental concerns the government decided to move the wind farm father offshore to 27-30km from the Belgium coast into an area they have specifically designated for the location of Belgium offshore wind farms. At the site location the wind turbines were estimated to be built in water depths of 10 to 24 meters.[52]

With the increased distance to shore developers were worried about the economic viability of building the wind farm. This caused the Belgium government to subsidize 30% of the cost for grid connection and rendering guarantees for energy sales prices.[53]

The construction of the Thornton wind farm was planned to take place over three different phases. The first phase of the construction process was to act as a pilot project for the wind farm and involved the installation of six wind turbines. Belgium officials planned this phase in order to study the environmental impact of installing the turbine foundations. The second phase of the project involved the installation of 18 more turbines in 2009 for a total of 24 wind turbines. The final stage in the Thornton Bank wind farm will involve 36 additional turbines for a total of 60 wind turbines and a generating capacity of up to 300 MW depending on whether 3.6 or 5 MW turbines are used.[54]

Overall, the Thornton Bank wind farm had three issues that affected its development. Due to the government's decision to move the wind farm so far offshore and to complete a pilot project the developers were faced with increased cost for grid connection. The third issue that affected the development of the Thornton Bank wind farm

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51 Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

52 [Ibid 51]

53 [Ibid 51]

54 [Ibid 51]

was the lack of knowledge on soil conditions at the project site. With the Belgium governments decision to move the wind farm farther offshore developers were not able to get up to date soil conditions before beginning construction.[55] This problem is explained to have been caused mostly by lack of government experience and was rectified through financial adjustments from the government. The major lesson learned from the construction of this wind farm was that early site investigation at an early stage and follow up investigations to obtain as much soil data as possible are very important in the engineering process.[56]

Borkum West:

The Borkum West wind farm was the first offshore wind farm project undertaken by Germany. The project was initially stalled due to due to approval problems with the grid connection sea cable and started official project planning in 1999. The Borkum West wind farm site location was found by following a set of main precautions:

- Keeping sufficient distance from both shipping traffic routes
- The location must not be a avifaunistic or other biological specifically important area
- Located north of the 54th degree of latitude to avoid fishing conflicts
- Provide a large distance to the East Frisian Islands to avoid interference with tourism.[57]

Once the site for the offshore wind farm had been chosen extensive site screening of the avifaunistic and marine environment was undertaken. This study included looking at birds, fish, sea mammals, and other benthos in order to discover if construction and

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55 Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions. [Ibid 55]

56 [Ibid 55]

57 [Ibid 55]

operation would impact the site. The site investigation operated under the following schedule:

- Basic assessment involving two consecutive years of investigation without interruptions.
- Continuous monitoring will be conducting during the installation phase.
- Wind farm site is to be monitored for three to five years after operations commence.[58]

During the planning process the Borkum West wind farm was to be built in two different phases. The first phase was to be used as a pilot project with 12 wind turbines. This phase was completed by October in 2006. The second phase of the Borkum West wind farm is set to have an additional 196 wind turbines installed with the start of construction starting sometime in 2008 and 2009 with a completion date of 2011 or 2012. The pilot phase of the wind farm is set to produce 60 MW of electricity and a total of 1000 MW once the second phase is completed. Due to the grid connection problems the time frame for the construction and completion of the Borkum West wind park had to be moved back.[59]

From the beginning of the Borkum West offshore wind farm developers had been planning on using 5 MW wind turbines. Due to the transfer of ownership of the farm three different types of wind turbines ranging from five to six megawatts will be installed at the farm. The type of foundations to be used at the site selected for the Borkum West wind farm was also heavily investigated. Overall, during the planning process of the Borkum West offshore wind farm seven different types of foundations were considered. These foundations

[58] Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

[59] [Ibid 58]

were subjected to simulations of static waves, high wind gust, and dynamic load conditions in order to address fatigue effects over time.[60] Figure 11 below shows an example of the foundations that were considered:

Figure 11: Foundations considered for the Borkum West offshore wind farm.[61]

At the end of the test the tripod support structure foundation was found to be the most economical for the site location. [62]

Overall, the Borkum West offshore wind farm attempted to address areas of early planning that were known for stalling development. By doing this the developers were able to solve issues without too much delay in the process. An overlying problem that still needs to be addressed is whether or not the wind farm is located too far offshore to be economically viable or if it is the best economic solution for a pilot project.[63]

Butendiek:

The Butendiek offshore wind farm is located in Germany and is owned by private parties in the region of Schleswig-Holstein. This wind farm has 80 Planned Vestas 3MW wind turbines and a total generating capacity of 240 MW. The Butendiek wind farm was separated into two different phases. The first phase included the proposal for the wind farm to be subject to a project hearing in July 2001. Once the project hearing was completed and

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60 Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions [Ibid 59]

61 [Ibid 60]

62 [Ibid 60]

63 [Ibid 60]

approved the first phase of the project continued through the contracting of negotiations and financing and ended in the second half of 2005. The start of phase marks the start of the construction phase of the Butendiek offshore wind farm.[64]

Butendiek was initially invested in and started by nine private parties. These parties preformed the pre-project planning for the development of the offshore wind farm. During the planning process in order to increase public acceptance of the project the developers held public hearings at various locations and times to address concerns.[65] Initially the Butendiek proposal was reviewed by the appropriate public agencies and stakeholders and was instructed to provide different investigations of the site. These investigations included collision risk analysis and environmental impact assessments focusing on birds, fish, common porpoises, and benthos. During the three year planning process of phase one all the relevant investigations had been completed.[66]

<u>Lessons Learned:</u>

The Butendiek offshore wind farm brought to the attention of developers that there is a poor ratio between project cost and reimbursement. Developers are still currently looking for cheaper offshore foundations. Developers of this project also found that banks are too demanding in covering the project risk. All project risks are covered by expensive guarantees and high interest rates. This problem can be addressed by improving the financial situation and strategies of banks in Germany. A third lesson learned from the construction of the Butendiek offshore wind farm was that German project costs are higher than those in other countries like Denmark and the UK. The reasons for these cost come from the long

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64 Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

65 [Ibid 64]

66 [Ibid 64]

distances of the wind farms from the coastline resulting in cables with lengths of up to 100km from the site.[67]

Greater Gabbard:

The Greater Gabbard wind farm is located in the Outer Thames Estuary of the UK. This area has been identified by the British government as one of the three strategic regions for installing a second round of wind turbine farms. The wind farm is located about 23 km off the Suffolk Coast in two areas known as the Inner Gabbard and the Galloper. Water depths in this area range from 3.6m to 50m in depth. The Greater Gabbard wind farm is planned to have up to 140 wind turbines with an installed capacity of 500 MW.[68] This wind farm will be connected by underground cable to a new substation that is to be located in the city of Sizewell where it will be connected to existing 400 kV electrical lines. The turbines that are to be used in the wind farm will vary between 3 and 7 MW. Overall, the Greater Gabbard wind farm is not expected to have turbines exceed a maximum tip height of 170m above sea level. The nominal hub height is expected to be 105 m with a 130 m rotor diameter. [69] The Greater Gabbard wind farm location can be seen below in figure 12.

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[67] Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

[68] [Ibid 67]

[69] [Ibid 67]

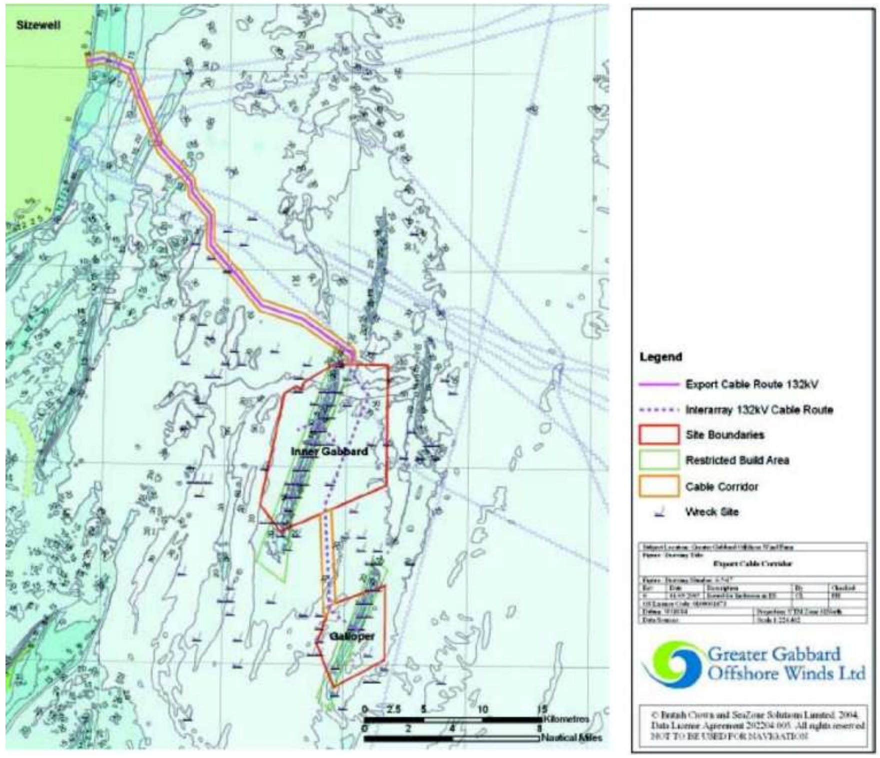

Figure 12: Location of Greater Gabbard offshore wind farm and shore connection cables to Sizewell.[70]

The timeline for the Greater Gabbard had the wind farm begin construction onshore in 2007 and to begin offshore production in 2008. Overall, the construction of the farm is scheduled to be completed in 2009. The Greater Gabbard wind farm was a joint venture project between the companies Airtricity Ltd. and Fluor Ltd. In addition to the regular planning stages of the project the developers also applied for several legislative safety zones around their wind turbines.[71] These zones will prevent entry for non project vessels from approaching closer than 50m around each wind turbine and also prohibits trawling, aggregate extraction, dredging, or anchoring of any vessel within 500m.[72]

During the development of the Greater Gabbard wind farm developers went about several different methods in order to choose an appropriate site and get the support of the

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[70] Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

[71] [Ibid 70]

[72] [Ibid 70]

media and local population on their side.[73] During the site selection process the Greater Gabbard location was chosen for several reasons. These were:

- Good wind resources
- Distance from shore reduces visual impacts
- Low maritime recreation usage
- No significant bird concentrations around the site
- Few sites designated for nature conservation near the wind farm location
- Onshore electrical infrastructure was already in place
- Candidate ports for construction and operation were located nearby
- Seabed properties for support structures were good
- No known marine affects
- Little amounts of fishing in the location
- No Ministry of Defense or Civil Aviation objections.[74]

In October 2005, the Greater Gabbard Offshore Ltd. published their environmental impact assessment.[75] The environmental impact assessment was very thorough and covered each phase of the construction process from the first phases of construction all the way to the operations and decommissioning of the wind farm. Along with conducting the environmental impact assessment the Greater Gabbard developers also provided a commercial navigation and risk assessment. This assessment conducted a navigation survey in order to account for measured shipping activity in the region. In order to account for

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73 Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

74 [Ibid 73]

75 [Ibid 73]

some navigational hazards with ships the developers revised the site boundaries in order to reduce chances of collision, drifting, grounding, construction, and access.[76]

One question that did arise during the planning process of the Greater Gabbard wind park was the type of foundations that would be used to support the wind turbines. The environmental statement that was presented gave the developers three different options to choose from which included the driven steel monopile, driven steel multi-pile, and a concrete gravity base. For each of the foundations that could be used for this wind park the developers were able to derive the amount of time it would take for each foundation installation. The monopole foundations were found to take an estimated 4 and 6 hours for the installation of each pile. The multi pile foundations with three piles were estimated to take between 2-3 hours per pile. The gravity foundations were found to require a crane barge that would be used for the installation. Before the installation of the gravity foundations the seabed will need to have the top layer removed until a layer of undisturbed soil is found. This usually amounts to around 2 m of seabed being removed. The gravity foundations that could potentially be used for this wind park will have a width at the base of 36 m and a concrete mass of 4600 tons. Along with the concrete weight there will also be 11,500 tons of sand and stones that will also be used to ballast the foundation. Regardless of which turbine foundation that is used all turbines must be spaced apart by at least 650 m for energy reasons.[77] During the installation the transformer platforms and the wind turbines may be moved in order to account for differing electrical connection designs that are used for the wind park.[78]

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[76] Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

[77] [Ibid 76]

[78] [Ibid 76]

Grid Connection:

The grid connection for the Greater Gabbard wind farm to Sizewell was selected due to its spare electrical capacity in the existing network and distance to the wind farm site. For the transmission of the electricity from the wind farm, the Greater Gabbard will use up to four offshore transmission platforms to collect the cables.[79] The electricity will be transformed up to 132kV for transmission to shore through up to four export cables. Overall, the cables leading to shore will extend 42km and will be buried between 1-1.5m underground.[80]

Lessons Learned:

The Greater Gabbard wind farm was developed in a manner in which the company targeted stakeholders and worked on getting a very high public acceptance. Along with a successful marketing strategy the Greater Gabbard Winds Ltd also had a proven track record in building wind farms including the Arklow Bank Wind Farm in the Irish Sea. The company was also able to capitalize on the need to reduce emissions of greenhouse and acid rain gases and therefore push for the need to move toward a more sustainable future. By advertising in this manner Greater Gabbard Wind Ltd was able to capitalize on the fact that the economy of east England would benefit from the installation of the farm. The joint venture company was also able to reduce the arguments on the visual impact of the farm by installing the wind farm 23km offshore.[81] Adding on to this the location of the wind farm has low maritime recreation usage and does not interfere with any major bird concentrations or migrations.[82]

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[79] Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.
[80] [Ibid 79]
[81] [Ibid 79]
[82] [Ibid 79]

Horns Rev:

The Horns Rev wind farm was the first wind farm built in the North Sea by Denmark. The site for this wind farm was originally chosen as an option in the Danish Offshore Action Plan. . The farm is located on the Danish west coast near the harbor of Esbjerg and was developed by two different companies. The first company, Elsam, was in charge of operating the wind farm, building the foundations, and laying internal cabling. The second company, Eltra, was in charge of the offshore transformer substation, sub marine cable laying to land, and onshore cable connection to the transmission grid.[83] The Horns Rev wind farm is spread out over 20 km^2 and is located in water depths between 6 and 14 m. The wind farm is located exactly 14km from the west coast of Denmark and has its turbines arranged in ten rows of eight turbines.[84] The location of Horns Rev compared to the coast can be seen below in figure 13.

Figure 13: Location of the Horns Rev wind farm near the harbor of Esbjerg.[85]

[83] Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.
[84] [Ibid 83]
[85] [Ibid 83]

The Horns Rev wind farm began being planned out around 1998 and was completed in mid 2003. Originally the wind farm was scheduled to be completed in 2002 but was pushed back due to problems after the installation. During the planning phase of the project the developers wanted to install 80 turbines over a six stage period with the last phase installing ten turbines. From the beginning of the planning stages Elsam designed strict strategies with dealing with the media, internal communications, and conflict management. Setting down these strict rules allowed Elsam to successfully manage these portions of the project.[86]

Due to the close proximity to shore the Horns Rev wind farm was able to easily connect to major electrical grids through short distance underwater high voltage lines. Because of Eltras joint cooperation on the project with Elsam, Eltra was obligated to build and own the offshore connection cable to the onshore electrical grid.[87] With only a short distance to the shore the companies chose to use a high voltage alternating current system. This system is directly connected to the onshore electrical grid at 150kV. In order to reach this high voltage the mid level voltage of the farm is transformed by a transformer station located at sea near the wind farm.[88]

<u>Installation:</u>

During the installation phase of building the Horns Rev wind farm the companies Elsam and Eltra decided that they would perform some of the installation work themselves and also contract some of the work out to other companies. From this point different vessels were hired for the pile driving process, substation erection, and wind turbine

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86 Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

87 [Ibid 86]

88 [Ibid 86]

erection.[89] For the task of driving in the monopoles a jack up platform was used from Ballast Nedam with a heavy duty ram.[90] The jack up platform that was used can be seen below in figure 14.

Figure 14: Jack up platform from Ballast Nedam that was used to drive in the monopoles for the Horns Rev wind farm.[91]

For the installation of the substation a "Asian Hercules" crane was used to in order to lift the substation into place onto the piles that were driven in order to support it.[92] This can be seen below in figure 15:

Figure 15: Substation of Horns Rev being installed with an □Asian Hercules□ crane.[93]

89 [Ibid 86]
90 Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.
91 [Ibid 90]
92 [Ibid 90]
93 [Ibid 90]

As the monopole foundations and transition pieces were installed the wind turbines themselves were able to be attached. For the installation of the wind turbines the vessel "Ocean Hanne" was used to transport the turbines from the harbor and install them on top of the transition pieces. This part of the project was completed without any problems.[94] The crane vessel used for this part of the process can be seen below in figure 16:

Figure 16: The crane vessel "Ocean Hanne" which was used for the transportation and installation of the wind turbines.[95]

Lessons Learned:

During the development and construction of the Horns Rev wind farm there were many lessons learned that could be passed on to future developers. During the initial development of the site the tourism industry at first wanted the wind farm to be moved further offshore.[96] Their arguments were presented to the Danish Energy Agency which decided that the arguments were not valid. With this decision the tourism industry decided

[94] Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

[95] [Ibid 94]

[96] [Ibid 94]

to look at the wind farm from a positive aspect and have now built the farm into future tourism strategies and have received no complaints to date.[97]

A large problem that was encountered during the Horns Rev project was the use of prototype turbines. During the initial installation process improvements were forced to be made during later stages of the installations and also after completion of the wind farm. The main lesson learned from this was that the assembly and final checks of the wind turbines should be completed onshore before installation. This is due to the fact that the quality of the assembly is better and costs for fixing any problems are far less when fixing them onshore.[98]

During the installation and operation of Horns Rev developers also overlooked the harbor logistics of preparing and launching the wind turbines to be moved to their installation sites. Although the Horns Rev developers were able to keep their time table it was much more expensive for them to fix problems offshore than to delay the project and fix them onshore.[99]

Nysted:

The Nysted Offshore Wind Farm was included under the Danish Energy Authority and was constructed south of the coast of Lolland, Denmark in the Baltic Sea with the nearest town being Nysted. This wind farm was planned out alongside the Horns Rev wind farm that was constructed by Denmark in the North Sea. Upon reaching an agreement the Nysted Offshore Wind Farm was developed by two major Danish offshore wind companies named Elsam and ENRGIE E2 which used to be known as Elkraft. The Nysted wind farm

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97 Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

98 [Ibid 97]

99 [Ibid 97]

was installed with a total of 72 wind turbines each operating at 2.3 MW giving the wind farm a maximum generating capacity of 165.6 MW.[100] These turbines were installed over a 24 km^2 area and are located 9 km from the shore in water depths ranging from 6-9.5m deep.[101]

The planning, approval, and communication process for the Nysted Offshore Wind Farm was handled by ENERGIE E2 and divided up between two teams. ENERGIE E2 was in charge of the wind farm itself while SEAS Transmission was responsible for the transformer station at sea and the cabling from the substation to Lolland onshore. ENERGIE E2 also contracted out work for the design and constructing of 73 wind turbine foundations to the company Per Aarsleff A/S. The foundations chosen for this project were concrete gravity foundations. 72 of these foundations were used as supports for the wind turbines and the last one was used in order to support the transformer station. Due to the size of the project Per Aarsleff A/S worked in a joint venture with Ballast Nedam in order to deliver the foundations.[102]

One very important lesson learned from past wind farm development by these companies was media exposure. ENERGIE E2 published information regarding the Nysted Offshore Wind Farm in local newspapers, opened a visitor center, and created a website with information relating to the project and its effects on the following[103]:

- Background on offshore wind turbines and technical data relating to the Nysted wind farm
- Environmental data relating to the construction, operation, and decommissioning of the wind farm

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100 Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.
101 [Ibid 100]
102 [Ibid 100]
103 [Ibid 100]

- Sailing directions and maps
- Links
- Tours of the farm
- And press photos and reports[104]

While this project had extensive testing done in order to select the types of turbines and blades to be installed at the Nysted Offshore Wind Farm this part of the summary will focus on the selection of the foundations. During the selection process the developer had to take into account multiple conditions and loads that would affect the site of the Nysted wind farm. The wind turbine foundations for this site were determined by the following conditions:

- Turbine size
- Soil conditions
- Water depth
- Wave heights
- Formation of ice[105]

Due to the high concentrations of boulders located in the seabed at the Nysted wind farm site the use of monopoles was ruled out. Overall, the developers chose to use gravity foundations for the installation of the turbines. The reason for using gravity foundations was that the seabed located at the Nysted wind farm is mostly composed of stiff moraine clay.[106] This clay is suitable for gravity foundations because it has a high weight bearing capacity. The foundation sites varied from -7.5m to -12.5 meters down. These sites were prepared

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104 Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

105 [Ibid 103]

106 [Ibid 105]

with a hydraulic excavator which dredged mostly below the sea bottom of around 2m. In order to raise the foundations and provide more support each location was raised by the construction of a compacted stone bed.[107]

Due to the transportation and installation procedures of the Nysted wind farm site the concrete gravity foundations were required to be minimized. This was done by designing the gravity foundation in a hexagonal base structure allowing for six open cells along with a shaft and an ice cone at the top of it. This new design provided the foundations with a base dimension of 15m and a height of around 16.25m. The weight of these gravity foundations amounted to around a total of 1,300 tons. These concrete foundations were transported to the Nysted wind farm on barges where they were moved and installed by using an EIDE V crane barge.[108] This barge can be seen below in figure 17:

Figure 17: Crane barge EIDE V used for the installation and construction of the foundations and turbines for the Nysted wind farm.[109]

Once the concrete gravity foundations were put in place the six cells are then filled with heavy material to raise the foundation weight by an additional 500 tons. The added weight

[107] Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

[108] [Ibid 107]

[109] [Ibid 107]

was necessary to provide stability against the turbine sliding and turning over.[110] A diagram of the site preparation and the foundations used can be seen below in figure 18:

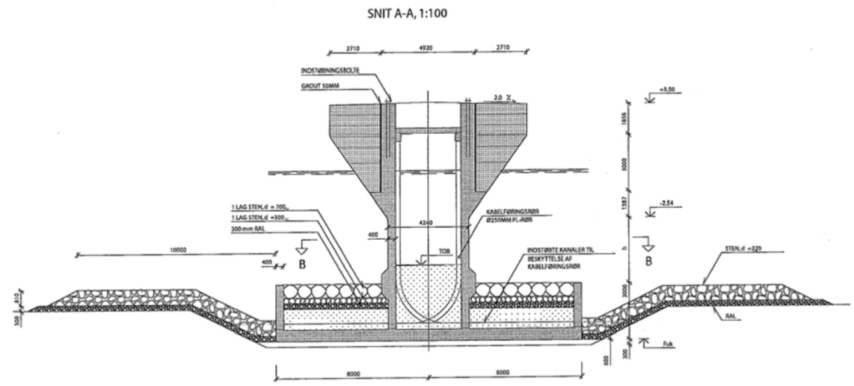

Figure 18: Diagram of site preparation and foundation of concrete gravity foundations used at Nysted wind farm.[111]

The concrete foundations for the Nysted wind farm were fabricated in Swinoujscie, Poland and transported by barges to the Nysted site. As mentioned above, upon arriving at the site these gravity foundations were then lowered onto pre-fabricated stone beddings. This can be seen below in figure 19. This figure shows the production site used for the creation of the gravity foundations in Poland.[112]

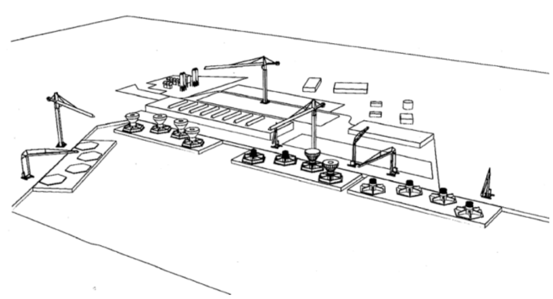

Figure 19: Diagram of fabrication and construction plant for concrete gravity foundations in Swinoujscie, Poland.[113]

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110 Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

111 [Ibid 110]

112 [Ibid 110]

113 [Ibid 110]

During the installation of these foundations four were loaded per barge and transported to the Nysted wind farm site.[114] Upon arriving the barge was then tied to a pre-placed anchors for the offloading of the foundations. Once the foundations were in place and ballasted down the turbines and blades were then erected and attached to them. During this installation process the developers were able to transport and install 72 turbines in 80 days allowing for the work to be completed one month ahead of schedule.[115]

Lessons Learned:

One of the main successes of the Nysted wind farm project was due to the fact that the developer had full access to the contractors design process and quality control. This allowed the developer to form a good relationship with the manufacturer from design and pre-installation through the commissioning process.[116]

Scroby Sands:

The last wind farm that will be discussed in this section is the Scroby Sands wind farm based in the United Kingdom. This wind farm is operated and owned by E.ON UK Renewables Offshore Wind Ltd. This wind farm was completed in 2004 and is located 2.5 km offshore of the Great Yarmouth on the east coast of Anglia. The farm is composed of 30 turbines which have a generating capacity of 60 MW. These turbines were installed in water depths between 5 and 10m deep.[117]

The foundations for this site were easily chosen due to the location and water depths. Gravity foundations were ruled out from the start of this project due to the fact that they were found to not be suitable to the Scroby Sands site location. In place of the concrete

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114 Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

115 [Ibid 114]

116 [Ibid 114]

117 [Ibid 114]

gravity foundations E.ON installed monopoles. The monopole foundation wall thickness and penetration depth was determined by using dynamic analyses.[118] These test included vibration behavior of the monopole along with loads put on them by winds and waves. The monopoles were designed to resist peak storm and fatigue loads for their operational lifetime. These foundations also had an integrated boat landing and access platform. During the installation process the turbines were pre-fitted with welded flanges and the top of them in order to connect the turbine. The monopoles were installed by having a hammer anvil placed on their heads and piled into the ground. For the installation of one foundation about 24 hours was needed.[119]

The Scroby Sands wind farm is also located on an enormous sand bank. This bank slowly changes over time as the currents move through the area. Due to this the developers decided to put in scour protection. This protection is used in order to keep the sand bed from shifting too much and exposing power cables and other lines. This protection consisted of stone which was unloaded from a barge.[120]

Lessons Learned:

The Scroby Sands wind farm was the first wind farm built in UK waters and was considered a successful project. Understandably the main obstacles that forced some delays in the project were the lack of experience and underestimations of the time required to plan and implement the project. The developers also learned important information concerning workers in the manufacturing and construction field. While jobs were initially created in

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118 Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

119 [Ibid 118]

120 [Ibid 118]

these fields developers found that once the site was completed the marketplace for those jobs and similar ones were either very small or not available.[121]

The developers also learned some lessons from the monopole installations. During the construction of this wind farm the developers had two different companies produce wind piles for the wind farm. The reason for this was to allow for lead time for the piles to be installed and for improved design changes. While installing the monopoles the developers also had to rent two different boats in order to perform the installation of the foundations. The reason for this was that one of the boats could not operate at low enough water levels for it to install some of the turbines.[122]

Overall Lessons Learned:

After briefly reviewing the eight wind parks listed earlier in this chapter the main lesson learned for future developers is in logistics and planning. It is essential that a wind farm should be thoroughly planned out before anything else is done. By doing this developers can find out what will be the most difficult parts of the installation and planning and make sure those sections get the attention that is necessary for an easy installation. One of the areas that needs increased planning is that of turbine testing and transportation. It is important that at least one turbine is fully erected and tested onshore. This is extremely important due to the fact that it will allow the developers and manufactures to catch any mistakes made in the design process as well as allow for changes in the design to be made. By doing this the developers can minimize the amount of offshore work that needs to be done. Developers should also attempt to complete as much assembly of the turbines

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121 Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

122 [Ibid 121]

onshore as well. This will reduce cost overall and will make maintenance and changes easier to implement.[123]

Developers also need to make sure that the logistics of transporting the foundations and turbines to the harbor being used for the installation process is well planned out. Many developers in the past have had to deal with serious mistakes in this process which has cost their companies millions of dollars. The harbors being used for the launching point of the foundations should also meet size requirements.[124] Developers have found in the past that harbors with not enough leased space have slowed down the installation process. An increase in size will allow installers time to pre-assemble turbines and will reduce cost over time. Developers should also be aware that harbors used for wind turbine assembly give priority to long term marine traffic. Adding in extra time for bad weather and other harbor traffic can be crucial in the preparation of installing offshore turbines. While developers have had difficulties in transporting and moving foundations to their locations they have not had any problems in testing and choosing which foundation would be best used for different sites.[125]

123 Gerdes, Gerhard, Tiedemann, Albrecht, and Zeelenberg, drs S. *Case Study: European Offshore Wind Farms - A Survey for the Analysis of the Experiences and Lessons Learnt by Developers of Offshore Wind Farms.* Vol. Final. Pusing Offshore Wind Energy Regions.

124 [Ibid 123]

125 Cape Wind:: America's First Offshore Wind Farm on Nantucket Sound. in Cape Wind Associates, LLC [database online]. 2009 [cited 06/28 2009]. Available from http://www.capewind.org/article24.htm.

Chapter 4: U.S. Coast Wind Farm Development and Federal Regulations

With the United States having access to four different coastlines it has a very unique opportunity when it comes to the development of offshore wind power. These waters include the Great Lakes, Pacific Ocean, Gulf of Mexico, and the Atlantic coastlines. With so many States having access to water, this gives the U.S. a distinct advantage over other countries when it comes to investing in offshore wind. Due to the nature of this thesis, this chapter will be focusing on the Atlantic coastline States and their current developments along with Federal guidelines that are being used to govern the development of these offshore wind farms.

Atlantic Coast Wind Farms:

Massachusetts Cape Wind

The Cape Wind offshore wind farm is the first proposed wind farm to be built in the United States. This wind farm is being developed by the company Cape Wind Associates and Energy Management Inc (EMI). The Cape Wind farm is currently being designed to have 130 wind turbines installed with a total generating capacity of 420 megawatts of clean energy. With this energy Cape Wind will be able to supply up to three quarters of the Cape and Islands electricity needs.[126]

Cape Wind Associates first applied for a permit with the U.S. Army Corps of Engineers in 2001. Soon after this time the Army Corps released a draft of the Environmental Impact Statement for the project. This draft was found to have deficiencies and problems by local communities and federal agencies causing the project to be slightly slowed down. During this review process the 2005 Energy Bill was passed. This energy bill

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126 Ebbert, Stephanie. Cape Wind Moves on to Federal Review. in The Boston Globe [database online]. Boston, MA, 2007 [cited 06/29 2009]. Available from http://www.boston.com/news/local/articles/2007/03/31/cape_wind_moves_on_to_federal_review/.

regulated authority for offshore projects from the Army Corps to the Minerals Management Service (MMS) which is a part of the Department of Interior. Originally the Cape Wind project was expected to obtain quick approval from the Army Corps to begin construction of the wind park. With the change in regulatory authority to the MMS the Cape Wind project was delayed. In 2007, the MMS released their Environmental Impact Statement draft to the public which was followed up by a 60 day comment and public hearing period. The final Environmental Impact Statement was released by the MMS on January 16, 2009. Financing for the Cape Wind project was set to be secured after leases for the project were obtained after March 21, 2009. Once construction of the Cape Wind Farm is started it is estimated to take 18 months to build with a completion date of sometime in 2010.[127]

Location:

The proposed site for this farm is located at Horseshoe Shoal which is located in Nantucket Sound, MA. and will be located three miles from the closest shore. Overall, the Cape Wind project will be the farther away from the nearest home than any other electricity generation facility in Massachusetts[128]. A map of the Cape Wind project can be seen below in figure 20:

[127] Ebbert, Stephanie. Cape Wind Moves on to Federal Review. in The Boston Globe [database online]. Boston, MA, 2007 [cited 06/29 2009]. Available from http://www.boston.com/news/local/articles/2007/03/31/cape_wind_moves_on_to_federal_review/.

[128] [Ibid 127]

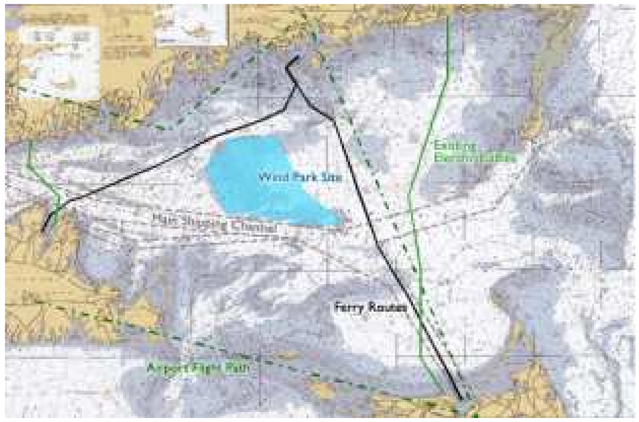

Figure 20: Map of the Cape Wind Project.[129]

<u>Cape Wind Details:</u>

The Cape Wind Farm is expected to have its turbines placed in a grid like pattern of parallel rows. In each of these rows the wind turbines will be placed 0.3 nautical miles apart with rows being placed 0.54 nautical miles apart. Each of the towers used for this wind park will extend from the water up to the center of the blades or hub height of 258 feet. The blades that will be attached to these turbines will have their lowest tip height at 75 feet above the water and their highest tip height at 440 feet above the water. In order to support these structures the foundations for the Cape Wind Farm will be monopoles. These monopoles will be 16 feet in diameter at their base and will be driven to 80 feet into the sandy seabed.[130]

Rhode Island DeepWater Wind

Rhode Island is in the process of developing an offshore wind park for clean energy generation. The developer, DeepWater Wind, is based out of New Jersey and is working with the State of Rhode Island to make this possible. Deepwater Wind has said that they are

[129] Project Siting and Visual Simulations. in Cape Wind Associates, LLC [database online]. 2009 [cited 06/29 2009]. Available from http://www.capewind.org/article7.htm.

[130] Ebbert, Stephanie. Cape Wind Moves on to Federal Review. in The Boston Globe [database online]. Boston, MA, 2007 [cited 06/29 2009]. Available from http://www.boston.com/news/local/articles/2007/03/31/cape_wind_moves_on_to_federal_review/.

hoping to provide 1.3 million megawatt hours of electricity per year which will cover about 15% of Rhode Island's electricity use. This project is expected to be built in 2 phases and expected to cost around $1.5 billion. During the first phase of the construction around 20 megawatts worth of generation capacity will be installed in Rhode Island State beginning later in 2010 with an expected operation date of around late June 2012. The second phase of the construction process will involve Deepwater Wind installing the rest of the planned wind turbines in offshore federal waters bringing the total generation capacity of the Rhode Island wind park to 1.3 million megawatt hours. In order to help convince Rhode Island on the deal Deepwater Wind also has pledged to establish one of their regional offices in Rhode Island and build a manufacturing facility in Quonset that would create up to 800 jobs with annual wages of around $60 million. Deepwater Wind will use the Quonset facility to produce the support foundations upon which the turbines and towers will be based.[131] Deepwater Wind has announced that they will be using Jacket foundations like those in the oil industry for its wind turbine foundations.[132]

New Jersey DeepWater Wind

New Jersey is hoping to become the first State in the U.S. to host deepwater offshore wind turbines. This project is part of an energy initiative by Garden State Offshore Energy to build a 350 megawatt wind farm 16 miles off the coast of New Jersey. The state is also hoping to expand with other wind parks after this project with a final generation capacity of

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[131] Rhode Island Chooses Deepwater Wind to Build Offshore Wind Farm. in RenewableEnergyWorld.com [database online]. Rhode Island, 2008 [cited 07/01 2009]. Available from http://www.renewableenergyworld.com/rea/news/article/2008/09/rhode-island-chooses-deepwater-wind-to-build-off-shore-wind-farm-53708.

[132] Nesi, Ted. R.I., Deepwater Sign Wind-Farm Agreement. in Providence Business News [database online]. R.I., 2009[cited 07/02 2009]. Available from http://www.pbn.com/stories/37176.html.

up to 3,000 megawatts or enough to cover 13% of New Jersey's total electricity needs.[133] An example of what these turbines will look like at a distance can be seen below in figure 21:

Figure 21: View of offshore wind turbines from shore at multiple distances.[134]

The New Jersey project was in part prompted by the change in federal legislations that allowed developers greater access to lands offshore. In the past wind developers were only limited to building in state waters which extend 3.5 miles offshore. With the new legislation wind developers can now expand out into federal waters which extend to around 230 miles out and onto the outer continental shelf. Currently, the Minerals Management Service is the federal agency with jurisdiction over the use of federal offshore lands. The agency has said that it plans to lease plots of the shelf to developers of wind farms and other renewable technologies.[135]

The wind farm being developed by Garden State Offshore Energy is expected to be built about 20 miles offshore with its closest turbine being around 16.2 statute miles from the Avalon coast. For this wind park Garden State Offshore Energy will also be partnering with the developer Deepwater Wind. Deepwater has already announced that it will be using

133 Waltz, Emily. Offshore Wind May Power the Future. in Scientic American [database online]. 2008 [cited 07/02 2009]. Available from http://www.scientificamerican.com/article.cfm?id=offshore-wind-may-power-the-future.

134 Richard, Michael G. New Jersey Approves Deep Water Wind Farm. in Treehugger [database online]. 2008 [cited 07/03 2009]. Available from http://www.treehugger.com/files/2008/10/new-jersey-deep-water-offshore-wind-farm-346-megawatts.php.

135 [Ibid 133]

the jacket or latticework foundation for the wind park instead of the traditional monopole foundation.[136]

Delaware Blue Water

Delaware is working on installing an offshore wind park off the coast of Rehoboth Beach. This offshore wind park is being developed by Delmarva Power and Bluewater Wind. These companies are hoping to provide 16% of their power from this offshore wind farm. The farm will be home to about 150 wind turbines and is estimated to cost upwards of $1.6 billion. Delmarva Power has estimated that enough electricity will be produced to light around 50,000 homes a year for the entire duration of its contract with power generation starting around 2012. The turbines to be installed for Delaware's wind farm should sit on a foundation about 250 feet above the waterline. The ocean is estimated to be around 75 feet deep with the foundation poles sinking 90 feet into the seafloor. These turbines will also be designed in order to withstand hurricane force winds. The blades mounted on each of the rotors will be about 150 feet long. Developers have created visual representations to show local and state officials what the wind farm will look like from shore.[137] One of these images can be seen below in figure 22:

136 Motavalli, Jim. New Jersey Wind Farm is Wind Energy Far Offshore. in TheDailyGreen.com [database online]. 2008 [cited 07/06 2009]. Available from http://www.thedailygreen.com/living-green/blogs/cars-transportation/offshore-wind-energy-new-jersey-461208.

137 Courson, Paul. Wind farm to be built Off Delaware shore. in CNN [database online]. 2008 [cited 07/07 2009]. Available from http://www.cnn.com/2008/TECH/06/23/wind.turbines/index.html.

Figure 22: View of offshore wind turbines from shore at multiple distances.[138]

Bluewater wind overview of Delaware:

Delaware has been interested in offshore wind energy generation for a long time. Recently State legislators passed energy legislations that require Delmarva Power to supply steady stable priced electricity to its consumers and to provide 20% of its total energy from alternative energy sources by 2019. With the passage of this legislation Delmarva Power negotiated a Power Purchase Agreement with Bluewater Wind. Bluewater is proposing to install a wind farm with a total generating capacity of around 450 megawatts of electricity. This wind farm is to be located 11.5 nautical miles from shore. At this distance the turbines should appear as faint lines on the horizon. Overall, the wind farm is expected to produce enough electricity for 110,000 Delaware households. Bluewater Wind is currently in the process of planning, verification, permitting, and construction which take around two years to complete.[139]

Federal Regulation of Water and the OCS:

In order to develop the water along the Atlantic coast and the OCS for offshore wind, wind developers must adhere to federal regulations and guidelines concerning the

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138 Murph, Darren. Offshore Wind Power Park to Energize Delaware Homes. in Switched.com [database online]. 2008 [cited 07/09 2009]. Available from http://www.switched.com/2008/06/29/offshore-wind-power-park-to-energize-delaware-homes/.

139 Background: How Bluewater Wind Came to Delaware. in Bluwater Wind LLC [database online]. 2009 [cited 07/10 2009]. Available from http://www.bluewaterwind.com/de_overview.htm.

leasing and use of these areas. The OCS surrounding the U.S. is managed by the United States MMS. The Federal government administers the submerged lands subsoil, and seabed, lying between the seaward extent of the United States jurisdiction and the seaward extent of Federal jurisdiction.[140]

Federal Jurisdiction:

Federal jurisdiction of waters off the coast of the United States is defined under accepted principles of international law. The seaward limit is defined by the MMS as the farthest of 200 nautical miles seaward based from which the breadth of the territorial seas is measured or if the continental shelf can be shown to exceed 200 nautical miles. This should be a distance not greater than a line 100 nautical from the 2500 meter isobath or a line 350 nautical miles from the baseline.[141]

Federal Offshore Lands:

Federal offshore lands are managed by the Submerged Lands Act (SLA) of 1953. This Act granted individual States rights to the natural resources of submerged lands from the coastline to no more than 3 nautical miles or 5.6 km into the Atlantic, Pacific, the Arctic Oceans, and the Gulf of Mexico. The only exceptions to this Act are Texas and the west coast of Florida. These two States have had their State jurisdiction extended from the coastline to no more than 3 marine leagues or 16.2 km into the Gulf of Mexico.[142]

The Submerged Land Act also continued the Federal claims to the lands of the OCS. These lands consist of the area that is located seaward of the State's jurisdiction. Eventually the SLA of 1953 led to the creation of the Outer Continental Shelf Lands Act (OCSLA) of

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140 Outer Continental Shelf. in Minerals Management Service [database online]. 11/06/2008 [cited 05/05 2009]. Available from http://www.mms.gov/aboutmms/ocsdef.htm.

141 Va. Code § 67-300. Offshore natural gas and wind resources.

142 Federal Offshore Lands. in Minerals Management Service [database online]. 2008 [cited 05/05 2009]. Available from http://www.mms.gov/aboutmms/FedOffshoreLands.htm.

1953.[143] The OCSLA and the later amendments added to it have outlined the Federal government's responsibility over the lands of the OCS and have authorized the Secretary of the Interior to lease those lands for mineral development.[144]

During his administration, President Ronald Reagan set up the U.S. Exclusive Economic Zone (EEZ). This zone consists of those adjoining territorial sea of the United States, the Commonwealth of Puerto Rico, the Commonwealth of the Northern Mariana Islands, and the U.S. overseas territories and possessions. The EEZ extends up to 200 nautical miles from the coastline. Of the area available to the U.S. in the EEZ about 15% of it is located on the geologic continental shelf and is shallower than 200m. From there another 10 to 15% lies on the continental slope and rise with depths between 200 and 2,000m. The remaining 70-75% of the EEZ is located in the abyssal plain where water depths reach 3,000 to 5,000m.[145]

Leasing of Federal Lands:

Once legislation and laws were set in order to regulate the use of the OCS the MMS began with the development of the OCS through the leasing of the lands to developers. So far this has provided the U.S. with a major source of natural gas and crude oil along with the production of salt and sulfur.[146]

5 year OCS Leasing Program:

The 5 year OCS leasing program was set up by the MMS in order to schedule out the sale of oil and gas leases. These schedules include the size, timing, and location of the

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143 Federal Offshore Lands. in Minerals Management Service [database online]. 2008 [cited 05/05 2009]. Available from http://www.mms.gov/aboutmms/FedOffshoreLands.htm.

144 [Ibid 143]

145 [Ibid 143]

146 [Ibid 143]

proposed leasing activity to the Secretary who will decide what leasing projects will provide the best national energy needs for the nation during those 5 years.[147]

These leasing programs are regulated by the MMS and in principles from the OCSLA and are outlined in it in Section 18[148]:

- Management of the OCS shall be conducted in a manner that considers economic, social, and environmental value for the renewable and nonrenewable resources contained on the OCS.
- Timing and location of exploration, development, and production of oil and gas shall be based on a consideration of:
    - Existing information, equitable sharing of developmental benefits, location of the region with respect to energy markets and resources, interest of potential oil and gas producers, law and policies of affected states, environmental sensitivity, and relevant environmental and predictive information of the OCS
- The Secretary shall select timing and location of leasing, to the maximum extent possible in order to determine the potential for environmental damage and adverse impacts on the coastal zone.
- Leasing activities shall be conducted to assure receipt of fair market value for lands leased and the rights conveyed to the Federal government.[149]

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[147] 5 Year - OCS Leasing Program. in Minerals Management Service [database online]. 2009 [cited 05/04 2009]. Available from http://www.mms.gov/5-year/.

[148] Outer Continental Lands Act Sec. 18. Outer Continental Shelf Leasing Program.

[149] [Ibid 148]

Steps in the OCS Leasing Process:

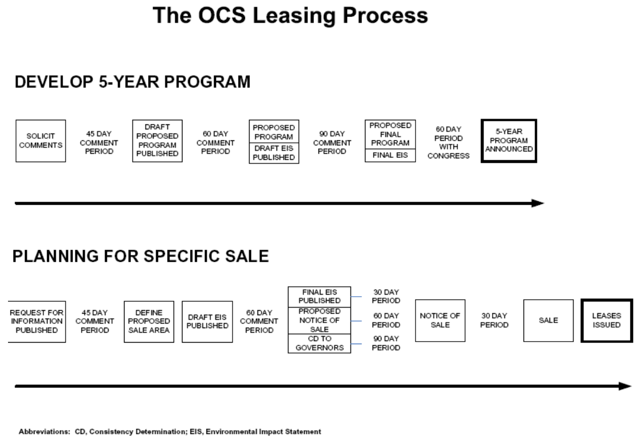

Figure 23: OCS 5 year leasing process and planning for specific sale processes.[150]

Current News:

<u>OCS Renewable Energy Framework:</u>

Recently, the Minerals Management Service released a new document titled *OCS Renewble Energy Program Framework* on April 22, 2009. This document outlines how the MMS will coordinate and consult with relevant Federal Agencies, with the Governor of any state, and the executive and local government that may be affected by a renewable energy lease. It also encourages companies that wish to pursue renewable energy activities on the OCS to conduct preliminary findings and outreach as early as possible in the process. Throughout the process this document also takes note that the MMS will adjust and apply its mitigation techniques on a case by case basis in order to mitigate damage to the environment.[151]

<u>Types of Lease</u>

The OCS Renewable Energy Framework outlines two different types of leases that will be issued. The first type of lease is a commercial lease which authorizes full build-out

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[150] The OCS Leasing Process. in Minerals Management Service [database online]. [cited 05/04 2009]. Available from http://www.mms.gov/ld/PDFs/LeasingProcess.pdf.

[151] OCS Renewable Energy Program Framework. in Minerals Management Service [database online]. 2009 [cited 05/04 2009]. Available from http://www.doi.gov/news/09_News_Releases/MMS_OCS_Renewable_Energy_Program_Specifics.pdf.

and commercial production of energy over a period of 25 years.[152] The second type of lease that will be issued is a limiting lease that authorizes data collection and technology testing activities over the period of 5 years. While looking at the two types of leases that will be issued above, the MMS also outlined how one might apply through the competitive leasing process and the non-competitive process.[153]

When following the competitive leasing process the subsequent steps must be completed:

- Issuance of the call for information. This step seeks to collect information from all parties that are interested or affected by the potential lease for sale.
- Publication of the area identification. The specific area that is being considered for leasing and any alternatives to the site should be documented and analyzed for mitigation measures and issues to be analyzed and considered for leasing.
- Preparation of necessary environmental compliance documentation. (NEPA, CZMA, ESA)
- Publication of the proposed sale notice requesting comments on the proposed bidding systems, fiscal terms, lease terms and conditions, mitigation, and award criteria.
- Publication of the final notice of sale.
- Conduct of lease auction and evaluation of bids
- Issuance of leases[154]

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152 The OCS Leasing Process. in Minerals Management Service [database online]. [cited 05/04 2009]. Available from http://www.mms.gov/ld/PDFs/LeasingProcess.pdf.

153 OCS Renewable Energy Program Framework. in Minerals Management Service [database online]. 2009 [cited 05/04 2009]. Available from http://www.doi.gov/news/09_News_Releases/MMS_OCS_Renewable_Energy_Program_Specifics.pdf.

154 [ibid 153]

When following the noncompetitive leasing the process the subsequent steps must be completed:

- MMS receives proposal for OCS renewable energy project.
- Publication of notice describing proposal and requesting information to use in determining whether competitive interest exist.[155]
- If no competitive interest exists then the MMS can proceed to issue a noncompetitive lease. However, if a competitive interest does exist then the MMS will proceed with the lease sale process of a competitive lease.
- Applicant submission of SAP
- MMS review of lease and SAP together and preparation of necessary environmental compliance documentation. (NEPA, CZMA, ESA)
- MMS determination of lease terms and conditions in consideration of environmental, socioeconomic, and market factors.
- Issuance of leases[156]

<u>Required Plans:</u>

Before a developer can move ahead with commercial development of the lease(s) they have procured they must decide on one of two required plans for development. The first plan is called a Site Assessment Plan or SAP. The second type of plan available is the Construction and Operation Plan or COP. The Site Assessment Plan describes the site assessment phase. This phase in the process is for the installation and collection of meteorological or marine data collection facilities in order to assess the renewable energy

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155 OCS Renewable Energy Program Framework. in Minerals Management Service [database online]. 2009 [cited 05/04 2009]. Available from http://www.doi.gov/news/09_News_Releases/MMS_OCS_Renewable_Energy_Program_Specifics.pdf.

156 [Ibid 155]

resources available in an area.[157] The Construction and Operation Plan describes the construction and operation phases of development. The COP also describes the general plans for decommissioning facilities after termination of the lease. It is important to know that during this process if sufficient information to support environmental and technical review is available the developer may submit one plan in order to cover both processes.[158]

It should also be noted that for activities on limited leases that a General Activities Plan (GAP) will be required. A GAP is required for technology testing and resource assessment activities. These plans are also required to describe activities on a renewable energy right of way or right of use and easement which will be covered later in the brief.[159]

Design, Fabrication, and Installation Requirements:

In this section of the Renewable Energy Framework that was released by the MMS they discuss the requirements of the lessees to submit reports describing the renewable energy's project's final design, fabrication, and installation of facilities once all of the appropriate forms have been completed. The MMS explains in this section that the Facility Design Report contains detailed descriptions of the proposed facility or facilities and location on the outer continental shelf. The Fabrication and Installation Reports should describe the plans and schedule for both the facility's fabrication and installation process. These reports should also include detailed environmental and engineering information. The MMS may also require a third party verification process that can include certification by a certified verification agent (CVA) to verify and certify that the projects are designed, fabricated, and installed in conformance with accepted standards and practices.[160]

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157 OCS Renewable Energy Program Framework. in Minerals Management Service [database online]. 2009 [cited 05/04 2009]. Available from http://www.doi.gov/news/09_News_Releases/MMS_OCS_Renewable_Energy_Program_Specifics.pdf

158 [Ibid 157]

159 [Ibid 157]

160 [Ibid 157]

Safety Management, Inspections, and Facility Assessment:

The MMS framework also includes the requirements to prevent or minimize the likelihood of harm or damage to the marine and coastal environments and to promote safe operations, including their physical, atmospheric, and biological components.[161]

Bonuses, Rentals, Royalties, and Other Fees to Ensure Fair Return:

In this section of the Renewable Energy Framework that was outlined by the MMS the document explains Commercial and Limited leases. Commercial leases when under a competitive issuance have a minimum bid level that is set at the sale notice. For non-competitive issuance a commercial lease must have a $0.25 per acre acquisition fee. Lastly all commercial leases have a $3.00 per acre annual rental until commencement of production and $5.00 per acre annual rental for project easement. There is also an operation fee based on the installed capacity. This fee is based on the following criteria[162]:

- Fee = Installed capacity * hours per year * capacity factor * power price * fee rate

For limited leases the MMS does not require as much work. The limited leases, if issued, under a competitive lease have a bonus bid minimum bid level that is set at the bid notice. If issued under a noncompetitive lease then the lessees must pay a $0.25 per acre acquisition fee. Overall, all limited leases have a $3.00 per acre annual rental and a $5.00 per acre annual rental project easement.[163]

This section of the renewable framework also covers the financial assurance that is required by the Federal government. This is done in order to minimize the risk of loss of Federal Government money if lessees default in fulfilling their obligations under the rule and

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161 OCS Renewable Energy Program Framework. in Minerals Management Service [database online]. 2009 [cited 05/04 2009]. Available from http://www.doi.gov/news/09_News_Releases/MMS_OCS_Renewable_Energy_Program_Specifics.pdf

162 [ibid 161]

163 [ibid 161]

other applicable laws or regulations. Along with financial assurance issues this section also deals with revenue sharing with states and the decommissioning obligations and requirements by the lessees. For the revenue sharing with states the EP Act requires the Federal Government to share 27% of its revenues received from any project that is wholly or partially within the area extending 3 nautical miles seaward of the state's submerged lands. These revenues must be shared with any state that has a coastline within 15 miles of the geographic center of the project. For the decommissioning obligations and requirements lessees must remove all facilities, including pipeline, cables, and other structures and obstructions. These facilities should be removed when they are no longer used for operations but no later than two years after the termination of the lease.[164]

The last section of this document covers the Right of Way (ROW) and Rights of Use and Easements (RUE). The MMS announced that a ROW or RUE grant will be issued to authorize OCS renewable energy activities that are not associated with an MMS issued renewable energy lease. If energy is transmitted across the OCS from renewable energy resources onshore in state waters then an ROW will apply. Similar to this the MMS describes the RUE as a grant that will be issued to authorize a facility on the OCS that supports renewable energy project located on state submerged lands. The rental fee of $5.00 per acre is set to be charged for ROW's and RUE's. There will also be a fee of $70.00 per statute mile that will be charged for ROW's as well.[165]

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[164] OCS Renewable Energy Program Framework. in Minerals Management Service [database online]. 2009 [cited 05/04 2009]. Available from http://www.doi.gov/news/09_News_Releases/MMS_OCS_Renewable_Energy_Program_Specifics.pdf

[165] [Ibid 164]

Key Considerations:

The U.S. Federal Government and States have been working hard to find ways to divide water rights and use between themselves. Some key points that need to be reviewed are:

- The State's jurisdiction is from the seaward limit and extended 3 nautical miles seaward of the baseline from which the breath of the territorial sea is measured.
- The Federal government holds jurisdiction from the seaward limit and is defined by the MMS as the farthest of 200 nautical miles seaward based from which the breadth of the territorial seas is measured or if the continental shelf can be shown to exceed 200 nautical miles.
- The Code of Virginia is not that specific but states that: it shall be the policy of the Commonwealth to support federal efforts to examine the feasibility of offshore wind energy being utilized in an environmentally responsible fashion.
- The OCS Renewable Energy Framework lays out outlines how the MMS will coordinate and consult with relevant Federal Agencies, with the Governor of any state, and the executive and local government that may be effected by a renewable energy lease.

Chapter 5: Regional and State Water Sovereignty Rights

This chapter will cover Regional and State sovereignty rights issues on water use and offshore development of the outer continental shelf for offshore wind farm development. In future development of offshore waters, the cooperation between regional and State governments will be instrumental in the process of moving forward with the growth of offshore wind energy. Sovereignty is the independence of a national, tribal, state, or local government combined with their right to regulate internal affairs without external approval. [166] These policies and issues are some of the major constraints for offshore wind developers when exploring new area in which to develop.

Background:

State Jurisdiction:

States in the U.S. have had their jurisdiction defined by the Minerals Management Service (MMS) as follows:

- In Texas and the Gulf coast of Florida the States jurisdiction is extended out to nine nautical miles from the baseline from which the breadth of the territorial sea is measure.[167]
- Louisiana's jurisdiction is extended 3 imperial nautical miles seaward of the baseline from which the breadth of the territorial sea is measured.[168]
- All other State's seaward limits are extended 3 nautical miles seaward of the baseline from which the breath of the territorial sea is measured.[169]

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[166] Legislation, State and Local Water. 2007 [cited 05/04 2009]. Available from http://www.waterencyclopedia.com/La-Mi/Legislation-State-and-Local-Water.html.

[167] Outer Continental Shelf. in Minerals Management Service [database online]. 11/06/2008 [cited 05/05 2009]. Available from http://www.mms.gov/aboutmms/ocsdef.htm.

[168] [ibid 167]

[169] [ibid 167]

Legislation on State and Local Water:

In the past there have been many complex issues associated with local, state, and federal regulation of surface water and groundwater. Currently, a very complex framework surrounds how these authorities and parts of government share legal authority over broad water development and management issues. This framework is based on common law which means that different government levels have control over certain water issues. For example, the U.S. Federal government has undisputed claims and sovereignty to develop and manage navigation on interstate or international bodies of water that are used for commerce. At the same time state and local governments have control of intrastate water quality and quantity issues. States in the U.S. have considerable authority to establish and implement water laws, policies, and programs that are suited to their concerns.[170]

Currently, Virginia is operating under the Riparian Doctrine. The Riparian Doctrine says that the right to use the water in natural rivers, lakes, and streams belongs to the owners of the banks on such bodies of water. However, while this doctrine does give an individual or group a right of use there are some limitations[171]:

- The right of use does not give ownership
- Public water supplies have no special status
- Use may not change quantity or quality
- Use must be within the watershed and cannot be removed from riparian lands
- Can do anything until another riparian sues[172]

170 Legislation, State and Local Water. 2007 [cited 05/04 2009]. Available from http://www.waterencyclopedia.com/La-Mi/Legislation-State-and-Local-Water.html.

171 Kudlas, Scott. Virginia's Current Regulation and How That Might Change? in Office of Water Supply Planning [database online]. [cited 05/04 2009]. Available from http://www.deq.state.va.us/export/sites/default/vrrbac/presentations/4-15-2008/VRRBAC_Scott_Kudlas_Presentation_041508.pdf.

172 [ibid 171]

Code of Virginia:

The Code of Virginia is the statutory law of the U.S. State of Virginia and consists of the codified legislation of the Virginia General Assembly. These codes are compiled by the Virginia Code Commission which is charged with the responsibility of publishing and maintaining a code of the general and permanent statutes of the Commonwealth.[173] The Code of Virginia is not very specific about the development of state lands for offshore natural gas and wind resources but states under § 67-300 that:

- In recognition of the need for energy independence, it shall be the policy of the Commonwealth to support federal efforts to determine the extent of natural gas resources 50 miles or more off the Atlantic shoreline, including appropriate federal funding for such an investigation. The policy of the Commonwealth shall further support the inclusion of the Atlantic Planning Areas in the Minerals Management Service's draft environmental impact statement with respect to natural gas exploration 50 miles or more off the Atlantic shoreline. Nothing in this Act shall be construed as a policy statement on the executive or Congressional moratoria on production and development of natural gas off the Atlantic shoreline.[174]
- It shall be the policy of the Commonwealth to support federal efforts to examine the feasibility of offshore wind energy being utilized in an environmentally responsible fashion.[175]

[173] Code of Virginia. in Wikipedia [database online]. 2009 [cited 05/05 2009]. Available from http://en.wikipedia.org/wiki/Code_of_Virginia.
[174] Va. Code § 67-300. Offshore natural gas and wind resources.
[175] [ibid 174]

Comments:

Virginia's State jurisdiction does not have any special considerations like Texas, Florida, or Louisiana. While these States have had their jurisdictions extended due to certain circumstances Virginia's jurisdiction only extends 3 nautical miles out from the seaward baseline. Currently, the Code of Virginia has made it so that the Commonwealth of Virginia is required to support federal efforts to examine the feasibility of offshore wind energy being utilized in an environmentally responsible fashion.

Options for the United States Federal government and the States are somewhat limited. At this point in time State and Federal jurisdictions overlap from the seaward limit to 3 nautical miles seaward of the baseline from which the breath of the territorial sea is measured. This overlap has caused issues between the Federal and State governments on water sovereignty rights in the past and will continue to do so until more clearly defined legislation has been passed.

The OCS Renewable Energy Framework released by the MMS has outlined the steps that must be completed when applying for competitive and noncompetitive leases. This framework has also outlined the process that lessees must follow once they acquire a lease all the way through the decommissioning process.

Discussion:

As the U.S. Federal government and States continue to move forward with offshore wind production there will be increasing cases of water sovereignty issues. Currently, legislation grants Virginia and most other States jurisdiction up to 3 nautical miles out while granting the Federal government jurisdiction out to 200 nautical miles. The Federal government also has jurisdiction to manage waters with respect to navigation rights in interstate or international waters. While this legislation gives the Federal government room to operate in State waters like Virginia's it still does not address a lot of jurisdictional issues that can arise from such a situation. The Code of Virginia outlines Virginia's current policy that it must support federal efforts to examine the feasibility of offshore wind energy. While this does require Virginia to help the Federal government with feasibility studies is does not explicitly state that Virginia must do anything after examining the feasibility.

This brief also reviews the OCS Energy Framework policy. Currently, this document states that the MMS will coordinate and consult with relevant Federal Agencies, with the Governor of any state, and the executive and local government that may be effected by a renewable energy lease. This policy also covers to an extent how the MMS will go about leasing blocks on the OCS for the development of oil, natural gas, and wind. More legislation will be required in the future to solve water use and sovereignty issues. By working together on these projects the Federal government and the States will be able to limit the amount of overlapping issues and move forward in the development of our natural resources and clean renewable energy located in Virginia's waters and the OCS.

VCERC:

The Virginia Coastal Energy Research Consortium (VCERC) was created by Virginia legislation in 2007 in order to develop coastal energy techniques and expand the Virginia knowledge base so as to assist in meeting the targets set out by the Virginia Energy Plan. In order to help achieve these plans VCERC has oriented its efforts towards three of Virginia's Energy Plan's objectives. These objectives include the creation of renewable energy resources, improving the environment, and increasing economic development.[176]

VCERC has been engaged in the research and development required to support the commercialization and implementation of renewable energy by using algal biomass, wind,

[176]Virginia Coastal Energy Research Consortium. in Virginia Coastal Energy Research Consortium [database online]. 2009 [cited 06/24 2009]. Available from http://www.vcerc.org/.

and wave resources that are readily available in Virginia. At the creation of VCERC the Virginia General Assembly set out key energy policy statements and objectives that VCERC's efforts would focus. These energy statements are as follows:

- Facilitate development of energy resources that are less polluting of the Commonwealth's air and water, and do not contribute to greenhouse gases and global warming.
- Foster research and development of alternative energy sources that are competitive at market price.[177]
- Develop energy resources and facilities that do not impose a disproportionately adverse impact on economically disadvantaged or minority communities.
- Increase Virginia's reliance on agricultural based ethanol and biodiesel from crops grown in the Commonwealth.
- Ensure that Energy generation and delivery systems are located in places that minimize impacts to pristine natural areas and other significant onshore natural resources. These areas should also be as near as possible to compatible development.[178]

VCERC was originally founded by five founding members but has expanded over the last two years and is currently composed of fourteen members. These members include representatives from eight partner universities and six government and industry partners.[179] The universities involved include:

- Old Dominion University – Founding Member

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177 Virginia Coastal Energy Research Consortium. in Virginia Coastal Energy Research Consortium [database online]. 2009 [cited 06/24 2009]. Available from http://www.vcerc.org/.

178 [Ibid 177]

179 [Ibid 177]

- Virginia Institute for Marine Science – Founding Member
- Virginia Tech Advanced Research Institute – Founding Member
- James Madison University – Founding Member
- Norfolk State University – Founding Member
- Virginia Commonwealth University
- University of Virginia
- Hampton University[180]

Government partners include:

- Hampton Roads Clean Cities Coalition
- Hampton Roads Sanitation District – Virginia Initiative Plant
- Hampton Roads Technology Council
- Virginia Department of Mines, Minerals, and Energy
- Virginia Department of Environmental Quality Coastal Zone Management Program[181]
- Virginia Marine Resources Commission

Industry partners include:

- Science Applications International Corporation
- Virginia Manufacturers Association
- Virginia Maritime Association[182]

180 Virginia Coastal Energy Research Consortium. in Virginia Coastal Energy Research Consortium [database online]. 2009 [cited 06/24 2009]. Available from http://www.vcerc.org/.
181 [Ibid 180]
182 [Ibid 180]

As stated above VCERC is mandated by the Virginia Energy Plan to focus its research on offshore winds, waves, and marine biomass. These focuses have been broken down into four main projects with the lead universities listed next to them:[183]

1) Feasibility level design and economic assessment for a reference baseline offshore wind power project. (VT-ARI)
2) Preliminary mapping of offshore areas suitable for offshore wind development, with identification of excluded area to avoid potential conflicts, and mapping of offshore benthic, pelagic, and avian habitats. (JMU, VIMS)
3) Evaluation of economic development impact of commercial offshore wind power development and associated workforce training and entrepreneurial development needs, and preliminary planning for ocean test bed. (NSU)
4) Feasibility level design and economic assessment for a biodiesel algae culture system. (ODU)[184]

James Madison University has the lead in mapping the offshore wind energy resources off of Virginia's coast.[185] These mapping efforts have identified excluded areas to avoid potential conflicts with ocean users, including the U.S. Navy training and exercise areas, U.S. Coast Guard designated shipping lanes, commercial fishing grounds, sand and gravel mining areas, dredge spoil disposal, archeological and other scientific research sites, and other potentially incompatible sites. JMU is also preparing GIS layers that show the distribution of offshore benthic biological communities, marine mammal sightings, and avian habitats. With this data, researchers will be able to conduct feasibility studies as well as

183 Virginia Coastal Energy Research Consortium. in James Madison University [database online]. Harrisonburg, Va., 2009 [cited 06/24 2009]. Available from http://www.cisat.jmu.edu/cees/windpowerva/vcerc/index.html.
184 [Ibid 123]
185 Virginia Coastal Energy Research Consortium. in Virginia Coastal Energy Research Consortium [database online]. 2009 [cited 06/24 2009]. Available from http://www.vcerc.org/.

educate the public on the impacts that offshore wind parks will have on Virginia's coastal and offshore environment and coastal industry.[186] VCERC is preparing a report using relevant research to address the following factors as pertinent to offshore wind development:

- Wind resource
- Foundation
- Stakeholder concerns
- Sub-station locations
- Turbine construction sites
- Supply chain
- Job creation[187]

As research and development of offshore waters continue to move forward this will give VCERC the opportunity to grow and transform itself into knowledge base and facilitator for future development of Virginia's waters.

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186 Virginia Coastal Energy Research Consortium. in Virginia Coastal Energy Research Consortium [database online]. 2009 [cited 06/24 2009]. Available from http://www.vcerc.org/.
187 [Ibid 186]

Chapter 6: Recommendation

Virginia is currently looking at developing its coastline and the outer continental shelf for the installation of offshore wind turbines. By developing its readily available wind resources, Virginia will be able to help lead the country in offshore wind energy generation. This growth of offshore wind will not only supply Virginia with clean renewable energy but it will also set an example for other coastal states to follow. This thesis has covered the types of offshore wind turbines and foundations that are available and discussed the seabed conditions for which they are the most applicable. It has analyzed the mistakes and lessons learned from past offshore wind farms that have been built throughout Europe and summarized the development of several U.S. wind farms that are currently in the process of being approved for construction. It has also reviewed Federal and State legislation on what is required of offshore wind developers. The last section of this thesis will contain a recommendation as to which types of wind turbine foundations should be used for the development of the Virginia coastline and Outer Continental Shelf. This recommendation will be based on where Virginia's territorial limits are located, the bathymetry data of the water available, and the soil composition of the seabed.

In order to recommend what types of turbine foundations that can be used for Virginia the first step is to determine the wind resources that are available in that region. An example of this can be seen in figure 24 below. This figure shows the wind resources located for the State of Virginia all the way out to the Outer Continental Shelf. Wind resources are measured on a scale from 1 to 7 by wind speeds. The higher the wind class the better the location is for the development of an offshore wind farm. As the figure below shows Virginia coastline is a prime location for offshore development due to its coast being primarily dominated by class 5 and 6 winds.

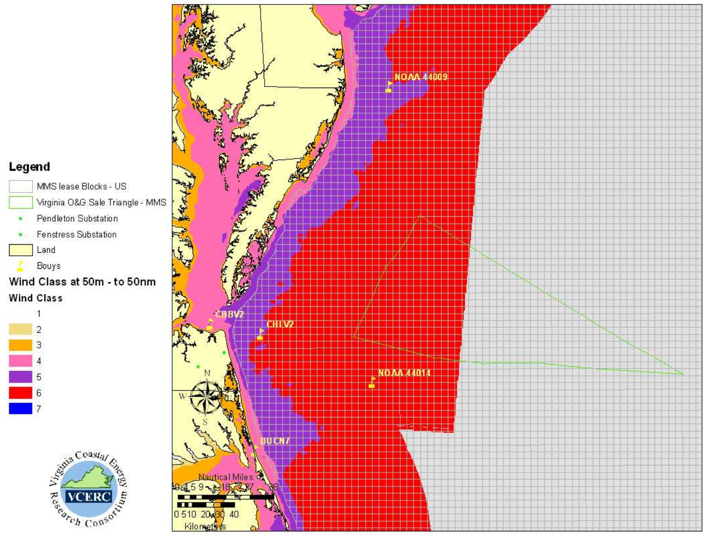

Figure 24: OCS 5 year leasing process and planning for specific sale processes.[188]

The second step determining what foundations Virginia should use for offshore development is to establish exactly what areas of water are available for Virginia to develop. This area can be seen below in figure 25:

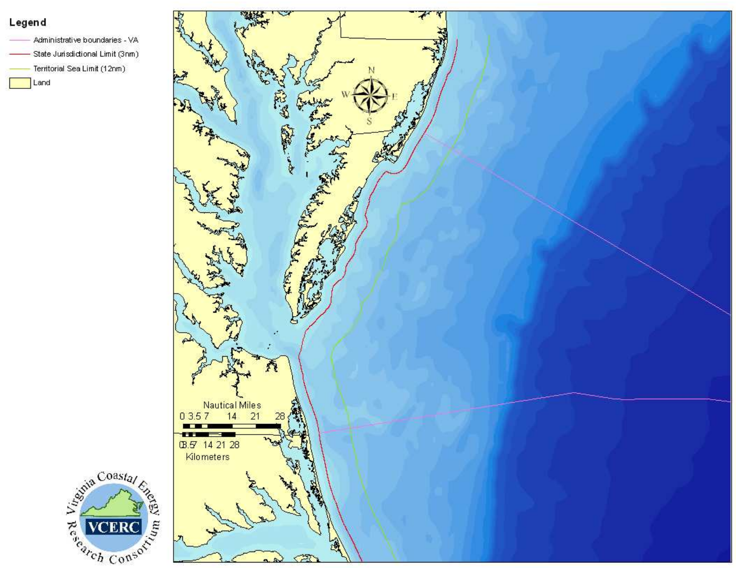

Figure 25: Virginia and Federal administrative boundaries.[189]

188 Luerssen, Remy (personal communication, March 6, 2009)
189 Luerssen, Remy (personal communication, May 21, 2009)

This figure shows Virginias state boundaries and their jurisdictions over the water. The red line shown marks the three mile mark from the shore as well as the limit of state jurisdiction. The green line shown above marks the 12 mile limit and the end of the states territorial sea limits. Beyond these two lines the waters are considered part of the exclusive economic zone. The main lines in figure 25 that affects where Virginia can develop are the pink lines that extend out from the coast towards the OCS. These lines represent Virginia's extended borders with other states territories and restricts where Virginia has the right to develop. For the purposes of this thesis all three of these jurisdictions located inside of Virginia's extended borders will be considered for use in the development of offshore wind farms.

The bathymetry data available for the waters located off the coast of Virginia and the OCS is also a major factor that will affect which foundations can be used. As discussed earlier in this thesis each type of foundation that is currently available for use has restrictions on the depth of water they can be deployed in. This range of depth, in which current foundations can be used, scales from several meters down to hundreds. By examining the bathymetry data of the waters located within Virginia's extended borders it is possible to minimize the number of foundations available for that region. The bathymetry data for Virginia's territorial waters can be seen below in figure 26:

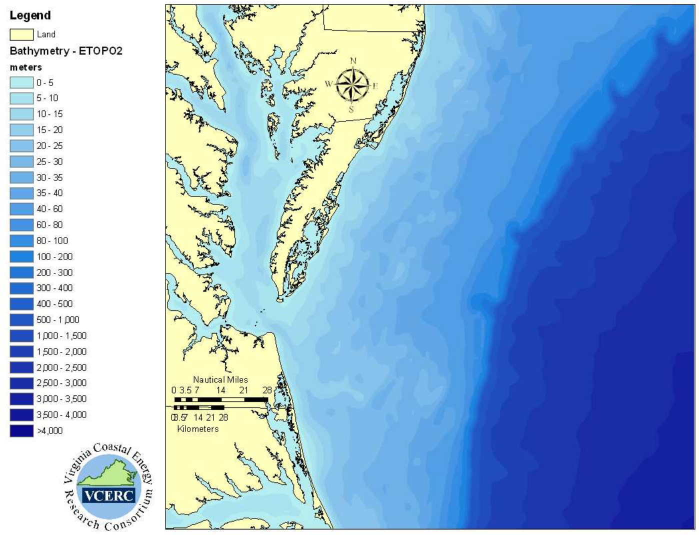

Figure 26: Bathymetry data for water off the Virginia coast.[190]

The data above in figure 26 shows that the water depth for the Virginia coast starts at between 0-5m and gradually drops the farther offshore a person travels to over 4,000m. Due to the steep drop off and depth of the outer continental shelf areas these areas have not been available in the past for development. With new and innovative designs for foundations being researched and prototyped, the wind industry is quickly increasing its options for future growth.

Another important aspect that must be taken into account is the current zoning of the waters off of the Virginia coastline by the Federal and State governments. With Virginia and its surrounding States playing a large role in military and space operations, different areas of the Atlantic and Virginia coast have been zoned off for specific purposes. These purposes range from military locations used for live fire training to NASA's Wallops Island Flight Facility. The specific areas that have been zoned off for Federal and State government operations can be seen below in figure 27:

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[190] Luerssen, Remy (personal communication, May 21, 2009)

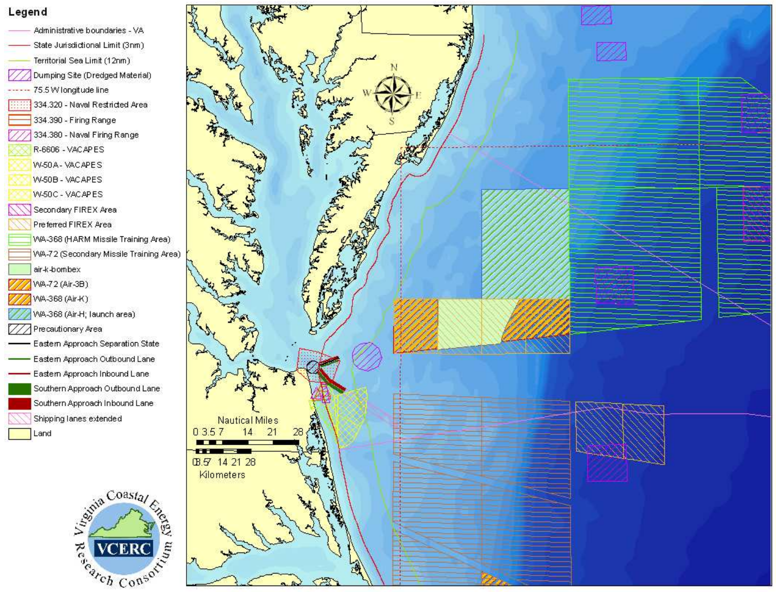

Figure 27: Areas zoned off for government use.[191]

As figure 27 above shows a large portion of the Virginia coastline and OCS has been zoned for government use. While these locations do not specifically remove these areas from being developed in the future, the areas marked would require special authorization from the Federal or State government in order to be developed.

The sediment data is also an extremely important part of deciding on the type of wind turbine foundation that can be used. The sediment that makes up the seabed in a certain location may prohibit the use of some foundations. An example of this can be seen in areas where boulders and other large rocks are located in figure 28. These locations are marked on figure 28 with "+"'s. Areas such as these are not suitable to foundations unless blasting is used in order to break through the boulders.

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191 Luerssen, Remy (personal communication, May 21, 2009)

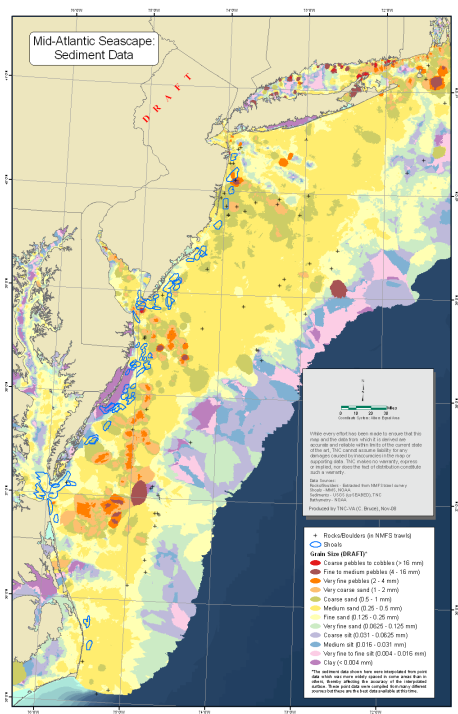

Figure 28: Sediment data for the mid Atlantic seabed.[192]

As figure 28 above shows, the seabed within Virginia's extended borders is mostly composed of medium and fine sand. The areas shown above that contain very coarse sand and up to coarse pebbles and cobbles are locations that should be avoided if possible. This is due to the fact that these locations will not have the suction or holding power needed to support the turbine tower. These locations will also require specialized equipment in order to install foundations for wind turbines.

Based on all three of the categories listed above, developers of offshore wind farms will be able to decide on the correct type of foundation that is needed for a particular location. The easiest waters that can be developed are those closest to the shoreline. Having an offshore wind farm located close to shore has many advantages over building them farther off. One advantage to this is that the cost and amount of time to transport and install

[192] TNC, (personal communication, May 21, 2009)

foundations and turbines from a harbor is decreased. Developers will also need to lay less cable in order to transmit the power generated from the wind farm to a shore based substation. For water depths of 30m or less the most popular and commonly used foundation is the steel monopole. The only environments the steel monopole foundation cannot be used in are seabeds with boulders or rocky sediment. If these conditions are encountered it is still possible to use concrete monopoles which can have a drill cutting head installed on them.

The best choice for foundations to install in the waters off the coast of Virginia leading offshore to the OCS is the truss tower and suction caisson foundation. Truss towers can be installed in water depths of up to 60m. This type of tower and foundation has been shown to be the most cost effective and easiest to install. Truss towers use half of the materials used in building a tubular tower and provide the same amount of support. This design allows for a large cost reduction and more turbines to be built than a developer might have been able to originally afford. On top of these advantages the truss tower is also well suited for use with suction pile foundations. These foundations are able to be installed in almost any environment and require little to no heavy machinery for their installation.

For the construction of offshore wind turbines in waters greater than 60m, suction caissons or suction piles are still the recommended foundations for use. These foundations have been used by the oil and natural gas industry for years and have proven to be extremely reliable in water as deep as 1000m. Suction caissons and piles can be used in extremely deep waters in order to anchor multiple kinds of floating turbines that are located on the surface above them. While the monopole foundation and tubular tower are currently the most popular, suction caissons should be considered for use in future wind farms that have sediment types that meet its requirements.

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