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Appendix A HVAC Technical Brief
ACKNOWLEDGEMENTS

The Massachusetts Clean Energy Center, its project partners at the Massachusetts Executive Office of Energy and Environmental Affairs and the Massachusetts Office of Coastal Zone Management, and ESS gratefully acknowledge the industry stakeholders who provided valuable comments during the preparation of this report. In particular, ISO New England’s System Planning team provided important information to validate technical details and shared their unique expertise as a helpful context to consider the integration of offshore wind into the regional electric system. Additional input was also provided during a pre-publication stakeholder consultation which included: the Massachusetts Department of Public Utilities Siting Division, Massachusetts Department of Environmental Protection, Deepwater Wind, Offshore MW, EMI, EDF Renewables, The American Wind Energy Association, National Grid, Northeast Utilities, Bonneville Power Administration, Elia Group, Anbaric Transmission, Atlantic Wind Connection, Whitman Transmission, the Bureau of Ocean Energy Management, U.S. Coast Guard, and the New Bedford Economic Development Council.
EXECUTIVE SUMMARY

The Massachusetts Clean Energy Center (MassCEC), working with the Executive Office of Energy and Environmental Affairs (EEA) and its Office of Coastal Zone Management (CZM) and other state agencies (the “Project Team”), commissioned this report to analyze and understand the transmission infrastructure necessary to interconnect future Massachusetts offshore wind projects to the regional electric grid. This report examines the technical aspects of offshore wind transmission interconnection and analyzes scenarios that minimize cost and environmental impact.

Since 2009, the Commonwealth of Massachusetts has been leading a planning and stakeholder process with the U.S. Department of the Interior’s Bureau of Offshore Energy Management (BOEM) for the Massachusetts Wind Energy Area (MA WEA), the largest offshore wind planning area along the East Coast. The National Renewable Energy Lab estimates the area can host 4000 to 5,000 MW of installed offshore wind capacity that could produce enough electricity to power the majority of homes in Massachusetts. The federal government is expected to conduct an auction of the Massachusetts Wind Energy Area later this year. Additionally, Massachusetts has been working with BOEM and the State of Rhode Island on the Rhode Island–Massachusetts WEA (RIMA WEA).

Development and growth of the Commonwealth’s offshore wind sector will be driven largely by policy and market factors. This study was undertaken to explore the technical characteristics of offshore wind transmission infrastructure independent of these factors. The results of the study will support EEA and CZM in the current update of the 2009 Massachusetts Ocean Management Plan, which will examine potential transmission cable routes within the context of critical marine habitat areas, other natural resources, and marine water-dependent uses.

Four build out scenarios were developed to represent potential stages in the development of the federal offshore wind planning areas (RIMA WEA and MA WEA). The center of the RIMA WEA is approximately 30 miles from the mainland coast of Massachusetts and the center of the MA WEA is approximately 50 miles off the coast. Together, the build out scenarios provide a framework to describe and evaluate the transmission infrastructure necessary to connect future Massachusetts offshore wind projects to the New England electric grid. The four scenarios for build out of the RIMA WEA and MA WEA areas are as follows:

- Scenario 1: 500 MW
- Scenario 2: 1,000 MW
- Scenario 3: 2,000 MW
- Scenario 4: 3,000 MW

Specifically, the study addresses (i) technical approaches for building offshore transmission lines, including transmission system components and design factors, (ii) identification of potential interconnection points to the existing electric grid, including generally the improvements and upgrades required to accept this energy, and (iii) the potential for expansion of offshore transmission as development advances in the federal wind energy areas WEAs.

While formal electric system impact studies (load flow and interconnection engineering) were beyond the scope of this effort, the study did result in a number of important high-level findings. Prior to finalizing this report, the Project Team reviewed these findings with key industry stakeholders that included ISO New England, electric utilities and private offshore wind and transmission developers. Key findings of the study include:

1. Transmission cable distance will range from 40 to 130 miles or more, which favor the use of high-voltage direct current (HVDC) technology. HVDC technology offers advantages to high-voltage

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1 Distance represents straight line distance from the center of the WEA to shore and does not represent transmission route length.
alternating current (HVAC) including reduced line losses, highly controllable power flow and lower cable costs due to fewer conductors and typically smaller cables.

2. Any transmission system will require one or more offshore collector stations to aggregate power from the wind turbines for transmission to land.

3. If an HVAC system was designed for a project location in the MAWEA close enough to shore and with operating characteristics to make it feasible for a project in the 250 MW range, voltage compensation and system protection equipment would be required and could be located on the offshore platforms as well as the land based interconnection station.

4. HVDC transmission systems include offshore collector station(s) which aggregate alternating current (AC) electricity from the turbines, an offshore converter station to convert the electricity from AC to direct current (DC) for transmission over longer distances, the undersea transmission cable bundle, and an onshore converter station located adjacent to the interconnection point to convert DC to AC.

5. The offshore converter station platform is a limiting factor for offshore wind energy facilities that rely on HVDC technology to deliver the electricity to the grid. Current technology limits the size of the converter stations to 1,000 MW.

6. There are a number of potential interconnection points in Massachusetts and coastal southern New England where offshore wind projects can interconnect to the grid.

7. The interconnection would be at the 345 kV level to integrate the large electric generating capacity anticipated from offshore wind projects with the existing electric grid. If a smaller (250 MW) project could be designed to operate in the MAWEA, it is possible that, in addition to the 345 kV substations, an interconnection could be made at a 115 kV sub. This report did not evaluate interconnection at this level.

8. It is technically feasible to interconnect 500 to 1,000 MW, and in certain cases up to 2,000 MW, of offshore wind capacity at each potential 345 kV interconnection point.²

9. The offshore transmission system can be developed to accommodate the sequential or phased build out of the wind energy areas.

These findings pertain to the technical characteristics of offshore wind transmission infrastructure independent of the market and policy factors widely recognized as principal drivers affecting the scale and pace of offshore wind development in the region. Accordingly, the increasing installed capacity captured in each build out scenario equates with the incremental addition of 500 to 1000 MW. While this development path is hypothetical, it does represent the optimal approach to achieve transmission-related economies of scale. However, market and policy factors may exhibit a greater influence on the size of offshore wind projects developed in the region. For example, projects in the 250 MW range could also be developed and are considered potentially more viable in the near term by some industry stakeholders due to the current status of policy, the market, and financing mechanisms.

The results of this study provide valuable insight for future planning efforts by the Commonwealth to help foster the development of offshore renewable energy. Further evaluation can be undertaken to help provide additional understanding. The next steps that could be undertaken to build upon this study could include:

- Further refine the understanding of interconnection requirements for an offshore wind project to the grid. One identified location could be selected for an ISO New England “Feasibility” level study. Brayton

² For this report, the transmission system was sized for the nameplate capacity of the wind projects considered.
Point substation may be a good candidate given the existing capacity interconnected at this location, the announced Brayton Point Generating station retirement and potential future re-uses.

- Further investigation of the potential ownership scenarios described in Section 7 would help provide insight on the implications of the regulatory (i.e., rate impact) and cost advantages or disadvantages of the described options.

- Constraints that need to be considered when siting cable routes, landfall locations, and converter station sites are generally described at a high-level in the report. A next step would be to expand the understanding of these factors and outline their potential importance to a developer.

- The injection of large amount of offshore wind energy to the grid will have an effect on the environmental characteristics of the overall electric system and on the cost of power. A next step to evaluate the offset in greenhouse gas emissions due to the displacement of existing fossil fuel generation by offshore wind generation and the potential effect on cost of energy such as price suppression would help further define the economic and environmental benefits of energy provided to the grid by offshore wind generating facilities.

- The development of offshore wind energy and the transmission systems to bring the power to market will present employment opportunities and economic impacts in Massachusetts and the region in general. An analysis of these potential effects from the build out of the wind farms, could evaluate the potential benefits to manufacturing, construction and long term operations in terms of goods and labors services and the ability of this developing sector to help drive economies of scale in offshore wind energy while benefitting state and local economy.

- Low frequency alternating current (LFAC) is a developing technology that may provide another option between HVAC and HVDC. However, because of the need to design and commercially develop several new pieces of equipment, this technology is many years in the future.
1.0 INTRODUCTION

1.1 Study Objective
Since 2009, Massachusetts public agencies have been working with the Bureau of Offshore Energy Management (BOEM) to identify potential leasing areas in federal waters south of Massachusetts. In 2012, BOEM identified two areas: the Massachusetts Wind Energy Area (MAWEA) and Rhode Island-Massachusetts (RIMA) Wind Energy Area (WEA) for commercial leasing for the future development of offshore wind energy projects (see Figure 1). This has involved a comprehensive planning and analysis process that has involved extensive coordination and input from federal, state, tribal, and local officials, as well as consultations with commercial and recreational fishermen and environmental groups.

With the potential for several offshore wind projects proceeding in the lease areas within the two WEAs, the Commonwealth recognizes the benefits of advanced planning for the siting of a single or multiple transmission corridor(s) from the offshore wind projects in federal waters across state waters to landside grid interconnection location(s) (Transmission Project). Through the Transmission Project, the Massachusetts Clean Energy Center, working in close coordination with the Executive Office of Energy and Environmental Affairs and its Office of Coastal Zone Management, and the Department of Energy Resources, undertook a study to assess, identify, and establish optimal single or multiple locations for transmission cables and infrastructure for the transmission of renewable energy generated from offshore wind projects in the MAWEA and the RIMA WEA. The desired features of this transmission system include:

- Consolidated transmission routes, or corridors, from the WEAs to one or more mainland interconnection points;
- Transmission rights (or access to the routes) available to multiple wind developers;
- Expansion capability as development advances in the WEAs;
- Coordinated and expedited state permitting and licensing for the transmission routes in state waters; and
- Coordinated federal access and permitting process for areas in federal waters.

It is generally understood and acknowledged that growth of the offshore wind Industry will be driven by markets and policies which determine the demand for offshore energy and ultimately drive how much generating capacity can be built. This report is intended to describe the relationship between sequential development of the RIMA WEA and MAWEA and associated transmission infrastructure, independent of these factors.

2.0 BACKGROUND

2.1 Status of the RIMA WEA and MAWEA Leasing Processes
The commercial lease sale for the RIMA WEA was held on July 31, 2013. Deepwater Wind New England, LLC was the winner of the lease sale and executed commercial wind energy leases for the two lease areas on September 12, 2013.

BOEM is in the process of preparing for a competitive lease auction of the MAWEA. During the most recent Massachusetts Task Force Meeting on January 16, 2014, BOEM indicated that the Proposed Sale Notice would be released in 2014. A 60-day comment period would follow issuance of the Proposed Sale Notice after which time BOEM would review the comments and prepare a Final Sale Notice. Based on the examples of the first two offshore competitive auctions (Rhode Island and Virginia), the Final Sale Notice could be issued 6 to 7 months after the Proposed Sale Notice, with the auction to be held another 1 to 2 months after that. If the process established for the Rhode Island and Virginia lease auctions is followed, winning bidders will be sent leasing documents following a Department of Justice antitrust review, which
can take up to 30 days. The winner then has 10 days to execute the lease agreement with BOEM. Upon execution and review by BOEM, the leaseholder is then required to provide BOEM with a Site Assessment Plan (SAP) within 12 months\(^3\).

Following a BOEM review of the SAP, which will involve the preparation of National Environmental Policy Act documentation (either an Environmental Assessment or an Environmental Impact Statement), BOEM is expected to approve the SAP with a 5-year SAP period. Prior to the end of that 5-year period, the leaseholder is required to submit a Construction and Operation Plan (COP) to BOEM for review and approval. BOEM will develop National Environmental Policy Act documentation for the COP prior to issuing an approval, which is expected to involve the development of an Environmental Impact Statement. Once the COP is approved, the leaseholder must provide BOEM with a Facility Design Report and Facility Installation Report prior to initiating construction. The timeline for this process is uncertain; however, responses to BOEM’s Call for Information and Nominations for the MAWEA suggested the development process could take an average of 9 years.

2.2 Developer Interest in the MAWEA

The degree of interest in a particular lease sub-block can be quantified by the number of developers that identified that particular sub-block. Areas with the most interest are anticipated to earn the highest auction price. In order to begin evaluating how the MAWEA might be developed, the responses to BOEM’s Call for Information and Nominations for MAWEA were evaluated by assuming the MAWEA would be divided into four lease areas, as proposed by the National Renewable Energy Lab (NREL) in their 2013 study\(^4\). Overlying each area in a geographic information system allows the extent of overlapping interest to be analyzed. A geographic information system was used to plot each of the areas identified by developers. Figure 1 presents the results of this analysis.

Developers who pay the highest price for a lease area are expected to have more incentive to develop their project than a developer who pays less, which translates to aggressiveness of the development schedule. Therefore, based on the results of this spatial analysis, it appears that Auction Area 2 has greater interest than Areas 1 and 3, which are higher than Area 4.

2.3 Offshore Wind Energy Projects under Development

There are several offshore wind energy projects under development in New England which may have an effect on the development of the MAWEA in that they would be interconnecting in the same general area of the New England Transmission grid and competing in the same renewable energy supply market (see Figure 2). These projects will be among the first U.S. offshore wind farms to achieve commercial operation and may thereby become test cases for the feasibility of constructing, operating, and maintaining offshore wind turbine generators in New England waters and the economic feasibility of offshore renewable energy production within the ISO New England (ISO NE) electricity market.

2.3.1. Cape Wind Project

As depicted in Figure 2, Cape Wind Associates, LLC is developing the Cape Wind Project, which is a 468 MW offshore wind farm with 130 wind turbines located in Nantucket Sound off Cape Cod, Massachusetts. The transmission system for the Cape Wind Project will consist of intra-array cabling that connects the turbines to an offshore Collector Substation platform (commonly referred to as an electric service platform) (see Section 4 for a description), and two 115 kV high-voltage alternating current (HVAC) submarine and land transmission cables from the offshore platform to the interconnection point on Cape Cod at the Barnstable Switching Station (115 kV). Assuming a 37%\(^5\)

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\(^3\) BOEM revised the time to submit the SAP for competitive and non-competitive auctions to 12 months effective May 19, 2014.


\(^5\) Capacity factor based on DPU 12-30 - NSTAR petition for approval of long-term contract to purchase wind power from Cape Wind.
annual capacity factor, the Cape Wind Project would generate approximately 1,500,000 megawatt hours (MWh) of energy annually. The Cape Wind Project is scheduled to achieve commercial operation in 2016. More information is available at the Cape Wind Project website: www.capewind.org.

Given its relatively large size, construction of the Cape Wind Project may have an impact on the pace of further development of the MAWEA and RIMA WEA.

2.3.2 Block Island Wind Farm

Deepwater Wind is developing the Block Island Wind Farm which is proposed as a 30 MW offshore wind farm located approximately 3 miles southeast of Block Island, Rhode Island. (Figure 2) The Block Island Wind Farm is expected to consist of five 6 MW wind turbine generators and a 34.5 kV submarine transmission cable from the northernmost offshore wind turbine generator to an interconnection point on Block Island. Assuming a 48% annual capacity factor, the Block Island Wind Farm would generate approximately 125,000 MWh of energy annually.

In connection with the development of the Block Island Wind Farm, a 34.5 kV submarine transmission cable will be installed by National Grid that will run approximately 22 miles from Block Island to the mainland and eventually connect with an existing National Grid substation in Wakefield, Rhode Island. The submarine transmission cable will be capable of delivering power both to and from the Rhode Island mainland.

Deepwater Wind plans to begin construction on the Block Island Wind Farm submarine transmission cable as early as 2014 and offshore wind turbine generator construction in 2015. Please refer to the following Deepwater Wind website for more information: www.dwwind.com.

Given its relatively small size, the Block Island Wind Farm should have minimal impact on the further development of the MAWEA.

2.3.3 Deepwater One

As depicted in Figure 2, Deepwater Wind has also proposed a 900 to 1,200 MW wind farm (Deepwater ONE) to be located within the RIMA WEA, approximately 30 miles east of Montauk, New York and 15 miles southwest of Martha’s Vineyard, Massachusetts. Assuming a 48% annual capacity factor, this project could generate approximately 3,800,000 to 5,000,000 MWh of energy annually.

Deepwater ONE has proposed to access the New York Independent System Operator and ISO NE electricity markets via the coincident development of a “regional” offshore high-voltage direct current (HVDC) transmission system. This system would enable Deepwater ONE to interconnect in Long Island at the Long Island Power Authority (LIPA) Shoreham Substation (138 kV) in Brookhaven, New York and in New England at the National Grid Brayton Point Substation (345 kV) in Somerset, Massachusetts. As described in Deepwater Wind’s submission to the New York Energy Highway7, the New England-Long Island Interconnector would be the first link between Long Island and southeastern New England and would reduce constraints on the flow of electricity from southern New England to the New York downstate area and expand the diversity of power generation sources. It is expected that this would also increase system reliability by providing a new source of locational capacity and creating a link between New York and a new section of the ISO NE system.

While Deepwater Wind has indicated an interest to connect to the ISO NE market at Brayton Point, additional details were not available at the time of this writing. However, given the potentially larger size, the project would have an impact on the development of the MAWEA. Deepwater Wind has

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6 48% is the upper capacity factor for Alternative 1 in the NREL report.
indicated that construction of Deepwater ONE could begin as early as 2017 with commercial operation to begin in 2018. Additional information is available at the Deepwater Wind website: www.dwwind.com.

2.4 Concept of Generator Lead

The privately owned and operated infrastructure associated with delivering electricity to the public utility infrastructure is commonly referred to as a “generator lead”. Generator leads are regulated differently by the Federal Energy Regulatory Commission as compared to transmission infrastructure owned and operated by a regulated utility. The details of how private developers differ from regulated utilities are beyond the scope of this study; however, consideration of what portion of an offshore wind facility is the generator lead and where the utility ownership starts is a critical issue. For one reason, the infrastructure owned by the utility is generally paid for by rate payers.

The anticipated components that will be required for the offshore wind energy facilities developed in the RIMA WEA and MAWEA are described in Section 4. At this time it is uncertain what components will be owned and operated by the developer (i.e., generator lead) and which will be owned and operated by the utility. The Cape Wind Project and the Block Island Wind Farm provide two possible scenarios and demonstrate that a one-size-fits-all configuration does not exist. As presently configured, Cape Wind would own all project components up to the mainland substation (wind turbines, intra-array cabling, offshore Collector Substation, and the HVAC cabling). In the case of the Block Island Wind Farm, as currently configured, the developer owns all project components up to the Block Island Substation (wind turbines and intra-array cabling). The local utility, National Grid, has agreed to own the offshore submarine cable required to deliver the power to the onshore mainland substation.

At a minimum, the wind turbines and intra-array cabling are expected to be privately owned and operated. As described further in Section 4, offshore wind energy facilities in the RIMA WEA and MAWEA will require HV transmission systems that include alternating current (AC) Collector Substations (similar to the Cape Wind offshore platform), HVAC transmission cables connecting to an offshore AC-to-DC Converter Station, a HVDC transmission cable system that connects to an onshore DC-to-AC Converter Station, and an HVAC cable system connecting to the mainland utility substation. As with Cape Wind, it is conceivable that the developer could own and operate all components up to the mainland substation. However, similar to the Block Island Wind Farm, developers may wish to limit their ownership to the wind turbines and intra-array cabling.

The proposed Atlantic Wind Connection provides a model whereby a third party owns and operates the HV transmission system and provides a link between the offshore wind energy developer and the onshore regulated utility. This model may prove viable in the RIMA WEA and MAWEA. However, it is far too early to know with any certainty how the ownership agreements will be structured for offshore wind development off the coast of New England. Presently, there appears to be a relatively high likelihood that the lease holder (i.e., auction winner) would own and operate the wind turbines and intra-array cabling up to the offshore Collector Substation and that these components could be considered a generator lead developed in the RIMA WEA and MAWEA.

3.0 CONCEPTUAL LEASING AND BUILD OUT SCENARIOS

The following sections provide the basis for the leasing and build out scenarios considered in Section 7. The build out scenarios are constructs for exploring potential industry development outcome based on incremental addition of capacity and associated transmission infrastructure.

In 2012, a total of ten developers responded to BOEM’s Call for Information and Nominations for the MAWEA. As a result, the number of auction participants (i.e., bidders) may exceed the total number of leases offered by BOEM such that multiple developers could emerge from the auction as lease holders. It is conceivable that each lease area could be awarded to a different developer.
The previous auctions for the RIMA, Virginia, and Maryland Offshore WEA suggest that all qualified developers may not actually bid in the auction. Prior to the auction for the RIMA WEA, a total of nine developers were qualified to bid, but only three developers participated in the auction. In the end, a single developer (Deepwater Wind) secured both of the lease areas being offered by BOEM. Similarly, during the Virginia WEA auction, a total of eight developers was qualified and only two participated in the auction. The Maryland auction had 16 qualified bidders and only three developers participated in the auction with the two lease areas going to a single developer (US Wind). Based on these examples, there is a possibility that the MAWEA auction could result in a single developer securing a lease and control the entire MAWEA.

3.1 Market and Policy Factors

Lease holders are not required to develop their entire area and in fact are likely to develop projects only in response to market demand for the electricity. While assessments and forecasts for the potential demand for offshore wind energy and the likelihood of Power Purchase Agreements issued by the regulated utilities (e.g., National Grid and NSTAR) is beyond the scope of this project, it is reasonable to assume that the full capacity of the RIMA WEA and MAWEA will not be developed immediately. For example, Deepwater Wind has responded to a Request for Proposals from LIPA to develop approximately 200 MW of their entire lease area capacity (estimated at up to 1,200 MW) by 2018 to supply Long Island with offshore wind energy. Plans to build out the remainder of the leased area have not been announced and whether or not Deepwater Wind would build out the 200 MW of capacity if they are not selected by LIPA is unknown.

Factors that influence when projects are constructed and how much energy capacity is developed include:

- State and Federal policies:
  - Market demand
  - Renewable Portfolio Standards requirements
  - Availability of long-term contracts (Power Purchase Agreements),
  - Tax and other credits,
  - Capacity value
- Ownership structures for transmission (i.e., generator financed/owned or separate transmission company);
- Location and capacity of potential interconnection points;
- Water depth; and
- ISO reliability requirements and technical characteristics of HVDC technology which limit individual transmission circuits to 1 GW.

### 3.1.1 Total Potential Wind Energy Production

If the Block Island Wind Farm, Deepwater ONE (assuming 1,200 MW), and Cape Wind Project achieve commercial operation, the total annual wind energy produced (assuming a 48% annual capacity factor for Block Island Wind Farm and Deepwater ONE and a 37% capacity factor for Cape Wind) is estimated to be:

- **Block Island Wind Farm:** 125,000 MWh
- **Deepwater ONE:** 5,000,000 MWh
- **Cape Wind Project:** 1,500,000 MWh

**Total Annual Energy Production:** 6,625,000 MWh
This is less than the 9,000,000 MWh of existing renewable energy produced within the ISO NE electricity market in 2013. Assuming that the annual 2013 ISO NE system load energy consumption of 130,000,000 MWh and the annual 2013 ISO NE renewable generation production of 9,000,000 MWh remain constant over time, the incremental impact of the three projects would result in a total ISO NE annual renewable energy production of 15,625,000 MWh and would be approximately 12% of the ISO NE system energy consumption.

As a practical matter, all three of these offshore wind energy projects may not achieve commercial operation or may ultimately be developed at different capacities based on market conditions. However, if constructed, each could provide an opportunity to evaluate offshore technologies in New England waters and each would contribute new renewable wind energy into the ISO NE system.

### 3.2 Alternating Current and Direct Current Transmission

The center of the RIMA WEA is approximately 30 miles from the mainland coast of Massachusetts and the center of the MAWEA is approximately 50 miles off the coast. The most direct submarine cable route to possible landside transmission interconnection points ranges from approximately 40 to 130 miles (see Section 5). Two technologies are used in current transmission system design to move bulk power: HVAC and HVDC. Transmission with HVAC submarine cables tends to be used at shorter distances than a DC system and is typically limited to approximately 600 MW and 35 miles per circuit for several reasons as described below.

#### 3.2.1 HVAC

As described above, HVAC systems are used for offshore wind projects where relatively shorter cable lengths are required. For example, the 468 MW Cape Wind Project will use two 115 kV AC submarine cables over a short cable distance of approximately 12 miles in length. The majority of currently operating offshore wind projects employ HVAC transmission lines. A review of offshore wind projects in development, under construction, or in service using HVAC technology is provided in Table 1. The data are derived from publicly available sources and include applications of HVAC technology for projects 100MW or larger. Each of these project utilized HVAC, 3-core, XLPE insulated submarine cables.

<table>
<thead>
<tr>
<th>Name</th>
<th>Location</th>
<th>Status</th>
<th>Output (MW)</th>
<th>Collector Substations</th>
<th>Voltage (kV)</th>
<th>Cable Length (mi)</th>
<th>Cables (3-core)</th>
<th>Cable size (mm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>London Array</td>
<td>UK</td>
<td>Operation</td>
<td>630</td>
<td>2</td>
<td>150</td>
<td>33 Sea 0 Land 4</td>
<td>630/800</td>
<td></td>
</tr>
<tr>
<td>Greater Gabbard</td>
<td>UK</td>
<td>Operation</td>
<td>504</td>
<td>2</td>
<td>132</td>
<td>28 Sea 0 Land 3</td>
<td>800</td>
<td></td>
</tr>
<tr>
<td>Anholt</td>
<td>Denmark</td>
<td>Operation</td>
<td>400</td>
<td>1</td>
<td>220</td>
<td>15 Sea 35 Land 1</td>
<td>1600</td>
<td></td>
</tr>
<tr>
<td>Sheringham Shoal</td>
<td>UK</td>
<td>Operation</td>
<td>317</td>
<td>2</td>
<td>132</td>
<td>14 Sea 13 Land 2</td>
<td>630</td>
<td></td>
</tr>
<tr>
<td>Thanet</td>
<td>UK</td>
<td>Operation</td>
<td>300</td>
<td>1</td>
<td>132</td>
<td>16 Sea 2 Land 2</td>
<td>1000/630</td>
<td></td>
</tr>
<tr>
<td>Lincs</td>
<td>UK</td>
<td>Operation</td>
<td>270</td>
<td>1</td>
<td>132</td>
<td>30 Sea 8 Land 2</td>
<td>630</td>
<td></td>
</tr>
<tr>
<td>Horns Rev 2</td>
<td>Denmark</td>
<td>Operation</td>
<td>209</td>
<td>1</td>
<td>150</td>
<td>26 Sea 37 Land 1</td>
<td>800</td>
<td></td>
</tr>
<tr>
<td>Rodsand 2</td>
<td>Denmark</td>
<td>Operation</td>
<td>207</td>
<td>1</td>
<td>132</td>
<td>32 Sea 18 Land 1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Walney Ph 1</td>
<td>UK</td>
<td>Operation</td>
<td>184</td>
<td>1</td>
<td>132</td>
<td>27 Sea 2 Land 1</td>
<td>630</td>
<td></td>
</tr>
<tr>
<td>Walney Ph 2</td>
<td>UK</td>
<td>Operation</td>
<td>184</td>
<td>1</td>
<td>132</td>
<td>27 Sea 3 Land 1</td>
<td>630</td>
<td></td>
</tr>
<tr>
<td>Robin Rigg</td>
<td>UK</td>
<td>Operation</td>
<td>180</td>
<td>2</td>
<td>132</td>
<td>8 Sea 1 Land 2</td>
<td>300</td>
<td></td>
</tr>
<tr>
<td>Nysted</td>
<td>Denmark</td>
<td>Operation</td>
<td>166</td>
<td>1</td>
<td>132</td>
<td>7 Sea 11 Land 2</td>
<td>760</td>
<td></td>
</tr>
<tr>
<td>Horns Rev 1</td>
<td>Denmark</td>
<td>Operation</td>
<td>160</td>
<td>1</td>
<td>220</td>
<td>21 Sea 0 Land 1</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
### Name | Location | Status | Output (MW) | Collector Substations | Voltage (kV) | Cable Length (mi) | Cables (3-core) | Cable size (mm²)
--- | --- | --- | --- | --- | --- | --- | --- | ---
Ormonde | UK | Operation | 150 | 1 | 132 | 27 | 2 | 1 | 800
Prinses Amalia Wind Park | Netherlands | Operation | 120 | 1 | 150 | 17 | 4 | 1
Riffgat | Germany | Operation | 108 | 1 | 150 | 31 | 19 | 1 | 630
Gwynt y Mor | UK | Construction | 576 | 2 | 132 | 13 | 7 | 4 | 500
West of Duddon Sands | UK | Construction | 389 | 1 | 155 | 25 | 2 | 2 | 1000
Borkum Riffgrund 1 | Germany | Construction | 312 | 1 | 155 | 7 | 0 | 2
Butendiek | Germany | Construction | 288 | 1 | 155 | 24 | 0 | 2
Humber Gateway | UK | Construction | 219 | 1 | 132 | 6 | 19 | 2
Westermost Rough | UK | Construction | 210 | 1 | 132 | 7 | 9 | 1
Tranche C | UK | Development | 1200 | 4 | 9 | 0 | 10
Beatrice | UK | Development | 664 | 2 | 14 | 12 | 3
Kriegers Flak | Denmark | Development | 600 | 1 | 220 | 28 | 3 | 2
Gemini | Netherlands | Development | 600 | 2 | 220 | 68 | 0 | 2
Race Bank | UK | Development | 580 | 2 | 40 | 7 | 4
Arkona-Becken Sudost | Germany | Development | 480 | 220 | 56 | 1 | 3
Cape Wind | USA | Development | 468 | 1 | 115 | 11 | 6 | 4 | 405
Den Helder 1 | Netherlands | Development | 468 | 2 | 150 | 53 | 0 | 2
Dudgeon | UK | Development | 402 | 1 | 132 | 26 | 30 | 2
Horns Rev 3 | Denmark | Development | 400 | 1 | 220 | 20 | 38 | 2
Nordergrunde | Germany | Development | 110 | 1 | 155 | 17 | 3 | 1

AC submarine cables require charging current due to the capacitance of the cable which is a function of distance. The cable needs to be sized to address the charging current and the amount of power to be delivered from the wind farm (e.g., 1,000 MW). Additionally, in an AC interconnection, the wind farm would not be isolated from the interconnected land electric network in the same way as with a DC system since it becomes part of the network. Therefore, fault current would need to be addressed and controlled to prevent damage to cables or other components as would potential network disruptions and dynamic stability. Some of the technical issues associated with HVAC-based offshore wind transmission that limit its application over longer distances include:

- Charging current and related thermal ratings of the cables;
- System voltage issues due to the use of long cables;
- Line losses due to length; and
- System stability issues during AC cable faults or during cable operation.

All AC cables have capacitance, or the ability to store an electric charge, and require current to charge the capacitance up to the voltage level applied to the AC cable. Higher voltage cables require larger amounts of charging current per mile than lower voltage cables for the same main conductor size. The capacitance of the cable produces reactive power (which supports the transfer of real power in an Alternating Current (AC) system) that tends to increase the voltage on the transmission network. Reactive power produced by the cable capacitance must be compensated for with equipment such as shunt reactors or SVCs (Static Var Compensators).
The cable has a second current component, the real power current, which is associated with the power transmission to the Interconnection Substation. The charging current and the real power current combine to form the total cable current. The total cable current cannot exceed the cables rated current which is determined from the cables main conductor type (copper or aluminum), conductor size, the thermal properties of the cable and the thermal properties of the burial material surrounding the cable.

To illustrate the impact of charging current and cable length, the maximum distance that could be achieved using a 220 kV conceptual system submarine cable, for power transfer levels of 200 MW and 250 MW, assuming the 60 Hz frequency used in the US was calculated based on publically available information from cable manufacturers (Table 2). The maximum distance at 200 MW is 44.5 miles and the maximum distance at 250 MW is 35 miles. The reactive power compensation devices could be placed at the onshore substation, so there would be no need for intermediate offshore platforms.

Table 2. Maximum Transmission Route Length – 60 Hz

<table>
<thead>
<tr>
<th>Offshore Wind Farm Power (MW)</th>
<th>Charging Current (60 Hz) Amps/mile</th>
<th>Maximum Transmission Cable Distance (mi)</th>
<th>Charging Current (Amps)</th>
<th>Reactive Power from Cable (MVAr)</th>
<th>Real Power Current (Amps)</th>
<th>Total Cable Current (Amps)</th>
<th>Rated Cable Current (Amps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>14.3</td>
<td>44.5</td>
<td>636</td>
<td>242</td>
<td>525</td>
<td>825</td>
<td>825</td>
</tr>
<tr>
<td>250</td>
<td>14.3</td>
<td>35</td>
<td>501</td>
<td>191</td>
<td>656</td>
<td>825</td>
<td>825</td>
</tr>
</tbody>
</table>

A hypothetical 100 mile, HVAC submarine cable operating at 220 kV for a 250 MW project would have a charging current of 1,430 Amps which alone is greater than the rated cable current of 825 Amps. The route could be split into lengths of 33 miles, 33 miles, and 34 miles with the required compensation equipment placed on intermediate offshore platforms. For this conceptual design, shunt reactor compensation could be used to reduce the reactive power produced by the submarine cable(s). A review of the technology and estimated costs associated with this conceptual design is provided in Appendix A.

The HVAC conceptual design provided in Appendix A is not included here as a scenario for the potential build out the RIMA WEA or the MAWEA. The fundamental operating premise for the study was to consider broader-scale, sustained development of the offshore wind areas. The HVAC conceptual design is limited to 250 MW and cannot be easily scaled up to achieve full build out of any individual lease area. In order to deliver 1,000 MW of offshore wind using HVAC from the MAWEA, four duplicate HVAC systems would be required in this conceptual approach.

The proposed 600 MW Gemini offshore wind project listed in Table 2 currently under development in the Netherlands has proposed two 220 kV submarine cables over a longer distance (110 km, 68.3 mi) with each cable interconnecting a 300 MW block of capacity. The European electric system operates at a frequency of 50 Hz (as opposed to the 60 Hz frequency used in the US) which also has the effect of reducing the charging current on the cable. Since Gemini is still in development, only general information is available on the cable system and therefore the specifics of the design are not known.

A new technology that utilizes low frequency AC transmission (LFAC) is in the conceptual stage of development. Longer cable distances than traditional AC systems may be possible because the charging current is lower for lower frequencies. LFAC power would be transmitted to the mainland where it would be converted back to 60 Hz AC using equipment very similar to an HVDC converter. Wind turbines, cables, converters, and associated equipment for use with LFAC technology still need to be developed, tested, and made commercially available. It may take 10 years or longer until LFAC technology is commercially applied to offshore wind turbines, collector substations and power transmission systems.
3.2.2 HVDC

While smaller offshore wind projects within acceptable distances from shore may be developed with AC technology, due to the large capacity and cable route distances between the RIMA WEA and MAWEA and the mainland the electric power transmission system will likely require HVDC technology because it does not have the cable route distance limitation of HVAC technology and can transmit approximately 1,000 to 1,200 MW using solid dielectric cables. The current technological limit of the offshore HVAC-HVDC Converter Station Platforms, a component of the HVDC system, is 1,000 MW which is presently a limiting factor for build out of the RIMA WEA and MAWEA. HVDC technology also offers advantages including:

- Reduced line losses
- Very low charging current and resultant greater transmission length
- Highly controllable power flow
- Lower cable costs due to fewer conductors and typically smaller cables.

Currently progress is being made in the advancement of HVDC applications for offshore wind transmission. These advancements include:

- Lower cost for offshore installation;
- Higher availability / reliability of HVDC equipment;
- Reduced equipment required for installations; and
- Higher transmission capabilities.

In the near future it is expected that these innovations will make offshore HVDC very attractive in applications where lower wind outputs currently make HVAC the better choice. There are several HVDC offshore wind transmission projects under construction or in development. These HVDC wind projects either have a capacity more than 500MW, greater than 40 miles offshore, or both.

3.3 Build Out Scenarios for the RIMA WEA and MAWEA

Based on the details provided above regarding the makeup of the existing generation capacity of the ISO NE system, offshore wind energy projects already in development, market and policy factors, build out of the full projected capacities of the RIMA WEA (~1,000 MW) and MAWEA (~ 5,000 MW) is considered unlikely. Additionally, it is estimated that the federal, state, and local permitting could take approximately eight years from award of a lease to the start of commercial operation.

As a result, short-term and long-term planning horizons are defined for the purpose of this study. The short-term covers the next ten years and includes projects that are anticipated to move forward within 12 to 24 months of the lease auction that will be developed with fixed-bottom foundations in waters depths less than 50 meters. The long-term is defined as more than ten years from present and is assumed to include projects that may employ next-generation floating technology installed where water depths exceed 50 meters. Four build out scenarios were developed for the near-term planning horizon, which is the focus of this study. The scenarios represent individual, hypothetical stages in the sequential development of the MAWEA and RIMA WEA. Together, the build out scenarios provide a useful framework to describe and evaluate the transmission infrastructure necessary to interconnect future Massachusetts offshore wind projects to the New England electric grid. The four scenarios for build out of the RIMA WEA and MAWEA are as follows:

- Scenario 1 (Highly Conservative): 500 MW
- Scenario 2 (Conservative): 1,000 MW
• Scenario 3 (Moderate): 2,000 MW
• Scenario 4 (Ambitious): 3,000 MW

For the purpose of this study, individual build-out scenarios are composed of one or multiple conceptual projects whose total capacities are influenced by technology and market factors. As described above, smaller (250 MW) projects may be developed that conceptually utilize HVAC transmission technology but would require a specific design. In this evaluation, the offshore wind energy facilities are conceptualized as independent 1,000 MW Transmission Blocks. A Transmission Block is made up of all of the necessary transmission components to serve a 1,000 MW offshore wind farm from the offshore HVAC Collector Substation to the mainland utility substation. In the case of Scenario 1 (highly conservative), the offshore facility is conceived as a 50% build out of the full Transmission Block (1,000 MW). Scenario 4 (ambitious) is conceived as three Transmission Blocks.

These scenarios will be discussed in detail in Section 7 of this report based on the details provided in Sections 4, 5, and 6. Section 4 provides an overview of the transmission system components and installation technologies required to build an offshore wind energy facility in the RIMA WEA and MAWEA. An assessment of the available interconnection points, with a focus on available capacity and cost to integrate at these locations, is presented in Section 5. The constraints for siting cable routes and the interconnection infrastructure are provided in Section 6.

4.0 OVERVIEW OF TECHNOLOGY AND INSTALLATION REQUIREMENTS

4.1 Offshore Wind Transmission System Design Factors and System Components

As described above, cable systems that rely exclusively on HVAC technology to connect offshore wind farms to the grid are not favored for the RIMA WEA and MAWEA for a number of reasons including the cable lengths required to connect to the mainland transmission system and the large power transfer requirements. The most reasonable approach for transmission of the energy from the RIMA WEA and MAWEA would employ the offshore 1,000 MW Transmission Blocks. The offshore Converter Station platform is currently the limiting factor for offshore wind energy facilities that rely on HVDC technology to deliver the electricity and current technologies limit the size of the Converter Stations to 1,000 MW. The Transmission Block concept is based on the principle that economies of scale justify maximizing the size/capacity of the Converter Station and HVDC transmission cable at the time of initial development. For example, it would be advantageous for a developer considering a 500 MW initial deployment to install a 1,000 MW HVDC transmission system if the developer had a high degree of certainty that 1,000 MW of wind energy development would be required in the future. This is due to the fact that a single HVDC Converter Station with excess capacity would be less expensive than installing a second 500 MW Converter Station.

Each Transmission Block, as shown in Figure 3, would have the ability to deliver approximately 1,000 MW to the mainland AC transmission system (i.e., the grid). As technology allows for larger Converter Stations, the size of the Transmission Block would likely increase; however 1,000 MW is currently the upper limit of available technology.

Transmission Block engineering and design considerations include:

• Each Transmission Block must be completely physically and electrically isolated to prevent a single-contingency event whereby more than one Transmission Block can trip or be lost at one time; and
• Each Transmission Block must be electrically integrated into the interconnection location 345 kV Substation in a manner consistent with ISO NE design practices to prevent a single-contingency event whereby more than one Transmission Block can trip or be lost at one time.
By utilizing the Transmission Block approach, the RIMA WEA and MAWEA could be developed in stages by first constructing a single offshore to mainland HVDC link with the required Collector Substation(s) to bring the first available wind resources to the mainland. As further generation is brought on-line, additional Collector Substation(s) can be installed and connected to the HVDC Converter Platform until the full capacity of the single Transmission Block (1,000 MW) is reached. The following sections provide detailed descriptions of each of the component that make up a Transmission Block.

4.1.1 Collector System Design

![Collector System Diagram]

A Collector System consists of medium voltage AC (MVAC) submarine cables that will bring the energy generated from the individual offshore turbines (generators) to the Collector Substation. Utilizing an estimated wind turbine machine size of 5 MW, available ratings of switching equipment, and final layout of the collector circuit, approximately five to eight wind turbines may be connected to each collector circuit.

Each generator (i.e., wind turbine) would be connected to the system using a 3-core 34.5 kV dielectric cable. This operating voltage optimizes the amount of generators that can be connected to each collector circuit, the size of the MVAC cables used, and the present-day equipment ratings available to interconnect the system. This 3-core cable bundle design, as shown in Figure 4, would contain the 3 phases required for the electrical connection along with a multi-core fiber optic cable for communication and control of the turbine(s). Solid dielectric insulated cables contain no insulating oil so there are no environmental impacts in the event of damage or failure of the submarine cable.

As described in Section 2.4, the Collector System and wind turbines are expected to be owned and operated by the lease holder and will (at a minimum) constitute the generator lead for the RIMA WEA and MAWEA offshore wind energy facilities.

The physical design of each collector circuit is highly dependent on several factors. These issues include but are not limited to:

- Physical location of turbine(s);
- Actual turbine generation power output (machine size);
- Length of the MVAC submarine cables required;
- Subsurface cable installation conditions; and
- Availability/reliability requirements of the Collector System.
The three typical Collector System configurations that are primarily used in offshore wind design are “radial”, “star”, or “open loop” arrangement.

The radial designed collector system consists of a multiple wind turbines connected in a “daisy-chain” fashion from the Collector Substation as shown in Figure 5. The radial system is a simple, cost-effective design allowing for easy construction and operation of the cable collector circuit. One significant drawback of this design is that, depending on the cable fault location, a failure of a single MVAC submarine cable could result in a loss of most or even all generation on the collector circuit until the submarine cable could be repaired.

The star-designed collector system consists of a main MVAC submarine cable connected from the Collector Substation to a center distribution point. From this center point, each generator is connected with a single MV cable as shown in Figure 6. The star system is a somewhat simple design with better generation availability than the radial design. A single cable failure may only affect one generator, with some exceptions. But the star design has several disadvantages. A single failure in the main cable between the Collector Substation center distribution point would result in a loss of all generation on the collector circuit until the submarine cable could be repaired. An additional shortcoming of this design is the significant amount of MVAC electrical switching equipment that would have to be located at the center distribution point and the number of cables that need to enter one single location. This may make construction and possible repairs more challenging.

The open loop designed collector system is very similar to the radial collector system but with an addition of a cable connecting the last two generators on each collector circuit as shown in Figure 7. The open loop system is a simple, cost-effective design allowing for easy construction and operation of the cable collector circuit with the benefit of the best generation availability. In the event of a submarine cable failure, the faulty cable can be isolated at each end allowing the circuits to be re-energized to reconnect all the generators. This open loop design also has few minor weaknesses: the need for an additional submarine cable to connect the last two generators between the collector circuits, the possible need to reduce the generation output to prevent cable overloading during abnormal circuit configurations, and the reduction in the generators connected to each collector circuit required to allow for multiple configuration possibilities between the collector circuits.

Based on the bundle type design of the Collector System cable and the proposed jet plow installation method, it is expected that the cable corridor required for installation and future repairs should be approximately 2.2 times the “water depth”. Ideally, the cable corridor would be designed to remain clear of any obstructions such as other cables or other subsurface obstructions.

Depending on the manufacturer, and final capacity required of the collector cable, it is expected that the overall bundle diameter would be approximately 5 to 7 inches.

Whenever possible, the cable should be buried approximately 4 to 6 feet below the sea bed. Burial will provide additional protection to the cable from dropped objects during maintenance/construction activities in proximity of the cable, and possible ocean currents that could move or damage the cable. In locations where burial cannot be accomplished due to subsurface conditions, additional cable protection such as concrete mattresses or crushed rock cover should be applied.
4.1.2 Collector Substation Design

The primary purpose of a Collector Substation is to gather the generation output from approximately six to eight collector circuits and raise the voltage for more efficient transmission. Each 1,000 MW Transmission Block will require several Collector Substations and the location of each substation would be optimized to minimize the total length of MV cable connecting turbines to the Collector Substation as well as to minimize the length of HV cable connecting the Collector Substations to the Converter Station. The optimized location of each Collector Substation will be determined (in part) by the total number of Collector Substations required for the full build out of the Transmission Block.

The physical design of each Collector Substation is contingent on several factors including:

- Physical location, generation output, and arrangement of turbine(s);
- Collector System design;
- Sea conditions at the installation location(s);
- Subsurface conditions for foundation design; and
- Availability/reliability requirements of the Transmission System.

The Collector Substation will consist of several major components to safely, reliably, and efficiently deliver the energy from the RIMA WEA and MAWEA. Some of these items include control and protection equipment for the HVAC and MVAC systems, power transformers to increase the voltage for transmission, and auxiliary systems for climate control and safety requirements. All of these components must be specially designed for the installation conditions at sea and the high system availability/reliability. Because of the remote and difficult location of the Collector Substation, the redundancy of the overall system design must be very high. Extreme weather conditions could delay work for days and even weeks at a time for an effective equipment repair.

As shown in Figure 8, the Collector Substation will contain several MVAC circuit breakers; bus bar; and disconnect switches (i.e., switchgear) for the operation, maintenance, and protection of the 34.5 kV collector circuits. This switchgear must be specially design for installation in a harsh marine environment. Most or possibly all of the MVAC switchgear will use Sulfur Hexafluoride gas (SF₆) as an electrical insulating medium within the equipment. The use of SF₆ insulation in MVAC and HVAC applications is common in locations where compact design and additional protection from harsh environments is required.
The Collector Substation will require two independent 34.5 to 220 kV step-up transformers for system redundancy. This equipment is a major component of the overall system. The need for independent transformers is based on the critical need for the transformer to deliver the generation to the transmission system. In the event of a transformer failure, the successful repair or replacement of the transformer may take several months and possibly up to a year. The long duration of repair is due to remote and difficult installation location on an offshore platform; the limited number of manufacturers that can complete a repair; and the type, size, and availability of construction equipment required to remove the transformer in need of repair. The redundant transformer design also allows maintenance to be performed on one transformer with only minimal impact to the generation output.

Depending on the transformer and required cooling system design, approximately 15,000 to 22,000 gallons of dielectric insulating fluid (transformer oil) will be contained in each transformer unit. The transformer oil provides electrical insulation to the transformer components and a method of cooling the transformer during operation. Special consideration will have to be made in the overall platform design to contain the oil in the event of a possible catastrophic transformer failure. Currently there is no technology available to operate a transformer at the required system voltages and capacity without dielectric insulating fluid.

The Collector Substation will also contain HV circuit breakers; bus bar; and disconnect switches (i.e., switchgear) for the operation, maintenance, and protection of the 220 kV transmission circuits to the HVDC Converter Platform. Similar to the MV switchgear, the HV switchgear must be specially designed for installation in a harsh marine environment. The HV switchgear will use SF₆ as an electrical insulating medium within the equipment. SF₆ insulation will be required due to the need for a compact design in the HV equipment.

Additional auxiliary systems are required for the operation of the HVAC substation equipment, MVAC substation equipment, and transformer equipment. This auxiliary equipment includes control and protection systems to operate the switches and circuit breakers; pumps and motors required for the transformer cooling systems; lighting, heating, ventilation, and climate control equipment, fire control and protection systems; and control communication equipment for the overall control of the system. All of the above equipment should be redundant to maintain the overall high reliability/availability of the system.

A backup emergency diesel generator would also be designed into the Collector Substation. The diesel generator would be required to provide backup power to the auxiliary systems due to the loss of power to the substation. It would also be required during some maintenance activities when the HV and MV systems must be disconnected. Powering the auxiliary systems from a backup generator will allow the auxiliary equipment to operate as needed to protect any equipment from damage and for the safety of the crew that may be at the substation during a power outage. Depending on the emergency diesel generator design, approximately 6,000 to 8,000 gallons of fuel may be required to be stored at the Collector Substation. This would be enough fuel to run the generator for several days and possibly up to a week until additional fuel could be delivered.

A personnel accommodation area (crew quarters) will be required on the Collector Substation. The crew quarters should be designed to house a minimum of 8 to 10 persons for a possible extended duration. Food and additional supplies must also be on hand to accommodate the largest crew size for the expected duration. The crew quarters must include areas for rest, meal preparation, showers, and sanitary facilities. These accommodations will be required during extended substation maintenance activities and possibly during severe weather events when crews may become stranded at the platform until they can be safely evacuated.
All the equipment, systems, and facilities described above will be packaged into platform type design similar in size to the Collector Substations shown in Figure 9. The approximate dimensions of the Collector Substation described above are:

- Platform Area: 30,000 to 43,000 sq. ft.;
- Platform Dimensions: 100 to 120 ft. (L), 100 to 120 ft. (W), 80 to 100 ft. (H);
- Platform Weight: 2500 to 3200 tons (foundation weight not included); and
- Height above sea level to be determined by expected ocean conditions.

As described in Section 2.4, the Collector Substation may be part of the generator lead and owned by the developer/lease holder. However, it is also conceivable that everything landward of the Collector Station (i.e., the entire HV system) could be owned and operated by a merchant transmission developer or the regulated utility. See Section 7.4 for a discussion of potential ownership considerations.

4.1.3 HVAC Submarine Cable Design

The offshore AC Transmission system will bring the energy from the Collector Substation to the HVDC Converter Platform via 220 kV HVAC submarine cables. Figure 10 shows the cable interconnections between the facilities.

The Collector Substation(s) would be connected to the HVDC Converter Platform using several solid dielectric insulated, single-core HVAC submarine cables as shown in Figure 11. Each transmission circuit would require three single-core submarine cables. Installed along with the HVAC submarine cables would be separate multi-core submarine fiber optic cable to be used for communication and control of the system.

The physical design of each transmission circuit is dependent on several factors. Some of these items include:

- Length of the HVAC submarine cables required;
- Operating voltage of the cable;
- Subsurface cable installation conditions;
- Thermal characteristics of the seabed;
- Required transmission capacity of the HVAC cables; and
• Availability/reliability requirements of the Transmission System.

Based on the three single-cable type design of the HVAC Transmission System and jet plow installation methods, it is expected that the width of the cable corridor required for installation and future repairs should be approximately 4.4 times the “water depth” with the cables placed in a flat configuration centered within the cable corridor. The corridor should be designed so as to remain clear of any obstructions such as other cables or other subsurface obstructions. Depending on the manufacturer, and final capacity required of the transmission cable, it is expected that the diameter of each cable would be approximately 5 inches.

Whenever possible, the cable should be buried approximately 4 to 6 feet below the sea bed. Burial will provide additional protection to the cable from dropped objects during maintenance/construction activities in proximity of the cable; commercial marine activities, such as fishing; and possible ocean currents that could move or damage the cable. In locations where burial cannot be accomplished due to subsurface conditions, additional cable protection should be applied.

As described in Section 2.4, the HVAC cable may be part of the generator lead and owned by the developer/lease holder. However it is also conceivable that everything landward of the Collector Station (i.e., the entire HV system) could be owned and operated by a merchant transmission developer or the regulated utility. See Section 7.4 for a discussion of potential ownership considerations.

4.1.4 Offshore Converter Platform

The Offshore Converter Platform combines generation output from the Collector Substations and transforms the HVAC voltage into HVDC voltage for delivery to the mainland. The location of the Converter Station will be optimized to minimize the total length of HV cable connecting the Collector Substations to the Converter Station, while simultaneously minimizing the HVDC submarine cable to shore. The optimized location of the Substation will be determined (in part) by the configuration of Collector Substations feeding the Converter Station at full build out of the Transmission Block.

As described in Section 2.4, it is conceivable that the HVDC system (Converter Stations) and HVDC cable system could be owned by a third party and not the lease holder. If a transmission developer secures a contract with multiple lease holders to deliver power to shore (e.g., the Atlantic Wind Connection Model) the optimal location of a Converter Station may be outside any individual lease area in order to minimize the length of the HVDC system.

There are several different types of HVDC technologies, with each having both positive and negative features in their design. The most appropriate system for the RIMA WEA and MAWEA Transmission
Block would be the Voltage Source Converter technology operated in a bipole configuration, which is most suitable due to the compact design, high reliability, and proven installations in offshore applications. The bipole operation would allow the HVDC system to operate at 50% capacity in the event of a failure in a major HVDC component, such as one of the DC cables. This is an important issue for reliability given the size of these proposed facilities relative to the existing ISO NE system and difficulty (distance from shore and marine environment) of accessing any failed components in the short term in the event of a severe system failure (e.g., transmission cable failure or partial Converter Station malfunction). It is also important from the developer’s perspective insofar as it provides a continuing revenue source for up to half of the output of the facility versus being completely offline until the cable is repaired. The expected operating voltage of the system would be ±320 kV DC.

The HVDC Converter Platform will consist of multiple major components for safe, reliable, and efficient operation of the Transmission Block. Some of these items include control and protection equipment for both the HVAC and HVDC systems, specialized cooling systems for the HVDC power electronics, and auxiliary systems for climate control along with other additional components. System redundancy is very important to the design to provide very high reliability/availability of the transmission system because the HVDC system is the key component for the delivery of power from the RIMA WEA and MAWEA.

Similar to the Collector Substation, the HVDC Converter Platform will contain multiple HVAC circuit breakers; bus bar; and disconnect switches (i.e., switchgear) for the operation, maintenance, and protection of both the HVAC and HVDC equipment. Due to the required compact design and harsh installation environment, the HVAC switchgear and some HVDC devices will use SF$_6$ as an electrical insulating medium within the equipment.

The HVDC Converter Platform will require two independent large step-up transformers for system redundancy because it is a major component of the overall system. The independent transformer requirement is based on the critical nature of the transformer in the HVDC system and the possible long duration for repair in the event of a serious failure. Having redundant transformers would allow the transmission system to operate at reduced capacity with one transformer out of service.

Depending on the final HVDC Converter design, it is expected that the transformers and associated transformer cooling equipment could contain approximately 50,000 to 60,000 gallons of transformer oil. Containment for this amount of oil would be designed into the overall platform in the event of a catastrophic failure causing a release of oil.

The HV power electronics used in the transformation of energy from AC to DC produce large amounts of heat during their operation. This heat must be removed from the power electronic modules to prevent failure. Currently the most cost efficient method is to use a closed loop water/glycol (50/50% mixture) system with air cooling radiators. It is possible for a system of this power transmission capacity to contain approximately 15,000 to 20,000 gallons of water/glycol coolant.

Auxiliary systems are required for the operation of the Converter Platform. These systems include control and protection for both the HVAC and HVDC; pumps, motors, fans, and valves required for cooling systems; lighting, heating, ventilation, and climate control equipment, fire protection systems; and control communication equipment for the for the overall system control. All of the above equipment must be redundant to maintain the overall high reliability/availability of the system.

A backup emergency diesel generator would also be designed into the HVDC Converter Platform. The diesel generator would be required to provide backup power to the auxiliary systems due to the possible loss of power to the platform and would also be required during some maintenance activities. Backup power to the Converter Platform is especially important because the HVDC power electronic modules are susceptible to irreparable damage if they are not maintained in a proper climate controlled...
environment. Depending on the emergency diesel generator design, approximately 9,000 to 12,000 gallons of fuel may be required to be stored at the HVDC Converter Platform. This would be enough fuel to run the generator for several days and possibly up to a week until additional fuel could be delivered.

A personnel accommodation area (crew quarters) will also be required on the HVDC Converter Platform. They should be similar in design to the Collector Substation requirements but with the possibility to house a minimum of 10 to 15 persons. Crew quarters are especially important on the Converter Platform because it will require more maintenance than the Collector Substation requiring overnight stays to complete maintenance activities.

All the equipment, systems, and facilities described above will be packaged into a platform type design similar in size to the HVDC Converter Platform shown in Figure 12. The approximate dimensions of the HVDC Converter Platform described above are:

- Platform Area: 180,000 to 275,000 sq. ft.;
- Platform Dimensions: 200 to 230 ft. (L), 150 to 200 ft. (W), 130 to 160 ft. (H);
- Platform Weight: 9,200 to 11,000 tons (foundation weight not included); and
- Height above sea level to be determined by expected ocean conditions.

As described in Section 2.4, the entire offshore energy facility from the wind turbines to the mainland utility substation may be part of the generator lead and owned by the developer/lease holder. However, it is also conceivable that everything landward of the HVDC Converter Station (i.e., the entire HVDC system) could be owned and operated by a merchant transmission developer or the regulated utility. See Section 7.4 for a discussion of potential ownership considerations.

### 4.1.5 HVDC Cable

The offshore HVDC Converter Platform will connect to the mainland via three individual DC cables along with a multi-core fiber optic cable for communication (see Figure 12A). Three DC cables are required because of the proposed bipole operation of the HVDC system. The two main HVDC power cable(s) will use solid dielectric insulation designed for ± 320 kV DC operation. A third DC cable insulated for approximately 30 kV will be used as the return path when the converter is required to operate with one ± 320 kV DC main cable out of service. The return path cable allows the HVDC system to operate at 50% reduced capacity.
Depending on the manufacturer, and final capacity required of the HVDC transmission cable, it is expected that the diameter of each main HVDC cable would be approximately 5 inches. The return path cable would have an approximate diameter of 3 inches and the three cables would typically be bundled together.

The submarine sections of the cable must be buried approximately 4 to 6 feet below the sea bed. Burial will provide additional protection to the cable from dropped objects during maintenance/ construction activities in proximity of the cable, commercial marine activities such as fishing, and possible ocean currents that could move or damage the cable. In locations where burial cannot be accomplished due to subsurface conditions, additional cable protection should be applied. The submarine cable corridor required for installation and future repairs of the Submarine HVDC cables should be approximately 4.4 times the “water depth”.

At the location where the HVDC submarine cable(s) make landfall, a high density polyethylene (HDPE) conduit would be installed from the land into the sea via horizontal directional drilling (HDD). After the conduit is installed, the HVDC submarine cable(s) would be pulled up through the HDD conduit where the submarine HVDC cable(s) would be spliced onto a land-type HVDC cable(s) inside a jointing bay on the land. This joint bay would be similar to an underground, utility-type manhole (30 by 15 feet in size). The transition from submarine to land cable(s) is required because the land type cables do not require the cable armor used on submarine cables to protect them from damage during the installation and burial process.

From the joint bay the HVDC land cables would make their way to the mainland HVDC Converter Station. The installation would use a typical “manhole and duct” system used currently in standard underground electric utility installations.

As described in Section 2.4, the entire offshore energy facility from the wind turbines to the mainland utility substation may be part of the generator lead and owned by the developer/lease holder. However, it is also conceivable that everything landward of the HVDC Converter Station (i.e., the entire HVDC system) could be owned and operated by a merchant transmission developer or the regulated utility. See Section 7.4 for a discussion of potential ownership considerations.

4.1.6 Mainland Converter Station

The Mainland HVDC Converter Station receives the HVDC undersea cables and converts the energy into HVAC for connection into the mainland HVAC transmission system. The Mainland HVDC Converter Station would be identical to the offshore HVDC Converter Platform but with major
differences in the overall layout of the facility. The major difference in layout is due to the space availability and environmental conditions found on land compared to a marine installation.

The Mainland HVDC Converter Station will also have multiple major components such as control and protection equipment for both the HVAC and HVDC systems, specialized cooling systems for the HVDC power electronics, and auxiliary systems for climate control along with the other components also found on the offshore HVDC Converter Platform. Again, system redundancy is very important to the design to provide very high reliability/availability of the transmission system.

The land-based HVDC Converter Station will likewise contain multiple HVAC circuit breakers; bus bar; and disconnect switches (i.e., switchgear) for the operation, maintenance, and protection of both the HVAC and HVDC equipment. Because the HVDC Converter is land-based, this allows for the design to be a more open design than the platform based equipment, allowing the use of typical electrical equipment found in other land-based HVAC and HVDC systems.

Depending on the final HVDC Converter design, it is expected that the transformers and associated transformer cooling equipment could contain approximately 30,000 to 50,000 gallons transformer oil. Containment systems to capture the transformer oil would be designed into the facility in the event of a catastrophic failure causing a release of oil.

Just like the offshore platform based HVDC Converter, the HV power electronics used in the transformation of energy from AC to DC produce heat during their operation. The power electronics heat removal system would also use a closed loop water/glycol system with air cooling radiators. It is possible for a system of this power transmission capacity to contain approximately 15,000 to 20,000 gallons of water/glycol coolant.

Auxiliary systems are required for the operation of the Converter Station. These systems include: control and protection for both the HVAC and HVDC; pumps, motors, fans, and valves required for cooling systems; lighting, heating, ventilation, and climate control equipment, fire protection systems; and control communication equipment for the overall system control. As with marine based Converter Platform, the land-based Converter auxiliary systems must also be redundant to maintain the overall high reliability/availability of the system.

All the equipment, systems, and facilities described above will be packaged into open air substation and Converter Building design type similar in size to the HVDC Converter Station shown in Figure 13. The approximate dimensions of the HVDC Converter Station described above are:

- Converter Station Property: 3 to 5 acres; and
- Building Dimensions: 200 to 250 ft. (L), 250 to 375 ft. (W), 30 to 50 ft. (H)

As described in Section 2.4, the entire offshore energy facility from the wind turbines to the mainland utility substation may be part of the generator lead and owned by the developer/lease holder. However it is also conceivable that everything landward of the offshore HVDC Converter Station (i.e., the entire HVDC system) could be owned and operated by a merchant transmission developer or the regulated utility. See Section 7.4 for a discussion of potential ownership considerations.

4.2 Cable Installation Technology

4.2.1 Jet Plow Embedment Technique

Jet plow uses both a specially designed cable laying vessel and a towed, hydraulically powered jet plow device shown in Figure 14. The jet plow has no propulsion system of its own, and depends on the cable laying vessel to provide its forward motion. The jet plow equipment uses pressurized water from pump systems on the cable vessel to fluidize sediments. Hydraulic pressure nozzles on the jet plow create a direct downward and backward “swept flow” force inside the trench which limits the upward
movement of sediments into the water column and maximizes the gravitational replacement of sediments onto the cable. The jet plow is towed along the seabed and fluidizes the *in-situ* sediment column such that the cable system settles into the trench under its own weight to the planned depth of burial.

Jet plow embedment simultaneously lays and buries the cable and ensures the placement of the submarine cable at the target burial depth with minimum bottom disturbance and with the fluidized sediment settling back into the trench. The ease of installation, the lack of the need to dredge and remove sediments, and the minimal environmental impacts make jet plow embedment the preferred method of submarine cable installation.

Depending upon the composition of the sediments and the plow configuration, the jet plow is capable of fluidizing a single trench of approximately 18 inches wide to the target depth below the present bottom. It is anticipated that the target depth will be 4 to 6 feet below present bottom. Therefore, the jet plow will allow the submarine cable to be installed in a bundled configuration such that only one trench will be required. The jet plow device is equipped with horizontal and vertical positioning equipment that records the laying and burial conditions, position, and burial depth.

The jet plow methodology offers the advantage of its ability to achieve the desired burial depth, its minimal environmental impacts to sensitive aquatic resources and water quality, and the elimination of the need to dredge and remove sediments along the submarine cable route. In the event that hard-bottom seabed conditions exist that prevent the submarine cable from reaching the target burial depth, other methods to protect the cable will be used such as sand bags, concrete mattresses, or rock-armor that would be placed over the cable to provide adequate protection. The thickness of protective cover will depend on how deep the cable is buried.

### 4.2.2 Mechanical Plow

Mechanical plowing relies on the physical displacement of the seabed surface sediments to create a trench to the planned depth of burial, into which the cable is then laid. This technology utilizes a mechanical plow on heavy skids that uses gravity (weight) to displace surface sediments, and is towed behind a robust service vessel. Mechanical plowing has far more potential for significant environmental and water quality impacts to the marine environment than the proposed method of jet plow for a number of reasons including the weight applied to the plow results in furrow depth and surface sediment displacements that remain on either side of the trench, the extensive area of seabed directly disturbed, the environmental impacts associated with greater turbidity, and trench side casting and backfilling. Moreover, the trench depression would likely require backfilling with large volumes of imported clean sediment material. Consequently, these activities result in increased direct impacts to the seabed, water quality, and navigation as compared to the preferred hydraulic jetting methodology. Due to its limited burial depth capabilities and relatively greater environmental impacts to the benthic environment and water quality, as compared to hydraulic jetting, mechanical plowing would most likely not be a favored method.

### 4.2.3 Mechanical Dredging

Mechanical dredging entails the physical removal and disposal of sediments from the trench footprint. Mechanical dredging enables installing the cable to the required depths; however, it would require the mobilization of a large dredge plant operation for an extended duration with significantly greater environmental impacts than the preferred hydraulic jetting method. As compared to the preferred method, dredging would involve direct impacts to much greater areas of the seabed and significantly larger volumes of sediments and would significantly increase suspended sediment concentrations and turbidity in the water column. For these reasons, mechanical dredging would not normally be used for this type of installation of the submarine cable.
Once at the landfall, where HDD may not be necessary, mechanical trenching may be utilized to make the transition from the marine environment to the upland.

4.2.4 Horizontal Directional Drilling

HDD operations will likely be required at landfall locations and may also be used at selected crossings along the land cable route (e.g., streams, railroads, major crossing streets). HDD activity will involve a land-based HDD drilling rig system, drilling fluid recirculation systems, residuals management systems, and associated support equipment. A summary of HDD operations is provided below.

HDD entry pits will typically be 10 by 10 feet within a staging area of approximately 5,500 square feet, and exit pits will typically be 10 by 20 feet. The HDD operations areas will each be approximately 75 feet long by 75 feet wide.

A bentonite and freshwater slurry will be injected into the borehole to hold the bore open for insertion of the plastic conduit casing as the bore proceeds. When the drill bit advances to exit points, the bit will be replaced with a series of reamers to widen the borehole. Once the desired borehole diameter is achieved, a pulling head will be placed on the end of the drill pipe and the pipe will be used to pull a section of HDPE conduit into the bored hole from the exit end. Once the cables have been pulled into the HDPE conduit, a clay/bentonite medium will be inserted to fill the void between the cable and the HDPE conduit, and the HDPE conduit ends will be sealed.

4.3 Conceptual Cost Estimates

Due to the size, complexity, and limited number of existing projects using this offshore technology, the estimates were produced using publicly available information. This information includes manufacturer press releases, conference papers, and other project cost documents using similar technologies.

Currently there are approximately four offshore projects that are either in the design, manufacturing, construction or commissioning phase that use HVDC for the offshore to onshore transmission system. Presently only one offshore HVDC project in the design phase is similar in size to the 1,000 MW Transmission Block described here. All of the projects referenced are in the North Sea region of Europe.

The cost estimates provided below are indicative estimates calculated by using the project pricing that is publicly available. This information has been used to estimate the low to high price range from the EPC (engineer-procure-construct) supplier(s). The EPC price also includes commissioning of the facilities, documentation, general warranty, training, and spare parts. Please note that the EPC price is typically 80% of the total project cost. Indirect costs (land and easements, permitting, regulatory, finance, insurance, project development, legal, Allowance For Funds Used During Construction, etc.) account for the remaining 20% of the project cost. A majority of the manufacturers that construct the specialized equipment required for the proposed project are located in Europe and Asia. This may result in pricing volatility due to the exchange rate between the foreign currency and the U.S. dollar. Transmission system costs are also highly sensitive to the price of raw materials, such as copper, steel, and aluminum, required which can vary widely depending on global demand.

Table 3 illustrates the indicative cost estimate of a 1,000 MW offshore wind farm collector and transmission system. This estimate assumes that the offshore HVDC Converter Platform would be located near the center of the MAWEA. The HVDC cable from the RIMA WEA would be approximately 50 miles shorter. This estimate does not include the cost of the wind turbines or intra-array cabling.
Table 3. 1,000 MW Transmission Block Cost Estimate

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Cost</th>
<th>Quantity</th>
<th>Estimated Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVDC Converters</td>
<td>$750M – $925M</td>
<td>1 pair</td>
<td>$750M – $925M</td>
</tr>
<tr>
<td>HVDC cables (submarine &amp; land)</td>
<td>$2.0M – $3.0M/mile</td>
<td>100 miles</td>
<td>$200M – $300M</td>
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<tr>
<td>220 kV AC cables</td>
<td>$1.8M – $2.4M/mile</td>
<td>74 miles</td>
<td>$133M – $178M</td>
</tr>
<tr>
<td>Collector Substation</td>
<td>$45M – $70M</td>
<td>4 units</td>
<td>$180M – $280M</td>
</tr>
<tr>
<td>Project Indirect Costs:</td>
<td></td>
<td></td>
<td>$354M – $483M</td>
</tr>
</tbody>
</table>

| Project Total Cost (not including wind turbines or intra-array cabling): | $1.62B – $2.17B |

Assumptions: 6 MW wind machine with 3,500 ft. spacing (i.e., 7X rotor diameter), six machines per collector circuit with eight collector circuits per substation, 12 to 13 miles between Collector Substation(s) and Converter Platform.

5.0 ELECTRIC INTERCONNECTION POINTS

In general, Transmission Blocks should be interconnected to the ISO NE 345 kV system which consists of HV lines and associated 345 kV substations that effectively provides a transmission “Super Highway” that transmits large blocks of power between generation resources and load. Under normal system conditions, 345 kV transmission lines can each typically transmit 1,000 MW. In comparison, the lower voltage 115 kV transmission lines can each typically transmit approximately 200 MW. As a result, it is assumed, for the purposes of this study, that the 115 kV transmission system is not suitable for interconnecting projects in the RIMA WEA and MAWEA to the mainland grid. Therefore, in identifying interconnection locations the following criteria were established:

- A 345 kV substation;
- Substation should be relatively close to shore to minimize the length of the upland tie in; and
- Each Transmission Block should be electrically isolated to prevent a single contingency event where more than one Transmission Block can trip or be lost at any one time,

Based on these criteria, the following substations were identified and evaluated:

- Kent County Substation, West Warwick, RI
- Canal Substation, Sandwich, MA
- Brayton Point Substation, Somerset, MA
- Carver Substation, Carver, MA
- Oak Street Substation, Barnstable, MA
- Millstone Substation, Waterford, CT
- Montville Substation, Montville, CT

Although not in the ISO NE system, Shoreham Substation in Brookhaven, Long Island, New York was also investigated due to its proximity, large load and indication of possible interconnection from developers. The location of each interconnection point is shown on Figure 15.

It is not the intent nor is it possible to make definitive determinations of the impact, new transmission facilities and associated costs needed to interconnect one or more Transmission Blocks with the ISO NE system. This would require specific and detailed studies. Best engineering judgment has been applied to make reasonable assumptions about interconnection locations based upon the following criteria:
A Transmission Block and each 1,000 MW of existing generation connected to (or near) the 345 kV substation interconnection location would require one 345 kV transmission line to emanate from the 345 kV substation interconnection location.

Offshore wind generation would be curtailed during the infrequent periods when one of the 345 kV transmission lines emanating from the 345 kV substation interconnection location was out of service (i.e., N-1 contingency).

A Transmission Block would require that one new circuit breaker position be integrated into the 345 kV substation interconnection location.

Each new 345 kV transmission line would require that one new circuit breaker position be integrated into the 345 kV substation interconnection location and one new circuit breaker position be integrated into the 345 kV transmission line terminal 345 kV substation.

5.1 Conceptual Cost Basis

The cost associated with interconnecting up to two Transmission Blocks and integrating up to 2,000 MW of offshore wind capacity into the ISO NE system is expected to be small in comparison to the cost of two Transmission Blocks. The cost associated with interconnecting more than two Transmission Blocks and integrating up to 6,000 MW of WEA resource into the ISO NE system is expected to be significant and could exceed $1,000,000,000 depending upon the interconnection location.

The following was assumed as the basis for determining conceptual cost estimates for interconnecting and integrating one or more Transmission Blocks into the ISO NE system:

- One 345 kV air-insulated (AIS) circuit breaker position: $2,500,000
- One 345 kV gas-insulated (GIS) circuit breaker position: $10,000,000
- One mile of new 345 kV overhead transmission line: $5,000,000

As no load flow or other interconnection studies were conducted as part of the scope, in circumstances where a new 345 kV line was indicated, best engineering judgment was used to determine which 345 kV substation would be the best location to interconnect a new 345 kV line and the estimated length was based on the utilization of existing transmission line rights-of-way. The cost associated with interconnecting one, two, or three Transmission Blocks at each interconnection point is provided below. Based on the preliminary assessment conducted and best engineering judgment, interconnecting 3,000 MW to the ISO NE system would require substantially more upgrades including the construction of a new 345 kV transmission line.

5.2 Kent County Substation

The Kent County Substation is located in West Warwick, Kent County, Rhode Island. Figure 16 presents a wide area view and close area view of the Kent County Substation location and its proximity to the Narragansett Bay. The Kent County Substation is owned, operated, and maintained by National Grid and its principal purpose is to supply load in Rhode Island via 345 kV to 115 kV transformation facilities.

5.2.1 Interconnection and Integration of Transmission Blocks

The two existing 345 kV transmission lines to the West Farnum Substation and the underlying 115 kV transmission system should provide sufficient transmission capacity to allow interconnection of two Transmission Blocks and the integration of up to 2,000 MW of nameplate capacity into the ISO NE system without any new 345 kV transmission lines.

One new 345 kV transmission line would be required to interconnect three Transmission Blocks and integrate up to 3,000 MW of nameplate capacity into the ISO NE system. This would be a 345 kV transmission line to the West Farnum Substation and be approximately 22 miles in length.
5.2.2 Conceptual Cost Estimates

The conceptual cost estimates associated with the Kent County Substation interconnection location are provided in Table 4.

Table 4. Kent County Substation Conceptual Cost Estimates

<table>
<thead>
<tr>
<th>Transmission Blocks</th>
<th>Nameplate Capacity</th>
<th>Conceptual Substation Cost Estimate</th>
<th>Conceptual T-Line Cost Estimate</th>
<th>Total Conceptual Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,000 MW</td>
<td>$2.5M</td>
<td>$ ===</td>
<td>$2.5M</td>
</tr>
<tr>
<td>2</td>
<td>2,000 MW</td>
<td>$5M</td>
<td>$ ===</td>
<td>$5M</td>
</tr>
<tr>
<td>3</td>
<td>3,000 MW</td>
<td>$12.5M</td>
<td>$115M</td>
<td>$127.5M</td>
</tr>
</tbody>
</table>

Notes:
- One Transmission Block and 1,000 MW nameplate capacity: one AIS Circuit Breaker Position at $2,500,000 per position.
- Two Transmission Blocks and 2,000 MW nameplate capacity: two AIS Circuit Breaker Positions at $2,500,000 per position.
- Three Transmission Blocks and 3,000 MW nameplate capacity: five AIS Circuit Breaker Positions at $2,500,000 per position; and 22 miles of 345 kV transmission line at $5,000,000 per mile.

5.2.3 Other Factors to Consider

The upland cable route segment for this interconnection could be as short as 1.5 miles. The Kent Substation is surrounded by a large undeveloped area that provides adequate space to construct a Converter Station in close proximity to the existing substation.

The Kent County Substation serves load in southwestern Rhode Island and there is currently no competing generation resources for the 345 kV transmission capacity emanating from the Kent County Substation.

5.3 Canal Substation

The Canal Substation is located in Sandwich, Barnstable County, Massachusetts. Figure 17 presents a wide area view and a close area view of the Canal Substation location and its proximity to the Massachusetts coastline and the Cape Code Canal. The Canal Substation is owned, operated, and maintained by NSTAR and its principal purpose is to integrate the Canal Generating Plant into the ISO NE system and to provide a connection to the ISO NE 115 kV system and associated load via 345 kV to 115 kV transformation facilities.

The Canal Generating Plant (total of 1,100 MW) is assumed to remain an ISO NE generation capacity resource and not retired and decommissioned.

5.3.1 Interconnection and Integration of Transmission Blocks

The four existing 345 kV transmission lines to the Carver Substation (two 345 kV transmission lines), Oak Street Substation, and Pilgrim/Auburn Street, and the underlying 115 kV transmission system should provide sufficient transmission capacity to allow interconnection of two Transmission Blocks and the integration of up to 2,000 MW of WEA resource into the ISO NE without any new 345 kV transmission lines.

One new 345 kV transmission line would be required to interconnect three Transmission Blocks and integrate up to 3,000 MW of WEA resource into the ISO NE system. This would be a 345 kV transmission line to the West Walpole Substation and be approximately 50 miles in length.

5.3.2 Conceptual Cost Estimates

The conceptual cost estimates associated with the Canal Substation interconnection location are provided in Table 5.
Table 5. Canal Substation Conceptual Cost Estimates

<table>
<thead>
<tr>
<th>Transmission Blocks</th>
<th>Nameplate Capacity</th>
<th>Conceptual Substation Cost Estimate</th>
<th>Conceptual T-Line Cost Estimate</th>
<th>Total Conceptual Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,000 MW</td>
<td>$2,500,000</td>
<td>$===</td>
<td>$2,500,000</td>
</tr>
<tr>
<td>2</td>
<td>2,000 MW</td>
<td>$5,000,000</td>
<td>$===</td>
<td>$5,000,000</td>
</tr>
<tr>
<td>3</td>
<td>3,000 MW</td>
<td>$12,500,000</td>
<td>$250,000,000</td>
<td>$262,500,000</td>
</tr>
</tbody>
</table>

Notes:
- One Transmission Block and 1,000 MW nameplate capacity: one AIS Circuit Breaker Position at $2,500,000 per position.
- Two Transmission Blocks and 2,000 MW nameplate capacity: two AIS Circuit Breaker Positions at $2,500,000 per position.
- Three Transmission Blocks and 3,000 MW nameplate capacity: five AIS Circuit Breaker Positions at $2,500,000 per position; and 50 miles of 345 kV transmission line at $5,000,000 per mile.

5.3.3 Other Factors to Consider

The upland cable route segment to Canal Substation is anticipated to be approximately 10 miles in length. The Canal Substation has adequate space to construct a Converter Station in close proximity to the existing substation.

Electricity generated by the Cape Wind Project, which will interconnect at the Barnstable Switching Station in Barnstable, Massachusetts, will transmit through 115 kV lines that connect through the Bourne Switching Station and therefore compete for transmission system capacity with capacity connected at the Canal Substation. Retirement and decommissioning of the Canal Generating Plant would be a benefit to WEA resource integration by removing 1,100 MW of capacity from the Canal Substation.

Reactive power provided by an interconnection at this location would provide a benefit to the ISO NE system in regulating and maintaining regional system voltage. This would be especially true if the Canal Generating Station is retired and decommissioned as its reactive power capability would no longer be available.

5.4 Brayton Point Substation

The Brayton Point Substation is located in Somerset, Bristol County, Massachusetts. Figure 18 presents a wide area view and a close area view of the Brayton Point Substation location and its proximity to Narragansett Bay. The Brayton Point Substation is owned, operated, and maintained by National Grid and its principal purpose is to integrate the Brayton Point Generating Plant into the ISO NE system and to provide a connection to the ISO NE 115 kV system and associated load via 345 kV to 115 kV transformation facilities.

All Brayton Point Generating Units are expected to be retired and will be decommissioned starting in 2017 and therefore have been presumed not in service for this evaluation.

5.4.1 Interconnection and Integration of Transmission Blocks

The existing 345 kV transmission lines to the West Farnum Substation and the Berry Street Substation and underlying 115 kV transmission system should provide sufficient transmission capacity to allow interconnection of two Transmission Blocks and the integration of up to 2,000 MW of WEA resource into the ISO NE system without any new 345 kV transmission lines.

One new 345 kV transmission line would be required to interconnect three Transmission Blocks and integrate up to 3,000 MW of WEA resource into the ISO NE system. This would be a 345 kV transmission line to the West Farnum Substation and be approximately 40 miles in length.
GIS switch gear, which is more expensive than AIS would be required in order to match the existing equipment configuration and due to space constraints.

### 5.4.2 Conceptual Cost Estimates

The conceptual cost estimates associated with the Brayton Point Substation interconnection location are provided in Table 6.

#### Table 6. Brayton Point Substation Conceptual Cost Estimates

<table>
<thead>
<tr>
<th>Transmission Blocks</th>
<th>Nameplate Capacity</th>
<th>Conceptual Substation Cost Estimate</th>
<th>Conceptual T-Line Cost Estimate</th>
<th>Total Conceptual Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,000 MW</td>
<td>$10,000,000</td>
<td>$===</td>
<td>$10,000,000</td>
</tr>
<tr>
<td>2</td>
<td>2,000 MW</td>
<td>$20,000,000</td>
<td>$===</td>
<td>$20,000,000</td>
</tr>
<tr>
<td>3</td>
<td>3,000 MW</td>
<td>$42,500,000</td>
<td>$200,000,000</td>
<td>$242,500,000</td>
</tr>
</tbody>
</table>

Notes:
- One Transmission Block and 1,000 MW nameplate capacity: one GIS Circuit Breaker Position at $10,000,000 per position.
- Two Transmission Blocks and 2,000 MW nameplate capacity: two GIS Circuit Breaker Positions at $10,000,000 per position.
- Three Transmission Blocks and 3,000 MW nameplate capacity: four GIS Circuit Breaker Positions at $10,000,000 per position; one AIS Circuit Breaker Position at $2,500,000 per position; and 40 miles of 345 kV transmission line at $5,000,000 per mile.

### 5.4.3 Other Factors to Consider

Brayton Point is located on shore of Mount Hope Bay and therefore the upland cable route segment could be shorter than 1 mile. The Brayton Point Substation is surrounded by a large industrial complex that could provide adequate space to construct a Converter Station in close proximity to the existing substation. Any long-term comprehensive planning for the Brayton Point site upon decommissioning of the existing facility should consider setting aside approximately 10 acres near the substation to support offshore wind interconnection infrastructure.

If new generation were to be developed at the Brayton Point Site, this would also compete for the transmission system capacity emanating from the Brayton Point Substation.

### 5.5 Carver Substation

The Carver Substation is located in Carver, Plymouth County, Massachusetts. Figure 19 presents a wide area view and a close area view of the Carver Substation location. The Carver Substation is owned, operated, and maintained by NSTAR and its principal purpose is to supply ISO NE load in Massachusetts via 345 kV to 115 kV transformation facilities.

It has been assumed that the Canal Generating Plant (total of 1,100 MW) remains an ISO NE generation capacity resource and is not decommissioned. Generation from the Canal Substation feeds into the 345 kV (and 115 kV) system that is interconnected to the Carver Substation via a 345 kV line.

#### 5.5.1 Interconnection and Integration of Transmission Blocks

The two existing 345 kV transmission lines to the Canal Substation, West Walpole Substation, and the underlying 115 kV transmission system should provide sufficient transmission capacity to allow interconnection of one Transmission Block and the integration of up to 2,000 MW of WEA resource into the ISO NE system without any new 345 kV transmission lines.

One new 345 kV transmission line would be required to interconnect three Transmission Blocks and integrate up to 3,000 MW of WEA resource into the ISO NE system. This would be a 345 kV transmission line to the West Walpole Substation which would be approximately 30 miles in length.
5.5.2 Conceptual Cost Estimates

The conceptual cost estimates associated with the Carver Substation interconnection location are provided in Table 7.

<table>
<thead>
<tr>
<th>Transmission Blocks</th>
<th>Nameplate Capacity</th>
<th>Conceptual Substation Cost Estimate</th>
<th>Conceptual T-Line Cost Estimate</th>
<th>Total Conceptual Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,000 MW</td>
<td>$2,500,000</td>
<td>$2,500,000</td>
<td>$2,500,000</td>
</tr>
<tr>
<td>2</td>
<td>2,000 MW</td>
<td>$5,000,000</td>
<td>$5,000,000</td>
<td>$5,000,000</td>
</tr>
<tr>
<td>3</td>
<td>3,000 MW</td>
<td>$12,500,000</td>
<td>$150,000,000</td>
<td>$162,500,000</td>
</tr>
</tbody>
</table>

Notes:
- One Transmission Block and 1,000 MW nameplate capacity: one AIS Circuit Breaker Position at $2,500,000 per position.
- Two Transmission Blocks and 2,000 MW nameplate capacity: two AIS Circuit Breaker Positions at $2,500,000 per position.
- Three Transmission Blocks and 3,000 MW nameplate capacity: five AIS Circuit Breaker Positions at $2,500,000 per position; and 30 miles of 345 kV transmission line at $5,000,000 per mile.

5.5.3 Other Factors to Consider

The Carver Substation is surrounded by residential areas and agricultural lands (cranberry bogs) and there is no obvious area to install a Converter Station in the immediate vicinity of the existing substation. This interconnection point will be challenging from the perspective of siting the Converter Station. If an interconnection was made at this location, it would provide reactive power that would benefit the ISO NE system in regulating and maintaining regional system voltage.

5.6 Oak Street Substation

The Oak Street Substation is located in Barnstable, Barnstable County, Massachusetts. Figure 20 presents a wide area view and a close area view of the Oak Street Substation location. The Oak Street Substation is owned, operated, and maintained by NSTAR and its principal purpose is to supply load on Cape Cod, Massachusetts via 345 kV to 115 kV transformation facilities.

It is assumed that the Canal Generating Plant (total of 1,100 MW) remains an ISO NE generation capacity resource that would utilize or compete for existing transmission capacity that may be needed for offshore wind capacity which would be integrated at the Oak Street Substation.

5.6.1 Interconnection and Integration of Transmission Blocks

The existing 345 kV transmission line between the Oak Street and Canal Substations and the underlying 115 kV transmission system should provide sufficient transmission capacity to allow interconnection of one Transmission Block and the integration of up to 1,000 MW of WEA resource into the ISO NE system without any new 345 kV transmission lines.

One new 345 kV transmission line would be required to interconnect two Transmission Blocks and integrate up to 2,000 MW of WEA resource into the ISO NE system. This would be a 345 kV transmission line to the Canal Substation and be approximately 15 miles in length.

Two new 345 kV transmission lines would be required to interconnect three Transmission Blocks and integrate up to 3,000 MW of WEA resource into the ISO NE system. In addition to the 345 kV transmission line to the Canal Substation, a 345 kV transmission line to the West Walpole Substation would be added and be approximately 65 miles in length.

5.6.2 Conceptual Cost Estimates

The conceptual cost estimates associated with the Oak Street Substation interconnection location are provided in Table 8.
Table 8. Oak Street Substation Conceptual Cost Estimates

<table>
<thead>
<tr>
<th>Transmission Blocks</th>
<th>Nameplate Capacity</th>
<th>Conceptual Substation Cost Estimate</th>
<th>Conceptual T-Line Cost Estimate</th>
<th>Total Conceptual Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,000 MW</td>
<td>$2,500,000</td>
<td>$===</td>
<td>$2,500,000</td>
</tr>
<tr>
<td>2</td>
<td>2,000 MW</td>
<td>$10,000,000</td>
<td>$75,000,000</td>
<td>$85,000,000</td>
</tr>
<tr>
<td>3</td>
<td>3,000 MW</td>
<td>$17,500,000</td>
<td>$400,000,000</td>
<td>$417,500,000</td>
</tr>
</tbody>
</table>

Notes:
- One Transmission Block and 1,000 MW nameplate capacity: one AIS Circuit Breaker Position at $2,500,000 per position.
- Two Transmission Blocks and 2,000 MW nameplate capacity: four AIS Circuit Breaker Positions at $2,500,000 per position; and 15 miles of 345 kV transmission line at $5,000,000 per mile.
- Three Transmission Blocks and 3,000 MW nameplate capacity: seven AIS Circuit Breaker Positions at $2,500,000 per position; and 80 miles of 345 kV transmission line at $5,000,000 per mile.

5.6.3 Other Factors to Consider

The estimated HVDC transmission cable route extending from MAWEA to the Oak Street Substation would likely be 50 to 60 miles if the route were to follow Muskeget Channel and cross Nantucket Sound in the vicinity of the Cape Wind lease area. This interconnection point is not considered viable for the RIMA WEA given the proximity of other interconnection points. Depending on where the submarine cable makes landfall, the upland cable route segment could be approximately 10 miles.

The Oak Street Substation is approximately 3.5 miles west of the 115 kV substation where the Cape Wind Project will interconnect. The results described above do not assume Cape Wind is in-service and the competition for transmission capacity at Oak Street once Cape Wind becomes operational may limit the availability of Oak Street to accept additional offshore wind capacity. Further load-flow analysis would be required to fully examine these implications.

Reactive power provided by an interconnection at this location would provide a benefit to the ISO NE system in regulating and maintaining regional system voltage. This would be especially true if the Canal Generating Station is retired and decommissioned as its reactive power capability would no longer be available.

5.7 Millstone Substation

The Millstone Substation is located in Town of Waterford, New London County, Connecticut. Figure 21 presents a wide area view and a close area view of the Millstone Substation location and its proximity to the Connecticut coastline. The Millstone Substation is owned, operated, and maintained by Northeast Utilities and its principal purpose is to integrate the Millstone Nuclear Generating Plant into the ISO NE 345 kV transmission system. It has been assumed that the Millstone Nuclear Generating Plant (total of 2,020 MW) will remain a generating resource.

5.7.1 Interconnection and Integration of Transmission Blocks

The four existing 345 kV transmission lines to the Southington Substation, Manchester Substation, Montville Substation, and Card Substation should provide sufficient transmission capacity to allow interconnection of one Transmission Block and the integration of up to 2,000 MW of WEA resource into the ISO NE without any new 345 kV transmission lines.

One new 345 kV transmission line would be required to interconnect three Transmission Blocks and integrate up to 3,000 MW of WEA resource into the ISO NE system. This would be a 345 kV transmission line to the Kent County Substation which would be approximately 50 miles in length.
5.7.2 Conceptual Cost Estimates

The conceptual cost estimates associated with the Millstone Substation interconnection location are provided in Table 9.

Table 9. Millstone Substation Conceptual Cost Estimates

<table>
<thead>
<tr>
<th>Transmission Blocks</th>
<th>Nameplate Capacity</th>
<th>Conceptual Substation Cost Estimate</th>
<th>Conceptual T-Line Cost Estimate</th>
<th>Total Conceptual Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,000 MW</td>
<td>$2,500,000</td>
<td>$150,000,000</td>
<td>$2,500,000</td>
</tr>
<tr>
<td>2</td>
<td>2,000 MW</td>
<td>$5,000,000</td>
<td>$150,000,000</td>
<td>$5,000,000</td>
</tr>
<tr>
<td>3</td>
<td>3,000 MW</td>
<td>$12,500,000</td>
<td>$250,000,000</td>
<td>$262,500,000</td>
</tr>
</tbody>
</table>

Notes:
- One Transmission Block and 1,000 MW nameplate capacity: one AIS Circuit Breaker Position at $2,500,000 per position.
- Two Transmission Blocks and 2,000 MW nameplate capacity: two AIS Circuit Breaker Positions at $2,500,000 per position.
- Three Transmission Blocks and 3,000 MW nameplate capacity: five AIS Circuit Breaker Positions at $2,500,000 per position; and 50 miles of 345 kV transmission line at $5,000,000 per mile.

5.7.3 Other Factors to Consider

The estimated HVDC transmission cable route extending from Lease Area 2 in the MAWEA to the Millstone Substation would likely be 110 to 120 miles. The cable route from the RIMA WEA is estimated to be nearly 50 miles shorter. The Millstone Substation is close to the Connecticut coastline thus minimizing the length and cost of each Transmission Block underground DC cable system and it appears that sufficient land options are available in the vicinity of the Millstone Substation to locate Transmission Block Converter Stations. However, certain lands in the vicinity of the Millstone Substation may be under the control of the Nuclear Regulatory Commission. Moreover, there are special technical considerations when integrating DC technology at the same location as a large thermal generating station and in particular a nuclear station that would require review and approval by the Nuclear Regulatory Commission. Therefore, this location is not as favorable a tie-in point relative to the Kent County Substation, Canal Substation, and Brayton Point Substation.

5.8 Montville Substation

The Montville Substation is located in the Town of Montville, New London County, Connecticut. Figure 22 presents a wide area view and a close area view of the Montville Substation location and its proximity to the Thames River and Connecticut coastline. The Montville Substation is owned, operated, and maintained by Northeast Utilities and its principal purpose is to integrate the Montville Generating Plant into the ISO NE system and to provide a connection to the ISO NE 115 kV system and associated load via 345 kV to 115 kV transformation facilities. It is assumed that the Montville Generating Plant (total of 80 MW) will remain an ISO NE generation capacity resource and is not retired and decommissioned.

5.8.1 Interconnection and Integration of Transmission Blocks

The two existing 345 kV transmission lines to the Millstone Substation and the Haddam Neck should provide sufficient transmission capacity to allow interconnection of one Transmission Block and the integration of up to 2,000 MW of WEA resource into ISO NE without any new 345 kV transmission lines.

One new 345 kV transmission line would be required to interconnect three Transmission Blocks and integrate up to 3,000 MW of WEA resource into the ISO NE system. This would be a 345 kV transmission line to the Kent County Substation which would be approximately 45 miles in length.

5.8.2 Conceptual Cost Estimates

The conceptual cost estimates associated with the Montville Substation interconnection location are provided in Table 10.
Table 10. Montville Substation Conceptual Cost Estimates

<table>
<thead>
<tr>
<th>Transmission Blocks</th>
<th>Nameplate Capacity</th>
<th>Conceptual Substation Cost Estimate</th>
<th>Conceptual T-Line Cost Estimate</th>
<th>Total Conceptual Cost Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,000 MW</td>
<td>$2,500,000</td>
<td>$ ===</td>
<td>$2,500,000</td>
</tr>
<tr>
<td>2</td>
<td>2,000 MW</td>
<td>$5,000,000</td>
<td>$ ===</td>
<td>$5,000,000</td>
</tr>
<tr>
<td>3</td>
<td>3,000 MW</td>
<td>$12,500,000</td>
<td>$225,000,000</td>
<td>$237,500,000</td>
</tr>
</tbody>
</table>

Notes:
- One Transmission Block and 1,000 MW nameplate capacity: one AIS Circuit Breaker Position at $2,500,000 per position.
- Two Transmission Blocks and 2,000 MW nameplate capacity: two AIS Circuit Breaker Positions at $2,500,000 per position.
- Three Transmission Blocks and 3,000 MW nameplate capacity: five AIS Circuit Breaker Positions at $2,500,000 per position; and 45 miles of 345 kV transmission line at $5,000,000 per mile.

5.8.3 Other Factors to Consider

The estimated HVDC transmission cable route extending from Lease Area 2 in the MAWEA to the Montville Substation would likely be 120 to 130 miles. The cable route from the RIMA WEA is estimated to be nearly 50 miles shorter. The Montville Substation is close to the Thames River thus minimizing the length and cost of each Transmission Block land cable system. However, it does not appear that sufficient land options are available in the vicinity of the Montville Substation to locate Transmission Block Converter Stations.

Given its proximity to the Millstone Nuclear Generating Plant, the same special technical considerations associated with the Millstone Substation interconnection location are also present here. Therefore this tie-in point is not as favorable relative to the Kent County Substation, Canal Substation, and Brayton Point Substation.

5.9 Shoreham Substation

The Shoreham Substation is located in Town of Brookhaven, Suffolk County, New York. Figure 23 presents a wide area view and a close area view of the Shoreham Substation location. The Shoreham Substation is owned, operated, and maintained by LIPA and its principal purpose is to integrate the Cross Sound Cable and generation resources into the LIPA 138 kV transmission system.

The New York Independent System Operator transmission system on Long Island is 138 kV and in comparison to the 345 kV ISO NE system is not able to transmit large blocks of power. There are four 138 kV lines emanating from the Shoreham Substation which currently provides for the transmission capacity needed for the Cross Sound Cable Project and local generation. The Shoreham Substation has been evaluated by Deepwater Wind as a potential interconnection location for up to 600 MW\(^8\) of offshore renewable energy generated in the RIMA WEA. The interconnection of just one Transmission Block of 1,000 MW would require significant 138 kV system upgrades on Long Island and possibly an Island-wide upgrade to 345 kV transmission. In addition, the integration of more than one Transmission Block would require significant upgrades to the transmission system into New York City and upstate New York. Therefore this location has been eliminated from any further consideration.

5.10 Interconnection Point Ranking

Table 11 was developed based on the information presented throughout this section to summarize the critical parameters for each of the substation locations and identify a tiered ranking (1, 2, and 3) to determine the preferred interconnection locations for each build out scenario. The ranking is based on the following parameters:

---

\(^8\) New York Energy Highway submittal May 2012.
• Cost of substation upgrades;
• Approximate total undersea cable length (as a proxy for cost);
• Approximate length of upland cable (as a proxy for stakeholder resistance);
• Proximity of space available for Converter Station; and
• Competition for transmission resources.

Results indicate that Brayton Point, Canal, and Kent County Substations are the most attractive interconnection points. While the overall distance to Canal and Brayton are roughly equivalent, the cost to upgrade the Brayton Substation is considerably higher than for Canal. The length of upland cable route estimated to connect at the Canal Substation is longer. Overall these three substations are considered to be the most likely targets for both near-term and long-term integration of offshore wind energy from the MAWEA and RIMA WEA.

Table 11. Summary of Interconnection Points

<table>
<thead>
<tr>
<th>Interconnection</th>
<th>State</th>
<th>Owner</th>
<th>Approximate Total Cable Route Length</th>
<th>Approximate Land Cable Route Length</th>
<th>Approximate Submarine Cable Route Length</th>
<th>Substation Improvement for a 1,000 MW Project</th>
<th>Proximity of Potential Converter Station Parcel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brayton Point</td>
<td>MA</td>
<td>National Grid</td>
<td>45 – 95</td>
<td>&lt;1</td>
<td>45 – 95</td>
<td>$10M</td>
<td>Close</td>
</tr>
<tr>
<td>Canal</td>
<td>MA</td>
<td>NSTAR</td>
<td>60 – 100</td>
<td>10</td>
<td>50 – 90</td>
<td>$2.5M</td>
<td>Close</td>
</tr>
<tr>
<td>Kent County</td>
<td>RI</td>
<td>National Grid</td>
<td>51 – 96</td>
<td>1</td>
<td>40 – 95</td>
<td>$2.5M</td>
<td>Close</td>
</tr>
<tr>
<td>Carver</td>
<td>MA</td>
<td>NSTAR</td>
<td>65 – 105</td>
<td>20</td>
<td>45 – 85</td>
<td>$2.5M</td>
<td>Not Close</td>
</tr>
<tr>
<td>Oak Street</td>
<td>MA</td>
<td>NSTAR</td>
<td>50 – 60</td>
<td>10</td>
<td>45 – 60</td>
<td>$2.5M</td>
<td>Not Close</td>
</tr>
<tr>
<td>Millstone</td>
<td>CT</td>
<td>Northeast Utilities</td>
<td>60 – 120</td>
<td>&lt;1</td>
<td>60 – 120</td>
<td>$2.5M</td>
<td>Close</td>
</tr>
<tr>
<td>Montville</td>
<td>CT</td>
<td>Northeast Utilities</td>
<td>65 – 130</td>
<td>&lt;1</td>
<td>65 – 130</td>
<td>$2.5M</td>
<td>Close</td>
</tr>
</tbody>
</table>

1. Land Cable Routes were estimated based on existing upland transmission rights-of-way and the assumption that space was available to accommodate the required lines. Detailed assessments of available space within the existing right-of-way or possible limitations (e.g., congestion) that might prohibit the use any given right-to-way for a proposed HVDC transmission cable are beyond the scope of this study.

6.0 LAND-BASED CONSTRAINTS

6.1 Criteria for Selection of Landfall

The objective of identifying and evaluating a potential landfall location would be to determine a location that meets the following criteria:

• Proximity to preferred substations in order to minimize overall cable length, electrical losses, environmental impacts, and costs;
• Sufficient space for landfall transition operations and equipment, including HDD operations as well as for locating the permanent transition vault;
• Construction accessibility;
• Availability of a route from the point of landfall to the Converter Station that is as straightforward as the natural environment and affected communities allow;
Minimal interference with maritime traffic;
Minimal risks of drilling under existing structures;
Minimal disruption to public amenities in the area; and
Minimal disruption to surrounding land uses, traffic, and community activities.

A detailed cable routing assessment is beyond the scope of this study and therefore landfall locations have not been identified. There are a variety of options for where to make landfall and for routing upland cables. Early stakeholder engagement and diligent routing assessments will be critical to identifying appropriate locations given the sensitivity of many of these coastal communities.

6.2 Criteria for Selection of Cable Routes

Once the onshore and offshore Converter Station sites are identified the HVDC cable route can be evaluated. To identify potential land and submarine cable routes, a number of factors concerning environmental impact, constructability, efficiency of the system, and cost are taken into account. Developers would likely attempt to minimize overall route length, avoid geologic and navigational constraints, and avoid environmentally sensitive areas. The following criteria would likely be used for selection of Cable Routes:

- Minimize overall cable length, to reduce electrical losses, environmental impacts and costs;
- Maximize use of existing rights-of-way;
- Minimize turns (related to acceptable bending radius of the cable) and significant elevation changes;
- Minimize disturbances to environmental resources such as wetlands and other environmentally sensitive lands;
- Reduce potential for navigational conflicts;
- Minimize the crossing impacts associated with established vessel anchorages, mooring areas, and existing submarine infrastructure such as cables, pipelines, municipal water intakes, etc.;
- Avoid or minimize environmental impacts to aquatic resources and known submerged historical resources;
- Locate subsurface geological conditions conducive to burial of the Submarine Cable by jet plow embedment to avoid potential damage to the cable system and to minimize environmental impacts;
- Avoid/minimize impacts to sensitive habitat areas such as protected species, essential fish habitat, and protected habitats where possible; and
- Water depth.

A detailed routing assessment is beyond the scope of this study. However, for a number of reasons consistent with the siting criteria described above and given the population density in Rhode Island and southeastern Massachusetts, upland cable routes for offshore wind energy projects are likely to follow existing overhead rights-of-way or transportation rights-of-way to the maximum extent practicable.

6.3 Criteria for Selection of Converter Station Location

Potential locations for land-side Converter Station sites would likely be identified and evaluated using the following criteria:

- Converter Station sites should be close to the selected substation interconnection to minimize overall cable length and corresponding electrical losses, environmental impacts and construction costs;
- Land must be available for purchase or long-term lease;
- Site must have sufficient space available to construct a Converter Station on relatively flat topography; and
- Use of site for Converter Station must be compatible with neighborhood and nearby land uses.

Identifying specific parcels that could be developed as a Converter Station location is beyond the scope of this study. However, aerial photography was reviewed for each potential interconnection point identified in Section 4 and potential sites were identified within several miles of the substations.

7.0 TRANSMISSION CONFIGURATION ALTERNATIVES/BUILD OUT SCENARIOS

As discussed previously, short-term and long-term planning horizons were defined for the purpose of this study. The short-term covers the next ten years and includes projects that are anticipated to move forward within 12 to 24 months of the lease auction that will be developed with fixed-bottom foundations in waters depths less than 50 meters. The long-term is defined as more than ten years from present and is assumed to include projects that may employ next-generation floating technology installed where water depths exceed 50 meters.

Four build out scenarios were developed for the near-term planning horizon, which is the focus of this study. The scenarios represent individual, hypothetical stages in the sequential development of the MAWEA and RIMA WEA. Together, the build out scenarios provide a useful framework to describe and evaluate the transmission infrastructure necessary to interconnect future Massachusetts offshore wind projects to the New England electric grid. The four scenarios for build out of the RIMA WEA and MAWEA areas are as follows:

- Scenario 1 (Highly Conservative): 500 MW
- Scenario 2 (Conservative): 1,000 MW
- Scenario 3 (Moderate): 2,000 MW
- Scenario 4 (Ambitious): 3,000 MW

As described previously, this study was undertaken to explore the technical characteristics of offshore wind transmission infrastructure independent of the market and policy factors widely recognized as principal drivers affecting the scale and pace of offshore wind development in the region. Accordingly, the increasing project size captured in each build out scenario equates with the incremental addition of 500 to 1,000 MW Transmission Blocks. While this development path is hypothetical, it does represent the optimal approach to achieve transmission-related economies of scale. However, market and policy factors may exhibit a greater influence on the size of offshore wind projects developed in the region. For example, projects ranging from 200 to 400 MW could also proceed and are considered more viable by some industry stakeholders due to scale of policy and financing mechanisms thought to be potentially feasible in the near-term.

7.1 Near Term Build Out Scenarios

7.1.1 Highly Conservative: 500 MW Total Capacity

A single project could provide this capacity from either the RIMA WEA or MAWEA. According to the NREL study, each of the MAWEA lease areas could host 1,000 MW of installed capacity. NREL estimates that each lease area has shallow water zones (30 to 50 meters) that are large enough to sustain at least 500 MW of total capacity using current wind turbine foundation technology. Furthermore, economies of scale associated with the transmission system required to deliver 500 MW of offshore wind energy to the grid would likely favor a single project over multiple smaller projects aggregating to a total capacity of 500 MW.
In light of the fact that current HVDC technology will allow for as much as 1,000 MW of transmission capacity with a single collector station it is likely that a single developer would deliver 500 MW of capacity through a single Transmission Block (see Figure 24A). If instead multiple projects are developed in parallel, the possibility exists that each developer may construct their own Collector Station but collaborate on the HVDC transmission system (Converter Stations and HVDC cabling) as shown in Figure 24B. Given the economics of building entirely independent HVDC transmission systems for two nearby projects, it seems unlikely that two entirely separate HVDC systems would be constructed under this scenario.

The most likely build out under this scenario involves a single HVDC transmission system interconnecting at one of the three Tier 1 substations (Kent, Canal, or Brayton Point). In either ownership scenario, it would seem reasonable to anticipate that the HVDC cable would be sized for 1,000 MW of capacity even if a project is only brought forward at the 500 MW level due to the relatively small incremental cost of the cable.

Based on the cost estimates provided in Sections 4 and 5, the total estimated cost to build transmission system adequate for 500 MW of generating capacity is presented in Table 12. At a minimum the economy of scale of one transmission cable system as compared to two independent systems will be realized in the added cost to construct two sets of Converter Stations and two HVDC cable circuits.

Table 12. 500 MW Scenario Project Cost

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Cost</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVDC Converters</td>
<td>$450M – $600M/pair</td>
<td>1 pair</td>
<td>$450M – $600M</td>
</tr>
<tr>
<td>HVDC cables (submarine and land)</td>
<td>$2.0M – $3.0M/mile</td>
<td>45 – 100 miles</td>
<td>$90M – $300M</td>
</tr>
<tr>
<td>220 kV AC cables</td>
<td>$1.8M – $2.4M/mile</td>
<td>37 miles</td>
<td>$67M – $89M</td>
</tr>
<tr>
<td>Collector Sub platform</td>
<td>$45M – $70M</td>
<td>2 units</td>
<td>$90M – $140M</td>
</tr>
<tr>
<td>Substation Upgrade at one Tier 1 Substation</td>
<td></td>
<td></td>
<td>$2.5M – $5.0M</td>
</tr>
<tr>
<td>Project Indirect Costs:</td>
<td></td>
<td></td>
<td>$177M – $245M</td>
</tr>
<tr>
<td><strong>Project Total Cost (not including the wind turbines or intra-array cabling):</strong></td>
<td></td>
<td></td>
<td><strong>$877M – $1.48B</strong></td>
</tr>
</tbody>
</table>

Assumptions: 6 MW wind machine with 3,500 ft. spacing (i.e., 7X rotor diameter), six machines per collector circuit with eight collector circuits per substation, 12 to 13 miles between Collector Substation(s) and Converter Platform.

### 7.1.2 Conservative: 1,000 MW Total Capacity

A single project could provide a total capacity of 1,000 MW, in a single lease area based on the resource assessment developed by NREL for the MAWEA lease areas. As described in Section 3, current HVDC transmission technology is limited to 1,000 MW of capacity which represents an upper limit for a single Transmission Blocks. Additional build out capacity (e.g., 2,000 MW) can be achieved, but will require more multiple Transmission Blocks. Therefore, regardless of whether the total capacity under this scenario is delivered within a single lease area or two lease areas (each 500 MW projects), it seems reasonable to anticipate that a single transmission system will be designed to carry the full generating capacity and would interconnect at one of the three Tier 1 locations (see Figure 25). Lease holders (i.e., wind energy developers) may not be inclined to collaborate on the transmission system and may prefer to maintain their independence.

Based on the cost estimates provided in Sections 3 and 4, the total estimated cost to build transmission system adequate for 1,000 MW of generating capacity is presented in Table 13.
Table 13. 1,000 MW Scenario Project Cost

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Cost</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVDC Converters</td>
<td>$750M – $925M/pair</td>
<td>1 pair</td>
<td>$750M – $925M</td>
</tr>
<tr>
<td>HVDC cables (submarine and land)</td>
<td>$2.0M – $3.0M/mile</td>
<td>45 – 100 miles</td>
<td>$90M – $300M</td>
</tr>
<tr>
<td>220 kV AC cables</td>
<td>$1.8M – $2.4M/mile</td>
<td>74 miles</td>
<td>$133M – $178M</td>
</tr>
<tr>
<td>Collector Sub platform</td>
<td>$45M – $70M</td>
<td>4 units</td>
<td>$180M – $280M</td>
</tr>
</tbody>
</table>

Substation Upgrade at one Tier 1 Substation | $2.5M – $5.0M

Project Indirect Costs: $354M – $483M

**Project Total Cost (not including the wind turbines or intra-array cabling):** $1.51B – $2.17B

Assumptions: 6 MW wind machine with 3,500 ft. spacing (i.e., 7X rotor diameter), six machines per collector circuit with eight collector circuits per substation, 12 to 13 miles between Collector Substation(s) and Converter Platform.

7.1.3 Moderate: 2,000 MW Total Capacity

Given the technology limitations for HVDC transmission systems, 2,000 MW of total capacity would require two independent 1,000 MW Transmission Blocks. Whether each Transmission Block is owned and operated by a single developer or multiple developers is difficult to predict at this time. Independent developers may not be inclined to collaborate on the HVDC transmission system, which could reduce the likelihood that the two Transmission Blocks would be co-located to the maximum extent practicable and minimize the environmental impact unless regulatory requirements were able to mandate, or incentives were developed that would promote co-location of transmission infrastructure.

The need for two independent 1,000 MW Transmission Blocks raises the question of whether they would interconnect at the same onshore substation or different substations. Arguably, environmental impacts and costs would be minimized if the two cable systems (including Converter Stations) could be co-located and interconnect at the same substation. Based on the information provided in Section 5, there is no cost difference associated with substation upgrades required to interconnect 2,000 MW at the same or different locations. From a system reliability perspective, interconnection of each 1,000 MW Transmission Block at a different location is preferable. The likely interconnection locations for this scenario are any two of the Tier 1 substations (See Figure 26). If Kent and Brayton were selected the cable routes could be parallel for a considerable distance.

Based on the cost estimates provided in Sections 4 and 5, the total estimated cost to build transmission system adequate for 2,000 MW of generating capacity is presented in Table 14.

Table 14. 2,000 MW Scenario Project Cost

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Cost</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVDC Converters</td>
<td>$750M – $925M/pair</td>
<td>2 pairs</td>
<td>$1.5B – $1.8B</td>
</tr>
<tr>
<td>HVDC cables (submarine and land)</td>
<td>$2.0M – $3.0M/mile</td>
<td>145 – 200 miles</td>
<td>$290M – $600M</td>
</tr>
<tr>
<td>220 kV AC cables</td>
<td>$1.8M – $2.4M/mile</td>
<td>148 miles</td>
<td>$266M – $355M</td>
</tr>
<tr>
<td>Collector Sub platform</td>
<td>$45M – $70M</td>
<td>8 units</td>
<td>$360M – $560M</td>
</tr>
</tbody>
</table>

Substation Upgrade two Tier 1 Substations | $5M – $12.5M

Project Indirect Costs: $708M – $966M

**Project Total Cost (not including the wind turbines or intra-array cabling):** $3.13B – $4.29B

Assumptions: 12 to 13 miles between Collector Substation(s) and Converter Platform.
7.1.4 Aggressive: 3,000 MW Total Capacity

Given the technology limitations for HVDC Transmission Blocks, 3,000 MW of total capacity would require three independent 1,000 MW Transmission Blocks. Whether each Transmission Block is owned and operated by a single developer or multiple developers is difficult to predict at this time. Independent developers may not be inclined to collaborate on the HVDC transmission system, which could reduce the likelihood that the two Transmission Blocks would be co-located to the maximum extent practicable and minimize the environmental impact unless regulatory requirements were able to mandate co-location of transmission infrastructure.

As there would be three independent 1,000 MW Transmission Blocks they could have a number of upland interconnection points. As with the previous scenario, environmental impacts and costs would be minimized if the three cable systems (including Converter Stations) could be co-located and interconnect at the same locations. Based on the information provided in Section 5, there are significant cost increases if all three HVDC Transmission Blocks are connected at the same substation. Therefore it is reasonable to expect they will be separated. The substation upgrade costs to integrate two Transmission Blocks at one substation and one at another or all three at different substations are negligible to the total overall cost of this scenario. From a system reliability perspective, interconnection of each 1,000 MW Transmission Block at a different location is preferable. Therefore, under this scenario integration of 1,000 MW Transmission Blocks are predicted to occur at all three Tier 1 substations (see Figure 27).

Based on the cost estimates provided in Sections 3 and 4, the total estimated cost to build transmission system adequate for 3,000 MW of generating capacity is presented in Table 15.

Table 15. 3,000 MW Scenario Project Cost

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Cost</th>
<th>Quantity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVDC Converters</td>
<td>$750M – $925M/pair</td>
<td>3 pairs</td>
<td>$2.3B – $2.8B</td>
</tr>
<tr>
<td>HVDC cables (submarine and land)</td>
<td>$2.0M – $3.0M/mile</td>
<td>245 – 300 miles</td>
<td>$490M – $900M</td>
</tr>
<tr>
<td>220 kV AC cables</td>
<td>$1.8M – $2.4M/mile</td>
<td>222 miles</td>
<td>$400M – $533M</td>
</tr>
<tr>
<td>Collector Sub platform</td>
<td>$45M – $70M</td>
<td>12 units</td>
<td>$540M – $840M</td>
</tr>
<tr>
<td>Substation Upgrade at all three Tier 1 Substations</td>
<td></td>
<td></td>
<td>$15M</td>
</tr>
<tr>
<td>Project Indirect Costs:</td>
<td></td>
<td></td>
<td>$1.1B – $1.45M</td>
</tr>
<tr>
<td>Project Total Cost (not including the wind turbines or intra-array cabling):</td>
<td></td>
<td></td>
<td>$4.82B – $6.54B</td>
</tr>
</tbody>
</table>

7.2 Long-Term Scenario

In the longer term (more than 10 years in the future), development could continue in a similar fashion to that described above under the near term scenario for the remaining total capacity of the RIMA WEA and MAWEA (to get to the estimated 6,000 MW of total capacity). As wind turbine technology advances, it may become more economically and technically feasible to develop the deeper water areas of the RIMA WEA and MAWEA. Additionally, improvements in wind turbine technology that increase energy capture per turbine could result in higher installed capacities than previously estimated. As result, both limited and full build out capacities of the RIMA WEA and MAWEA may be achievable with fewer wind turbines.

Undeveloped areas in either the RIMA WEA or MAWEA after the original (near term) build out activity could be developed by the lease holders incrementally (500 to 750 MW blocks) as described above. Because conceivably, all the best and/or lowest cost interconnection locations and cable routes will be utilized by the initial phases of development, the subsequent transmission development could be more challenging and/or
expensive. Given the planning horizon considered, other factors may come into play including advances in transmission technology that could reduce costs or allow higher transfer capacities. Other upgrades that may be required to the electric grid for reasons beyond the interconnection of offshore wind could also factor into the interconnection of the later phases of development offshore as could the power market and political atmosphere.

### 7.3 Potential Offshore Wind Project Schedules

Under the BOEM process, the lease area auction only involves the area that will be occupied by wind turbine generators, inner array cabling, electric Collector Substation, HVAC cable, HVDC Converter Station and the length of the HVDC cable to the three-mile limit. The lease areas do not specify landfall locations for a cable connecting the offshore energy generating facility to the distribution grid on land.

The BOEM Renewable Energy Rule requires any proposed project easements outside the limits of their lease area to be identified in the COP and must provide site characterization data on the proposed easement. BOEM will issue an addendum to a developer’s lease, specifying the terms of the project easement, as part of approving the COP.

The primary site characterization activities associated with a project easement are geologic, cultural resource, and benthic habitat assessments. These activities are conducted as part of large remote sensing survey investigations, which are also required to characterize the lease area. The duration of a comprehensive remote sensing investigation is contingent on a number of variables that include the size of the area being investigated and the weather conditions during the field program.

The Deepwater Wind lease off the coast of Rhode Island was executed on September 12, 2013. Assuming Deepwater will be allowed to submit their SAP under the recently revised BOEM Rule, it would be due by September 12, 2014. In order to develop a timeline, we have assumed BOEM will develop an Environmental Assessment during review of the SAP and will issue an approval in Q2 of 2015. Deepwater will then have until Q2 of 2020 to file a COP and finalize its plan to interconnect the facility.

For the MAWEA, we have assumed that the competitive auction is held in Q4 of 2014. In this case, then winners of the lease sale would be required to submit SAPs by Q4 of 2015. Using the same assumption we made for Deepwater (preparation of an EA), we assume the SAP would be approved in Q4 2016 and COPs would be due by Q4, 2021.

### 7.4 Structure Consideration/Ownership Options

As described in Section 2.4, a possibility exists that lease holders may not be interested in developing the HV transmission system (HVAC and/or HVDC). The transmission development would be left to others such as the utilities Northeast Utilities/NSTAR or National Grid or a third-party developer (i.e., a merchant transmission developer). As with current land-based transmission projects, the generators would pay for the transmission services through approved tariffs or other financial mechanism. The Block Island Wind Farm Project is an example where a regulated utility is functioning in the role of the transmission provider for an offshore wind energy facility. Similarly, the proposed Atlantic Wind Connection demonstrates that merchant transmission companies may be interested in developing an independent transmission system to be used by offshore wind energy developers. Speculation on the ownership structure of offshore wind facilities and the interconnection infrastructure developed in the RIMA WEA and MAWEA is premature at this point, but instructive to consider.

Although beyond the scope of this evaluation and therefore not examined in any detail, both the Block Island Wind Farm and Atlantic Wind Connection models have the potential to reduce the development cost to the lease holder (i.e., wind energy developer) by eliminating some of the components that they are

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9 BOEM extended the deadline for Site Assessment Plans to 12 months (Federal Register Notice April 17, 2014).
responsible for and by shifting some of the development risk to a second party. The lease holder would likely be responsible for the wind turbine generators and the intra-array cabling. The components and costs presented above (Table 1 and Tables 10 through 13) would then be incurred by the transmission provider.

Another option that is a variation on the transmission developer option described above may be for the transmission system to be developed by a special purpose government entity similar to Massachusetts Municipal Wholesale Electric Company, a non-profit, public corporation and political subdivision of Massachusetts or an Authority. This entity may have financing options not available to the more traditional developers. This option would need to be further evaluated to determine its viability.

The development of the transmission system by a party other than the wind generation developer may also lead to cost reductions because of the ability of multiple generation projects to utilize a single transmission system, i.e., two lease area developers each construct a 500 MW project and interconnect to a single third-party offshore transmission system which would help to maximize the capacity utilization the single Transmission Block as opposed to each wind project developing its own system.

One fundamental issue with developing the transmission system (HVDC and HVAC infrastructure) independent of the generating system (wind turbines and intra-array cabling) is the question of which one should come first. The generating system has no value if it cannot deliver its power to market and similarly the transmission system has no value if there is no power to deliver. Under the scenario where the lease holder does not construct, own, and/or operate the transmission system it would be important that the transmission developer work closely with the lease holder (wind energy developer) to ensure schedule alignment and the ability to meet any in-service date commitments made to the utility. Other questions regarding financing ability and risk apportionment also present issues insofar as the ability of a wind developer to finance a project without a firm and enforceable commitment to have transmission available or vice versa in the case of an “independent” cable developer.

Additional considerations regarding potential ownership structures are beyond the scope of this review.

8.0 SUMMARY

Below is a summary of the findings of the Transmission Project, which provides considerations for the potential build out of offshore wind energy facilities in the RIMA and MAWEA.

Factors that Influence Development of Projects

In addition to the permitting schedule, there are a number of factors that will influence when projects are constructed and how much energy capacity is developed. These factors include:

- State and federal policies:
  - market demand,
  - Renewable Portfolio Standards requirements,
  - availability of long-term contracts (Power Purchase Agreements),
  - tax and other credits, and
  - capacity value;
- Ownership structures for transmission, i.e., generator financed/owned or separate transmission company;
- Location and capacity of potential interconnection points;
- Water depth; and
- ISO reliability requirements and technical characteristics of HVDC technology which limit individual transmission circuits to 1 GW.

**System Configuration**

The center of the RIMA WEA is approximately 30 miles from the mainland coast of Massachusetts and the center of the MAWEA is approximately 50 miles off the coast. The most direct submarine cable route to possible landside transmission interconnection points ranges from approximately 40 to 130 miles. Given limitations of HVAC technology the electric power transmission between the RIMA WEA and MAWEA and the mainland will likely require HVDC technology due to the high power rating and cable route distance.

The most reasonable approach for transmission of the energy from the RIMA WEA and MAWEA would be to install offshore Transmission Blocks, which would have the ability to deliver approximately 1,000 MW to the mainland AC transmission system (i.e., the grid). Each Transmission Block would include the following components:

- Wind turbine generators;
- Intra-array cable system (MV);
- Collector substation platforms (to convert MVAC to HVAC);
- HVAC system (to connect Collector Substations to Converter Station);
- Offshore Converter Station platform (to convert HVAC to HVDC);
- HVDC cable (to connect offshore Converter Station to onshore Converter Station); and
- Onshore Converter Station (to convert HVDC to HVAC).

**Interconnection Location Analysis**

Offshore wind projects in the RIMA WEA and MAWEA will connect to the mainland grid via the 345 kV transmission system. Consisting of HV lines and associated substations, the 345 kV transmission systems is effectively a transmission “Super Highway” that can transmit large blocks of power between generation resources and load. Under normal system conditions, 345 kV transmission lines can each typically transmit 1,000 MW. In comparison, the lower voltage 115 kV transmission lines can each typically transmit approximately 200 MW. As a result it is assumed, for the purposes of this study, that the 115 kV transmission system is not suitable for connecting projects in the RIMA WEA and MAWEA to the mainland grid.

Based on the stated assumptions, the following ISO NE 345 kV substations would likely have the ability to interconnect and integrate two Transmission Blocks and would likely have the collective ability to interconnect and integrate up to 6,000 MW of wind energy capacity from the RIMA WEA and MAWEA:

- Kent County Substation, West Warwick, RI
- Canal Substation, Sandwich, MA
- Brayton Point Substation, Somerset, MA
- Carver Substation, Carver, MA
- Oak Street Substation, Barnstable, MA
- State Forest Transition Station, Myles Standish State Forest, MA
- Millstone Substation, Waterford, CT
• Montville Substation, Montville, CT
• Shoreham Substation, Brookhaven, Long Island, NY

Each substation was evaluated based on a number of factors and classified into a tiered ranking (1, 2, and 3) based on available information. The tiers were based on the following parameters:

- Cost of substation upgrades;
- Approximate total undersea cable length (as a proxy for cost);
- Approximate length of upland cable (as a proxy for stakeholder resistance);
- Proximity of space available for Converter Station; and
- Competition for transmission resources.

Results indicate that Canal, Brayton Point, and Kent County Substations are the most likely targets for interconnecting offshore wind energy facilities (Tier 1). Carver and Oak Street are less likely to be targeted (Tier 2) based on proximity to the RIMA WEA and MAWEA and the anticipated distance required to construct a Converter Station relative to the existing substations. Millstone and Montville are the least likely targets for interconnecting the RIMA WEA and MAWEA given the submarine cable distance required for these two sites (Tier 3).

**Build Out Scenarios**

Four build out scenarios were developed as hypothetical stages in the sequential development of the MAWEA and RIMA WEA. Together, the build out scenarios provide a useful framework to describe and evaluate the transmission infrastructure necessary to interconnect future Massachusetts offshore wind projects to the New England electric grid. The four scenarios for build out of the RIMA WEA and MAWEA areas are as follows:

- Scenario 1 (Highly Conservative): 500 MW interconnected at one of the Tier 1 substations
- Scenario 2 (Conservative): 1,000 MW interconnected at one of the Tier 1 substations
- Scenario 3 (Moderate): 2,000 MW interconnected at two of the Tier 1 substations
- Scenario 4 (Ambitious): 3,000 MW interconnected at each of the Tier 1 substations

**Ownership Considerations**

A possibility exists that lease holders may not be interested in developing the transmission components (HVAC and/or HVDC) of a project beyond the offshore collection substation and associated cabling to connect with it. The transmission development would be left to others such as the utilities: Northeast Utilities/NSTAR or National Grid or a third party developer (i.e., a merchant transmission developer). As with current land-based transmission projects, the generators would pay for the transmission services through approved tariffs or other financial mechanism. The Block Island Wind Farm Project is an example where a regulated utility is functioning in the role of the transmission provider for an offshore wind energy facility. Similarly, the proposed Atlantic Wind Connection demonstrates that merchant transmission companies may be interested in developing an independent transmission system to be used by offshore wind energy developers. This could be a complex issue with a multitude of opportunities and different approaches.
Figures
MAWEA Density of Developer Interest

MassCEC Offshore Wind Energy Study
Offshore Massachusetts and Rhode Island

Legend
Call responses (count)

Source: 1) ESS, Transmission Infrastructure, 2014
2) BOEM, Wind Energy Areas, 2011
3) ESS, Call Responses, 2013

Figure 1
Figure 2

Legend
- Massachusetts Wind Energy Area
- Deepwater Wind Project Area
- Cape Wind Project Area
- Block Island Wind Farm (Deepwater Wind)
- Deepwater Wind Conceptual Transmission Cable Route
- Cape Wind Transmission Cable
- Block Island Wind Farm Proposed Transmission Cable Route

Note: Transmission Cable routes are approximate and based on publicly-available information.

Massachusetts Clean Energy Center
Offshore Wind Transmission Project

Source: 1) BOEM, Lease Areas, 2011
2) NOAA-NGDC, CRM data, 201
3) ESS, Transmission Infrastructure, 2014

Drawing Date: 4/28/2014

© 2014 ESS Group, Inc.
1,000 MW Transmission Block

Massachusetts Clean Energy Center
Offshore Wind Transmission Project

© 2014 ESS Group, Inc.
Typical design of a medium-voltage submarine cable with a maximum voltage up to 36 kV, including fibre optic cable.

Type: [F]2X5/[F]2Y>><RAA
1. Conductor: copper, circular stranded compacted, longitudinally waterproof
2. Conductor screening: extruded semi-conductive compound
3. Insulation: XLPE
4. Insulation screening: extruded semi-conductive compound
5. Screen: copper wires and copper helix, swelling powder or tape
6. Laminated sheath: aluminium tape bonded to overlying PE sheath plus conductive coating
7. Fibre optic cable, optional
8. Fillers: polyethylene strings
9. Binder tapes
10. Bedding: polyethylene strings or polyester tape
11. Armour: galvanized round steel wires
12. Serving: bituminous compound, hessian tapes, polyethylene strings with coloured stripe
Radial Collector System

Max. Distance ≈ 12 – 15 miles
Figure 6

Max. Distance ≈ 12 – 15 Miles
Open Loop Collector System

Max. Distance ≈ 12 – 15 miles

COLLECTOR SUBSTATION PLATFORM

220kV/34.5kV TRANS.

NORMAL OPEN POINT

Massachusetts Clean Energy Center
Offshore Wind Transmission Project

© 2014 ESS Group, Inc.
Collector Substation Platform

220kV AC submarine cable to HVDC Converter Platform

Max. Distance = 17 – 20 miles

220kV AC submarine cable

COLLECTOR SUBSTATION PLATFORM

Massachusetts Clean Energy Center
Offshore Wind Transmission Project

Figure 8

© 2014 ESS Group, Inc.
Figure 9

Offshore Collector Substation

Photo Credit: Walney (UK) Offshore Windfarms Ltd.

Photo Credit: Trianel Windkraftwerk Borkum GmbH
Single Core HVAC Submarine Cable

Source: ABB

© 2014 ESS Group, Inc.
Photo Credit: Gulf Marine Services
<table>
<thead>
<tr>
<th><strong>HVDC Submarine Cable</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DC Voltage</strong></td>
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<tr>
<td><strong>Conductor</strong></td>
</tr>
<tr>
<td>Type / material</td>
</tr>
<tr>
<td>Cross-section</td>
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<tr>
<td>Water blocking</td>
</tr>
<tr>
<td>Diameter</td>
</tr>
<tr>
<td><strong>Conductor binder</strong></td>
</tr>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Thickness</td>
</tr>
<tr>
<td><strong>Conductor shield</strong></td>
</tr>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Thickness</td>
</tr>
<tr>
<td><strong>Insulation</strong></td>
</tr>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Thickness</td>
</tr>
<tr>
<td><strong>Insulation shield</strong></td>
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<td>Thickness</td>
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<tr>
<td><strong>Outer serving</strong></td>
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<tr>
<td>Material</td>
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<tr>
<td>Thickness</td>
</tr>
<tr>
<td><strong>Complete cable</strong></td>
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<tr>
<td>Diameter</td>
</tr>
<tr>
<td>Weight in air</td>
</tr>
<tr>
<td>Weight in water</td>
</tr>
</tbody>
</table>

*Note: All data shall be considered nominal*
Photo Credit: ABB
Jet Plow Device

Photo Credit: ABB
Cape Wind Project Area
Deepwater Wind Project Area
Massachusetts Wind Energy Area

Shoreham
Carver
Brayton Point
Kent
Montville
Millstone
Rhode Island
Connecticut
New York

0 4.75 9.5 14
10 15 20
Nautical Miles

Legend
Massachusetts Wind Energy Area
Deepwater Wind Project Area
Cape Wind Project Area
Block Island Wind Farm (Deepwater Wind)

Potential Interconnection Locations
Deepwater Wind Transmission Cables
Cape Wind Transmission Cable
Block Island Wind Farm Transmission Cables

Target Interconnection Locations

Figure 17
Source: 1) BOEM, Lease Areas, 2011
2) NOAA-NGDC, CRM data, 2011
3) ESS, Transmission Infrastructure, 2014

Massachusetts Clean Energy Center
Offshore Wind Transmission Project

Note: Transmission Cable routes are approximate and based on publicly-available information.
Offshore Wind Energy Areas
Existing Substations
Kent Substation

Legend
- Potential Interconnection Locations
- Existing ROW

Massachusetts Clean Energy Center
Offshore Wind Transmission Project

Source: 1) BOEM, Lease Areas, 2011
2) NOAA-NGDC, CRM data, 2011
3) ESS, Transmission Infrastructure, 2014

Depthwater Wind Energy Area

Legend
- Potential Interconnection Locations
- Existing ROW

Kent Substation

Source: 1) BOEM, Lease Areas, 2011
2) NOAA-NGDC, CRM data, 2011
3) ESS, Transmission Infrastructure, 2014

Massachusetts Clean Energy Center
Offshore Wind Transmission Project

Legend
- Potential Interconnection Locations
- Existing ROW

Kent Substation
**Figure 19**

**Legend**

- Potential Interconnection Locations
- Existing ROW

**Sources:**
- BOEM, Lease Areas, 2011
- NOAA-NGDC, CRM data, 201
- ESS, Transmission Infrastructure, 2014

**Massachusetts Clean Energy Center**

**Offshore Wind Transmission Project**

**Offshore Wind Energy Areas**

- Existing Substations
- Canal Substation

**Environment**

- Massachusetts Clean Energy Center
- Offshore Wind Transmission Project

**Drawing Details**

- Drawing Date: 3/28/2014
- Path: G:\GIS-Projects\M363-000 MASSCEC\00-mxd\Substation Detail Figures\Canal.mxd

**Legend**

- Potential Interconnection Locations
- Existing ROW
Offshore Wind Energy Areas
Existing Substations
Brayton Point Substation

Massachusetts Wind Energy Area

0 150 300
0 2,500 5,000

Legend

★ Potential Interconnection Locations

Existing ROW

1 inch = 2,000 feet

Source: Esri, DigitalGlobe, GeoEye, I-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 18

Massachusetts Clean Energy Center
Offshore Wind Transmission Project

environmental consulting & engineering services

Path: G:\GIS-Projects\M363-000 MASSCEC\00-mxd\Substation Detail Figures\Brayton Point.mxd

Drawing Date: 3/28/2014

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Figure 21: Offshore Wind Energy Areas

Massachusetts Clean Energy Center

Legend

- Potential Interconnection Locations
- Existing ROW

Deepwater Wind Project Area

Cape Wind Project Area

Massachusetts Wind Energy Area

Potential Interconnection Locations

Massachusetts

Connecticut

Rhode Island

New York

Carver

Offshore Wind Transmission Project

Source: 1) BOEM, Lease Areas, 2011
2) NOAA-NGDC, CRM data, 201
3) ESS, TransmissionInfrastructure, 2014

Massachusetts Clean Energy Center

environmental consulting & engineering services

Envision, Inc.

Offshore Wind Energy Areas
Existing Substations
Carver Substation

Figure 19
Massachusetts Clean Energy Center
Offshore Wind Transmission Project

Legend

- Potential Interconnection Locations
- Existing ROW

Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Offshore Wind Energy Areas
Existing Substations
Oak Street Substation

Figure 22

Source: 1) BOEM, Lease Areas, 2011
2) NOAA-NGDC, CRM data, 201
3) ESS, Transmission Infrastructure, 2014

Massachusetts Wind Energy Area

Deepwater Wind Project Area

Massachusetts Wind Project Area

New York
Connecticut
Rhode Island
Massachusetts

Oak Street Substation

1 inch = 2,000 feet

Legend

- Potential Interconnection Locations
- Existing ROW

Massachusetts Clean Energy Center
Offshore Wind Transmission Project

Legend

- Potential Interconnection Locations
- Existing ROW

Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Offshore Wind Energy Areas
Existing Substations
Oak Street Substation

Figure 22

Source: 1) BOEM, Lease Areas, 2011
2) NOAA-NGDC, CRM data, 201
3) ESS, Transmission Infrastructure, 2014

Massachusetts Wind Energy Area

Deepwater Wind Project Area

Massachusetts Wind Project Area

New York
Connecticut
Rhode Island
Massachusetts

Oak Street Substation

1 inch = 2,000 feet
Massachusetts Clean Energy Center
Offshore Wind Transmission Project

Legend

Potential Interconnection Locations

Existing ROW

Offshore Wind Energy Areas
Existing Substations
Millstone Substation

Legend

Potential Interconnection Locations

Existing ROW

Figure 21
Montville

Source: Esri, DigitalGlobe, GeoEye, I-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Offshore Wind Energy Areas
Existing Substations
Montville Substation

Figure 25

Source: 1) BOEM, Lease Areas, 2011
2) NOAA-NGDC, CRM data, 201
3) ESS, Transmission Infrastructure, 2014

Massachusetts Clean Energy Center
Offshore Wind Transmission Project

Legend

Potential Interconnection Locations

Existing ROW
Offshore Wind Energy Areas
Existing Substations
Shoreham Substation

Massachusetts Clean Energy Center
Offshore Wind Transmission Project

Legend

Potential Interconnection Locations
Existing ROW

Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

1 inch = 2,000 feet
1 inch = 3,000 feet

Figure 23
Tier 1 Substations: Kent, Brayton Point, & Canal
Tier 1 Substations: Kent, Brayton Point, & Canal
1,000 MW Build Out Scenario

Figure 28

Tier 1 Substations: Kent, Brayton Point, & Canal

Massachusetts Clean Energy Center
Offshore Wind Transmission Project

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Tier 1 Substations: Kent, Brayton Point, & Canal

2,000 MW Build Out Scenario

Figure 26
Massachusetts Clean Energy Center
Offshore Wind Transmission Project

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3,000 MW Build Out Scenario

Figure 27

Tier 1 Substations: Kent, Brayton Point, & Canal
Appendix A

HVAC Technical Brief
The most direct submarine cable routes between RIMA WEA and MAWEA to onshore 345 kV interconnection substations are estimated to be 40 to 130 miles. A conceptual design for a 250 MW offshore project and HVAC transmission system approximately 100-miles long with 1-mile of on land cable was developed to support a high-level evaluation of the potential applications of HVAC technology to the development of the MAWEA.

The conceptual design utilizes a 3-core, HVAC submarine cable with solid dielectric, XLPE insulation and a 1,000mm² copper main conductors. This cable is representative of HVAC submarine cables that connect operating offshore wind farms in Europe to the onshore interconnection points. This type of cable burial is favored over single-core cables because a 3-core cable can be installed with one pass of the burial equipment.

The conceptual design discussed here has not been confirmed by any power systems studies which may determine that the conceptual design is not technically feasible.

**Conceptual Design System Components**

The conceptual, 250 MW, 100 mile, HVAC transmission system for MAWEA requires an offshore Collector Substation(s) and Collector Systems. The cable system will consist of two circuits to provide the necessary capacity to bring the power to shore and for reliability and availability of the system. Each circuit will consist of one, 3-core 100 mile 220kV submarine cable and three single-core, and 1 mile 220kV land cables. The Collector Substation will require additional equipment to provide reactive compensation for the HVAC cables. The 100 mile submarine cable route will be split into three smaller segments using two additional offshore platforms. Compensation equipment will be needed on each of these two additional platforms to provide the necessary reactive power compensation. HVAC transmission system components are shown in Figure 1.

**Collector Substation**

The Collector Substation(s) are similar in design to those described in the Report and will include:

- Control and Protection Equipment for the HVAC and MVAC (medium voltage AC) equipment
- MVAC switchgear for the connection of the Collector System
- Step-up Transformers to raise the voltage from the Collector System to the Transmission System
• HVAC switchgear for the connection of the Transmission System
• Auxiliary systems for lighting, climate control, communications, fire protection, etc.
• Emergency Generator
• Personnel accommodation area (crew quarters)

Each HVAC cable will require its own independent shunt reactors. This equipment is similar in design to the step-up transformers that are part of the platform. Depending on the shunt reactor size and required cooling system design, approximately 10,000 to 14,000 gallons of dielectric insulating fluid (the same as transformer oil) will be contained in each shunt reactor unit. The transformer oil provides electrical insulation to the shunt reactor components and serves as a method of cooling the shunt reactor during operation. Special consideration will have to be made in the overall platform design to contain the oil in the event of a possible catastrophic shunt reactor failure. Based on the proposed design of the cable system and the required size of the shunt reactors, fluid filled equipment will be required.

The addition of shunt reactors to the Collector Substation would increase its size relative to comparable collector substations used in HVDC transmission systems.

• Platform Area: 57,000–70,000 sq. ft.
• Platform Dimensions: 140–160 ft. (L), 140–160 ft. (W), 80–100 ft. (H)
• Platform Weight: 2800–3500 tons (foundation weight not included)

**High Voltage AC Cable Technology**

The offshore HVAC Transmission system will transmit the power from the Collector Substation to the mainland substation via two circuits each rated at 220 kV and using XLPE insulated, 3-core HVAC submarine cables. A multi-core, fiber optic cable would be installed within each 3-core cable to provide a path for telecommunications between the onshore and offshore facilities.

*Figure 0 – 3-core Submarine HVAC Cable (Source: ABB)*

The physical design of each transmission circuit is dependent on several factors which include:

• Length of the HVAC submarine cables required
• Operating voltage of the cable
• Subsurface cable installation conditions
• Water depth at installation location
• Thermal characteristics of the seabed
• Required transmission capacity of the HVAC cables.
• Availability/reliability requirements of the transmission system

Based on the 3-core cable design of the HVAC transmission system, and jet plow installation methods, a typical cable corridor for installation and future repairs for each cable should be approximately 2.2 times the water depth. Individual project or site-specific factors may result in different spacing which could be less than described here.

Depending on the manufacturer, and final capacity required of the transmission cable, each typical 3-core cables would be approximately 9 to 10 inches in diameter and weigh approximately 70 lbs per foot but may vary depending on the transmission cable manufacturer and the cable’s final capacity.

Compensation Substation

Because of the proposed long lengths of HVAC cables used in the design, Compensation Substation(s) will be necessary, and reactive compensation will be required at both ends of the cable system and two locations along the cable route.

The Compensation Substation will be similar in design to Collector Substation but with less HVAC and MVAC equipment. The Compensation Substation will contain control and protection equipment for the HVAC and MVAC systems, auxiliary systems for climate control and safety requirements, and power transformer to supply electricity to the auxiliary systems. As with other offshore transmission platforms installed in remote and difficult location, redundancy of key components will be incorporated into the design of the Compensation Substation.

Depending on the shunt reactor design and required cooling system design, approximately 12,000 to 20,000 gallons of dielectric insulating oil (the same as transformer insulating oil) will be contained in each shunt reactor unit. The transformer oil provides electrical insulation to the shunt reactor components and provides a method of cooling during operation. The power transformer required for the auxiliary systems will also be oil insulated and contain approximately 4,000 to 6,000 gallons of dielectric insulating oil.

For the operation of the shunt reactor equipment and HVAC/MVAC substation equipment, additional auxiliary systems are required which include control and protection systems to operate the switches and circuit breakers, pumps and motors required for the transformer and shunt reactor cooling systems, lighting, heating, ventilation, and climate control equipment, fire control and protection systems, and control communication equipment for the overall control of the system.

Compensation Substations will contain backup emergency diesel generators to provide power to the auxiliary systems in the event of a loss of power or during some maintenance activities when the HV and MV systems must be disconnected. Powering the auxiliary systems from a backup generator will allow the auxiliary equipment and shunt reactors to operate as needed to protect any equipment from damage and for the safety of the crew that may be at the substation during a power outage. Depending on the emergency diesel generator design, approximately 6,000 to 8,000 gallons of fuel may be required to be stored on the platform to enable up to a week of continuous operation.

Although major maintenance activities are not expected, Compensation Substations will include an emergency personnel accommodation area (crew quarters) in addition to supplies to accommodate the largest crew size for the expected duration.

Currently no offshore wind HVAC transmission systems include Compensation Substations installed offshore. As a result, the conceptual Compensation Substation design was developed using data from
several different sources such as publicly available offshore oil and gas platforms and smaller sized collector platforms used in offshore wind applications.

- Platform Area: 10,000–14,000 sq. ft.
- Platform Dimensions: 80–110 ft. (L), 80–110 ft. (W), 30–40 ft. (H)
- Platform Weight: 1000–1300 tons (foundation weight not included)

Based upon research of publicly available information there are no offshore wind systems that use reactive compensation as proposed by the conceptual design of the 250 MW, 220 kV HVAC transmission system with reactive compensation along the proposed cable route. Currently most offshore wind systems have cables that are far shorter than 100 miles in length and can therefore install reactive compensation at the end locations only. The conceptual design provided herein is based on best engineering judgment for a 100 mile long interconnection without conducting any detailed power flow modeling or sophisticated analysis.

**Dynamic Compensation Interconnection Substation**

The Interconnection Substation would be similar in design to a typical HVAC substation common in the existing power grid. The substation would contain multiple HVAC circuit breakers; bus bars; disconnect switches, transformers and shunt reactors for the interconnection of the submarine cables into the existing electric transmission grid.

A dynamic compensation system will be required at the Interconnection Substation to provide voltage stability. Based on publicly available data, the majority of offshore wind projects larger than 200MW which use HVAC technology employ dynamic compensation associated with the mainland substation. A Static Var Compensator (SVC) or similar device will be required for each individual cable interconnection to maintain the system voltage and provide network stability in response to variability in wind generation.

The Interconnection substation would be a new facility constructed as close to the existing on shore substation as possible and could require approximately 3-5 acres. This facility would be similar in appearance to a substation but would contain the HVAC and dynamic compensation equipment.

**Conceptual Cost Estimate**

The estimated cost for a 250 MW transmission shown in Error! Reference source not found. were developed using publicly available information. This information includes: manufacturer press releases, conference papers, and other project cost documents using HVAC transmission.

The following equipment is required for the HVAC transmission system to shore:

- Collector Substation including reactive compensation due to the long length of HVAC cables
- Added Compensation Substation cost
- HVAC cables 3-core cables
- Interconnection Substation which includes 2 x ±50 MVAr, SVCs for voltage support
<table>
<thead>
<tr>
<th>Item</th>
<th>Unit Cost</th>
<th>Quantity</th>
<th>Cost</th>
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<tbody>
<tr>
<td>Collector Substation</td>
<td>$55M – $90M</td>
<td>1 Unit</td>
<td>$55 – $90M</td>
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<tr>
<td>2 x 220kV 3-core AC cable</td>
<td>$1.9M – $2.5M / mile</td>
<td>100 miles</td>
<td>$380M – $500M</td>
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<tr>
<td>Interconnection Substation</td>
<td>$61M – $71M</td>
<td>1 Unit</td>
<td>$61M – $71M</td>
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<td>Compensation Substation&lt;sup&gt;10&lt;/sup&gt;</td>
<td>$26M – $30M</td>
<td>2 Units</td>
<td>$52M – $60M</td>
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</table>

**Project Indirect Costs:** $137M – $180M

**Project Total Cost (for transmission system):** $685M – $901M

<sup>10</sup> The Compensation Platform estimate developed using data from several different sources such as publicly available offshore oil and gas platforms and smaller sized collector platforms used in offshore wind applications.