Final Technical Report

NEW ENGLAND AQUA VENTUS I
100% Hull Design

Recipient: University of Maine, 186875787
Award Number: DE-EE0006713

NEW ENGLAND AQUA VENTUS I

Federal Agency to which Report is submitted: Department of Energy, Golden Field Office

Recipient: University of Maine, 186875787
Award Number: DE-EE0006713
Project Title: New England Aqua Ventus I
Project Period: October 1, 2014 – December 31, 2020
Principal Investigator: Dr. Habib J. Dagher, P.E., Director of the Advanced Structures and Composites Center
Report Submitted by: Dr. Habib J. Dagher and Dr. Anthony Viselli
Contact: hd@maine.edu
Date of Report: May 19th, 2023

Working Partners:
DOE Award Administrator: Mr. Charles D'Angelo
DOE Project Officer: Mr. Michael Carella
Recipient Business Office: Christopher Boynton, christopher.boynton@maine.edu, 207-581-1486
Recipient Principal Investigator: Dr. Habib Dagher, hd@maine.edu, 207-581-2138

Signature of Submitting Official: Dr. Habib J. Dagher, P.E., Director of the Advanced Structures and Composites Center

Acknowledgements: This report is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the award DE-EE0006713.

Abstract: This report serves as the final technical report for the US Department of Energy (DOE) award DE-EE0006713 (Award 6713). The project is titled "New England Aqua Ventus I Offshore Wind Advanced Technology Demonstration Project 100% Front-End Engineering and Design (FEED)". The New England Aqua Ventus I (NEAV) project demonstrates a unique prestressed concrete semi-submersible floating hull technology, called VolturnUS. The technology is applicable to harness nearly 60% of the US offshore wind resource within 50 miles of the coast. The hull will be demonstrated at full-scale with a commercial scale wind turbine connected to the grid in the Northeast US off Monhegan Island, Maine for 20 years. In this project the following key achievements were made:

1. Completion of the design of a 100% FEED for a 6MW floating offshore wind turbine (FOWT) hull which successfully passed a 3rd Party Review by the American Bureau of Shipping
2. Completion of technical due diligence reviews from project investors which led to development agreements between UMaine, Diamond/ Mitsubishi, and RWE representing approximately $100M in investment in NEAV I.
3. Execution of a Power Purchase Agreement with the State of Maine
4. Continued permitting, outreach, and environmental data collection efforts relevant for the project.
5. Completion of preliminary construction and operations plans
6. Development of financial plans and models needed to finance the project

Table of Contents

Table of Figures

1. Executive Summary

This report serves as the final technical report for the US Department of Energy (DOE) award DE-EE0006713 (Award 6713). The project is titled "New England Aqua Ventus I Offshore Wind Advanced Technology Demonstration Project 100% Front-End Engineering and Design (FEED)". This report serves as a summary of the work completed under the award and consists of two sections organized based on two project budget periods.

The New England Aqua Ventus I (NEAV) project demonstrates a unique prestressed concrete semi-submersible floating hull technology, called VolturnUS. The UMaine developed technology, according to a National Renewable Energy Laboratory (NREL) report[1], could significantly reduce the Levelized Cost of Energy by 2032. The technology is applicable to harness nearly 60% of the US offshore wind resource within 50 miles of the coast. The hull will be demonstrated at full-scale with a commercial scale wind turbine connected to the grid in the Northeast US off Monhegan Island, Maine (**Figure 1**) for 20 years.

Award DE-EE0006713 represents one source of funding for the project from the DOE. This award enabled significant advancement of the technology and project which will be directly leveraged to support the completion of the project. This award achieved several critical design and development milestones including:

- Completion of the design of a 100% FEED for a 6MW floating offshore wind turbine (FOWT) hull
- Completion of technical due diligence reviews from project investors which led to development agreements between UMaine, Diamond/ Mitsubishi, and RWE representing approximately $100M in investment in NEAV I.
- Execution of a Power Purchase Agreement with the State of Maine
- Continued permitting, outreach, and environmental data collection efforts relevant for the project.
- Completion of preliminary construction and operations plans
- Development of financial plan and models needed to finance the project

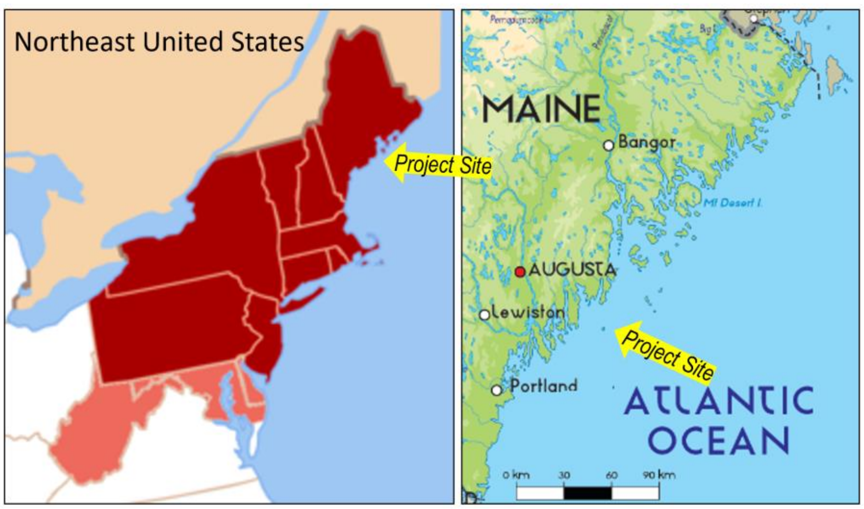

Figure 1 The New England Aqua Ventus I Project Location

Summaries of these deliverables are presented in this following report organized by the project budget periods and task structure following the Project Statement of Project Objectives (SOPO).

[1] Musial, W, Beiter, P, Nunemaker, J., "Cost of Floating Offshore Wind Energy Using the New England Aqua Ventus Concrete Semisubmersible Technology", NREL/TP-5000-75618, National Renewable Energy Laboratory, January 2020.

2. Budget Period 1

2.1 Introduction and Objectives

This chapter provides a summary of the project outcomes for Budget Period 1. The New England Aqua Ventus (*NEAV)* 1 project aims demonstrates a unique prestressed concrete semisubmersible floating hull technology, called VolturnUS at full-scale by 2024 off the coast of Maine. During Budget Period 1, the Project consisted of a 12-MW floating wind farm, using two 6MW horizontal-axis turbines deployed in Maine state waters off the coast of Monhegan Island as shown in Figure 1 and 2. Each of the two VolturnUS hulls were to be moored with three catenary mooring chains connected to drag embedment anchors. From each hull, a 6 MW dynamic subsea cable runs approximately one mile to a subsea T-connection point. From here, a 12 MW static subsea cable runs approximately 16 miles to a landing on the mainland. Water depths in the 1.78 x 3.38 km test site range from 60 to 110 m.

Figure 2 In BP 1 the Aqua Ventus I Project Consisted of Two 6MW Wind Turbines Supported atop VolturnUS Concrete Floating Hulls

The primary tasks and objectives of the Budget Period 1 were as follows:

1. Complete 100% Hull Front End Engineering and Design (FEED) including:
    a. **Develop a FEED** for the following hull related items: (a) the concrete floating hull, (b) composite and/or steel towers, (c) wind turbine integration, (d) mooring lines and anchors, (e) dynamic cable. *[Note: Excluded from the work are: (f) subsea cable, (g) land-based transmission grid connection, (h) hull mechanical and hull electrical, (i) environmental and permitting]*.
    b. Conduct Third-Party Hull Design Review with the American Bureau of Shipping (ABS)
    c. Conduct Optional Lab Testing as needed to qualify design innovations and materials
2. Conduct Independent Cost Estimating to Demonstrate the US-Wide Advantages of the Concrete Hull Technology as follows:
    a. **Obtain Hull Cost Estimates:** Obtain two independent cost estimates for the concrete hull, in two geographic regions in the US (preferably one on the west coast, and another one in the northeast).
    b. **Evaluate the Cost Benefits of Two Design Innovations:** (a) Concrete hull versus steel hull, and (b) composite tower versus steel tower.
    c. Compare cost tradeoffs of lightweight vs normal weight concrete.
    d. Obtain Levelized Cost of Energy (LCOE) analyses for the 12 MW demonstration project and for a 500MW project on both the east and west coasts.

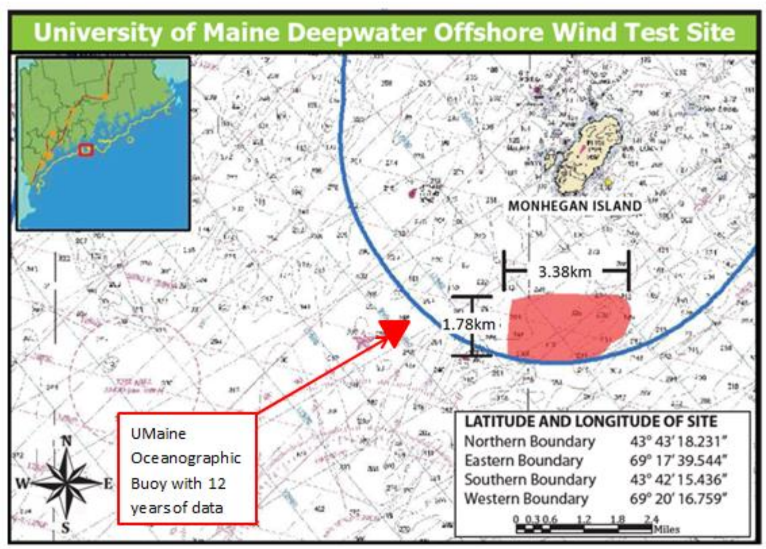

Figure 3 Project Site Control Exists at the UMaine Deepwater Offshore Wind Test Site (blue line indicates federal waters)

3. **Disseminate project information** through conference participation and submission of articles to peer reviewed journals.

2.2 List of Key Project Accomplishments by Task

All award BP1 objectives have been successfully met or exceeded. A summary of accomplishments for each task is given below.

1. **1.** The 100% Hull FEED has been successfully completed
   - 1.1 Wind turbine OEM, agreed to provide a 6MW unit for the project during this budget period and support the FEED.
     - i. The turbine OEM provided a firm TSA offer for a 6MW wind turbine generator (WTG)
     - ii. The turbine OEM has conducted a positive due-diligence review of the VolturnUS technology and agreed to assign engineering resources to support the project.
     - iii. UMaine-NREL conducted a complete coupled-load analysis using FAST for the FOWT turbine.
     - iv. The turbine OEM conducted its own coupled modeling effort and concluded that the turbine is suitable for the Monhegan test site.
   - 1.2 Both a 100% FEED for a steel and composite tower design was completed.
   - 1.3 A 100% FEED for the concrete hull was completed:

- Hull was optimized from the 50% FEED. The concrete volume was reduced by 13%, the steel reinforcement has decreased by 29%, the prestressing strands have decreased by 52%, and the transverse post-tensioning in the bottom beams were eliminated.
- A hull third-party concrete design review was completed by an offshore engineering firm with concrete expertise.
- Concrete joint performance and modular construction confirmed using 1:4 model construction mockups and tests.
- Another third-party review was completed by the American Bureau of Shipping

   - 1.4 Hull mechanical and electrical designs were advanced.
   - 1.5 Mooring and anchor designs, and dynamic cable design were completed.
   - 1.6 A new LiDAR buoy, developed by UMaine and named DeepCLiDAR, was deployed at the test site since Dec 2015, complementing 14 years of surface level buoy data collected by UMaine at the site.
   - 1.7 79,896 coupled model load simulations were completed to cover all ABS load cases
   - 1.8 The ABS approved the design basis document as well as the analysis and design tools used to design the hull.

2. **2.** Cost estimates:
   - 2.1 Nine independent cost estimates for steel hulls and four US independent cost estimates for VolturnUS concrete hulls were obtained. At commercial scale, the concrete hulls could be produced in the US at nearly half the cost of steel hulls, but also at less cost than steel hulls produced in Southeast Asia and transported to the US.
   - 2.2 Based on an NREL-Report, composite towers are 13% less expensive than conventional steel towers
   - 2.3 A cost-benefit analysis was completed for lightweight and normal-weight concrete. The analysis showed that lightweight concrete hulls are more cost effective than normal-weight concrete hulls when draft restrictions exist at construction and assembly ports. With no draft restrictions, the costs are equivalent.
3. **3.** NREL completed a study of Levelized Cost of Energy (LCOE) and impact of VolturnUS concrete technology. The main conclusions were:
   - 3.1 For utility-scale projects, for VolturnUS concrete hulls could decreases LCOE by 28% versus steel hulls
   - 3.2 Using the NREL cost reductions pathways for a project with 2030 COD, it was estimated that the LCOE for utility-scale projects using the UMaine concrete hull could be reduced significantly over time. This report has since been updated in Budget Period 2 for larger turbines and saw even lower LCOE. [2]
   - 3.3 Approximately 70% (2281 GW) of available US offshore wind energy supply would be suitable for floating substructures, similar to the UMaine concrete floating semi-submersible hull.
   - 3.4 Quoting the NREL report: "The LCOE shows that for the utility-scale projects, UMaine's concrete semi-submersible substructure could be effective at lowering the cost of offshore wind energy compared to the conventional steel hulls. In addition, given the ability for the concrete hull to be built anywhere, it can be installed on both the Atlantic as well as Pacific side economically and could be an important step in

[2] Mone, C, Stehly, T, and Musial, W (2016). Levelized Cost of Energy Analysis using a Floating Concrete Semi-Submersible Foundation for the University of Maine. National Renewable Energy Laboratory.

increasing domestic content for offshore wind in the United States."

2.3 Task 1.0 100% Hull FEED

The VolturnUS concrete semi-submersible hull 100% FEED was successfully completed. The FEED is basic engineering which comes after the Conceptual design or Feasibility study. The FEED design focuses on the technical requirements as well as preparing information to be able to determine the investment cost for the project. The FEED is divided into separate packages covering different portions of the project. The FEED is used as the design basis for bidding the Execution Phase Contracts (Engineering, BOP, EPC, etc.) and securing bids for the purchase of major equipment. The FEED reflects all the client's project specific requirements and avoids significant changes during the execution phase.

The VolturnUS concrete semi-submersible hull design represents a shift from typical use of steel as a primary construction material in offshore construction practices necessary to get costs down. The hull consists of a corrosion-resistant, fatigue-resistant, prestressed concrete floating platform. Mass-production costs for the VolturnUS prestressed concrete hull are about 50% of that of a comparable semisubmersible steel hull and take advantage of known domestic construction techniques in the precast concrete building/bridge industry.

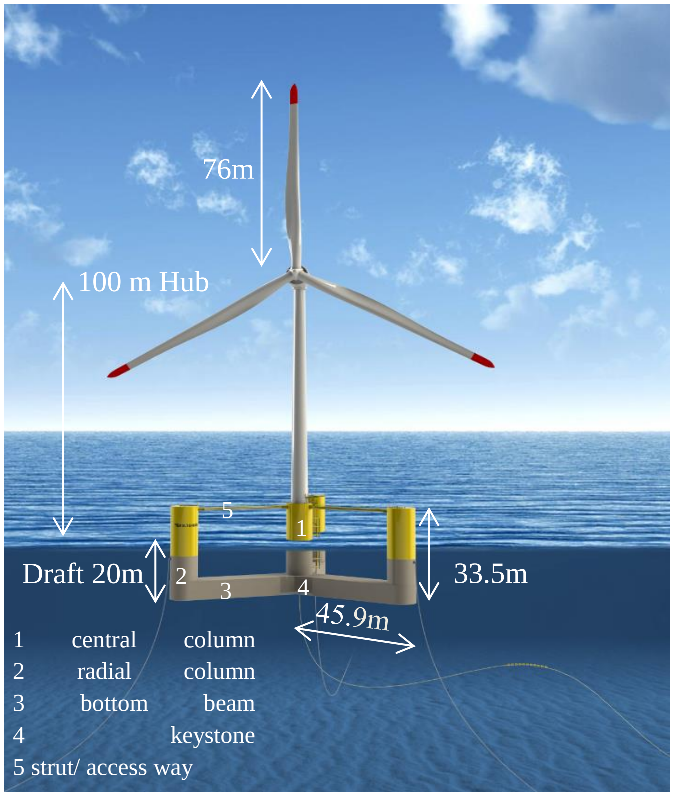

Figure 4 VolturnUS 6MW Floating Concrete Hull

The VolturnUS 100% FEED represents a culmination of a decade of work. The design has been successfully tested at 1:50 scale, 1:8 scale, received an Approval in Principle by ABS in 2014, has received a 3rd party review from an offshore concrete engineering firm, and is currently undergoing a final design review with ABS for an 11MW system using the results of this work. Figure 4 shows the VolturnUS floating wind hull supporting a 6MW wind turbine and identifies key elements of the design. The hull design consists of a central column with three radial arms each comprised of a concrete bottom beam, concrete radial column, and steel axial strut member/access way. Three chain mooring lines connect the structure to three drag embedment anchors. A lazy-wave electrical umbilical connects the turbines to the grid. The hub height is 100m from the waterline. The following subtasks summarize key design milestones.

Subtask 1.1: Wind Turbine Integration

This task was successfully completed, and all milestones were met. The goal of this subtask was to select a turbine OEM for the project and work with the turbine OEM to integrate turbine into the system to allow the 100% FEED for the floating support structure to reach completion. This work included an evaluation of turbine suitability on the platform by conducting independent coupled loads analyses by both the turbine OEM and NREL/UMaine, as well and turbine electrical integration.

Turbine OEM Selected. A commercial 6MW turbine was selected for use in this project. The turbine OEM provided a TSA agreement. This effort is a culmination of numerous due-diligence meetings held between and represented a major commitment from the OEM.

Completed turbine integration for 100% Hull FEED. Working with the turbine OEM, the following turbine integration activities with the hull were completed resulting in a 100% FEED:

1. **Completed a coupled loads analysis per ABS using a turbine model provided by the Turbine OEM.** UMaine, working with NREL, completed a full coupled loads analysis using the FAST software. The software and models were validated against 1:50 and 1:8 scale test data and these

results reviewed and approved by ABS. The FAST model included a turbine model supplied by the turbine OEM and included all ABS Design Load Cases. The loads calculated in this report also served as inputs for the design of the hull, mooring, and towers.

2. The turbine OEM independently confirmed that the WTG is suitable for use on the VolturnUS hull offshore Maine and is within its type certificate load ranges. The turbine OEM has completed its own engineering design review of the turbine suitability atop the floating concrete hull off Monhegan Island. The technical adequacy of the WTG on top of the VolturnUS was confirmed. Based on selected key DLC's, the turbine was shown to stay within the WTG type certificate operating ranges. This was demonstrated both by using the UMaine/NREL FAST loads analyses and by the turbine OEM comparisons of FAST vs Bladed model results in the frequency and time-domains. A preliminary assessment was also made for key WTG components like the Tower, Nacelle, and Blades as well as assessments of the technical adequacy of the 6MW for US compliance for electrical integration, the EHS US standards compliance, the functional requirements needed from the access to the tower interface, and last but not least the WTG staging at the quay. All areas were given a positive review.
3. **Turbine OEM due diligence of VolturnUS technology.** The turbine OEM conducted an in-depth due diligence effort on the VolturnUS floating concrete hull technology. This due diligence effort was extremely positive for greenlighting future commitments for the VolturnUS technology by the turbine OEM.
4. **Remaining turbine integration work plan developed:** In preparation for the next phase of turbine integration work, the turbine OEM and UMaine have completed a detailed SOPO, including items such as calibration of UMaine coupled and design models against the turbine OEM Bladed and FAST models, optimizing the turbine controller for the hull, integrating electrical equipment, hull transition for tower support and ancillary structure design.

Subtask 1.2: Tower Design using Steel and/or Composites

The goal of this effort was to develop a 100% FEED design of a steel tower or a composite tower. The final tower material choice was to be selected after working with the selected turbine OEM and using a cost-benefit-risk analysis. The 100–200-ton lighter composite tower reduces the hydrostatic stability demand for the floating platform and also reduces gravitational and inertial loads compared to a heavier steel tower. Therefore, a composite tower reduces the hull size. UMaine has been developing composites tower technology for the past six years which has resulted in the deployment offshore of a 1:8 scale composite tower on the VolturnUS 1:8 platform in 2013. In addition, UMaine completed construction and static/ fatigue structural testing of a ½ scale composite tower as shown in Figure 5, and received an approval in Principle from ABS for the composite tower design. NREL and UMaine completed a value-analysis of a steel versus a composite tower which showed that a composite tower is likely to result in a less expensive hull/tower system than a steel tower would (see subtask 2.2). Under this award, 100% FEED tower designs for both a composite tower and a steel tower were completed and submitted to ABS. The hull was designed to support both steel and composite towers. However, to reduce innovation risk and accommodate the highly integrated steel tower and electrical equipment provided by the turbine OEM, the first demonstration project will use a steel tower.


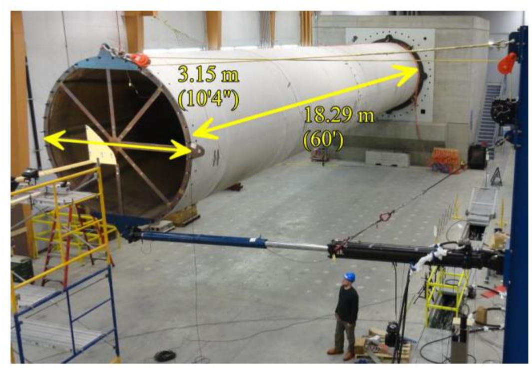

Figure 5 1/8 and 1/2 Scale Testing of Composite Towers

Subtask 1.3: VolturnUS Concrete Hull 100% FEED

The VolturnUS concrete hull design was successfully taken from a 50% to a 100% FEED level. Key milestones from this effort were:

1. **Hull significantly optimized:** The VolturnUS concrete hull design was further optimized based on successful offshore testing of a 1:8 scale VolturnUS hull off Castine Maine, updated design requirements for concrete tensile stresses and steel rebar cover approved by ABS, improved design features to resist loads more efficiently, and more detailed analysis of extreme metocean conditions in the Gulf of Maine. As a result, between the 50% and 100% FEED designs, the concrete volume was reduced by 13%, the amount of steel reinforcement has decreased by 29%, the amount of prestressing strands has decreased by 52%, and the transverse post-Tensioning threadbars in the three bottom beams were eliminated altogether. The design reports and drawings reflect the following work:
    A. Detailed reinforcement and post tensioning layouts
    B. Fatigue checks
    C. Serviceability/water tightness
    D. Ultimate strength checks
    E. Construction loading and stress analysis
    F. Creep design
    G. Tow load analysis
    H. Refinement of construction methodology
    I. The hull currently accommodates either a steel tower or a composites tower.

2. **Hull received third-party review by offshore concrete company** specializing in offshore concrete structures. A letter summarizing the results of the third-party review is included in Ref. 14**.**

3. **Concrete materials, fatigue, joints performance and modular construction confirmed**: The concrete optimization and design requirements were confirmed through the fabrication and testing of a 1/4 scale model of a segmental match-cast hull bottom beam, as well as material testing. The 1/4 scale bottom beam model was made with the same concrete, post-tensioning steel, rebar, and modular construction method planned for the full-scale VolturnUS. The 1/4 scale beam model was subjected to fatigue equivalent to a lifetime of service and the concrete and watertight joints continued to perform as designed as shown in Figure 6.

Figure 6 Assembly of ¼ Scale Prototype of Concrete Hull Member to Demonstrate Modular Construction and to Test Connections

Subtask 1.4: Hull electrical and mechanical design as needed to advance hull design

The hull electrical and mechanical systems have been updated to allow the hull to reach 100% FEED and were simplified significantly to cut costs. For the 50% design, a complex active ballast system was proposed to minimize heel angles due to wind turbine overturning moment. The cost of this system proved to be quite high and working with a mechanical detailing subcontractor, a significantly less expensive ballast system was developed. The new system is passive and can be used to trim the structure in damaged conditions. Because the concrete hull is inherently more stable because of its higher mass, the net effect on the hull size remained largely unchanged and the marine/ hull electrical systems costs were reduced by a factor of three.

Subtask 1.5: Mooring, Anchor, and Dynamic Cable Design

The mooring system consists of three chain catenary lines designed in accordance with the *American Bureau of Shipping Guide for Building and Classing Floating Offshore Wind Turbines (ABS)*. In accordance with the ABS Guide, the analysis considered survival, strength, and fatigue cases and accounted for corrosion effects sustained over the 25-year deployment.

This design was developed following receiving an Approval in Principle from ABS in 2014. Anchor sizes vary and are based on the soil characteristics obtained from geophysical data collected in 2010. The 100% FEED for the 3-chain catenary mooring systems has been further developed to ease installation with domestic US vessels and to reduce costs. The dynamic cable was also sized by the mechanical detailing subcontractor. Details for these items are provided in three reports.

Subtask 1.6: Metocean Analysis and Site Data Collection

Several key activities were completed to support the refinement of metocean data used in the design. More detailed metocean design conditions were developed, added to the Basis of Design for the VolturnUS 6MW and were approved by the ABS. Further the DeepCLiDAR, an UMaine-developed and fabricated buoy equipped with a Windcube V2 LiDAR capable of measuring hub height wind speeds, was successfully deployed at the project site in Dec 2015 (Figure 7).

Figure 7 UMaine DeepCLiDAR buoy was deployed offshore Monhegan Island in December 2015 continues to collect hub-height wind speed. It supplements 14 years of metocean data collected by an UMaine surface level buoy.

The buoy results have been validated by AWS Truepower following a prior deployment offshore Castine, Maine in 2013. A reference LiDAR was also placed on land for validation of the buoy LiDAR data by partner AWS Truepower. The buoy has been on the offshore test site collecting hub-height wind data off Monhegan Island along with a second LiDAR located on the island since December, 2015. The buoy is as part of the official wind resource measurement campaign.[3,4]

Subtask 1.7: Coupled Modeling and Simulation

Significant modeling efforts occurred to support the 100% FEED of the hull design. Notable highlights from the reports include:

- **The American Bureau of Shipping (ABS) has third-party reviewed and approved all UMaine's analysis and design tools** used to develop loads and estimate motions. The validation of UMaine's design tools was documented in a report approved by ABS and shared with the DOE. The report included validation against 1:50 and 1:8 scale test data. These are critical milestones as ABS has greenlighted all the numerical analysis and design tools for the hull.
- **79,896 coupled model load simulations were completed to cover all for the ABS load cases.** The complete coupled loads analysis using FAST and the turbine OEM-supplied wind turbine model carried out**.** The analysis was conducted jointly by NREL

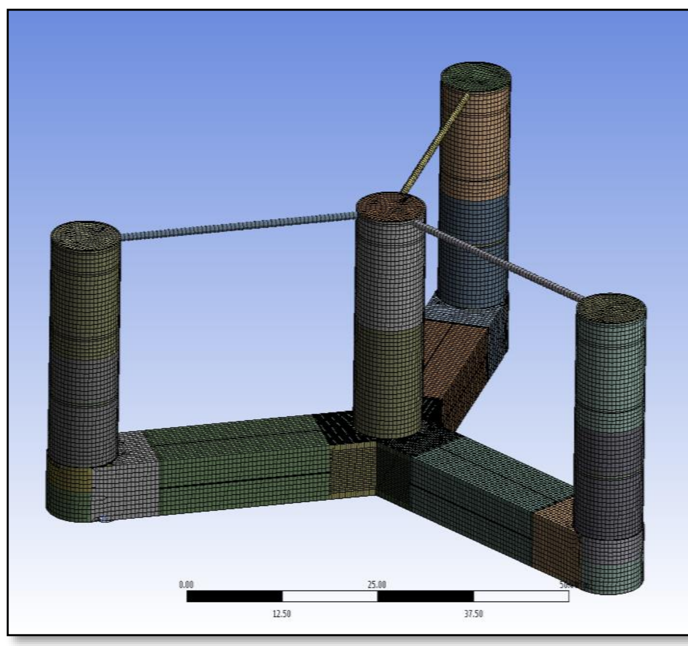

Figure 8 VolturnUS Finite Element Model in ANSYS.

[3] Viselli, A, Filippelli, M, Pettigrew, N, Dagher, H, Faessler, N (2019). Validation of the First LiDAR Wind Resource Assessment Buoy System Offshore the Northeast United States, Journal of Wind Energy. 2019;1–15. DOI 10.1002/we.2387.

[4] Viselli, A, Filippelli, M, Faessler, N (2022). Analysis of LiDAR Wind Speed and Shear Measurements Offshore in the Northeast US. Journal of Offshore Mechanics and Artic Engineering. 2022.

and UMaine, and the turbine OEM has provided input on the modeling methodology and reviewed the results.

- **Hull finite element modeling completed. Over 17,900 stress states were analyzed** and used to design the hull per ABS requirements. The model is shown in Figure 8.
- **A full stability analysis per ABS** requirements was completed in General Hydrostatics.

Subtask 1.8: Classification Society Review

ABS approval: The American Bureau of Shipping (ABS) third-party reviewed and approved all design requirements for the hull (some turbine-related design requirements pending review), and reviewed and approved UMaine's analysis and design tools. The design tool validation was documented in a report approved by ABS and shared with DOE. These are critical milestones as ABS has greenlighted all the numerical analysis and design tools for the hull. All other 100% FEED reports and drawings have been submitted to ABS and are expected be reviewed and approved by the end of May 2016 leading to a Final Design Approval of the hull.

2.4 Task 2.0: Cost Estimating

Subtask 2.1 Hull Cost Estimates

Concrete hull bid process: An engineering company specializing in concrete offshore structures, developed a bid package for the 6MW VolturnUS concrete hulls, and obtained independent concrete hull cost estimates using the FEED VolturnUS concrete hull drawings and quantities.

Four cost estimates were collected through this process. Production costs for 2 hulls, 83 hulls, and 166 hulls were requested to evaluate the economies of scale. A production rate of one hull per week was specified in the bid package for the 83 and 166 hull projects, to match production rates of steel jacket structures in Europe. By collaborating with four leading US concrete contractors, serial modular production methods for the concrete hull were developed. One of these contractors was visited by the DOE and UMaine and can be prepared to produce VolturnUS concrete hulls at the rate of one per week for a 1000-MW project with approximately a 6-8 months' notice. Similar precasting facilities can be set up near large project sites, as is often the case for the construction of large segmental concrete bridges and significantly increase local content.

Steel hull bid process: Nine independent cost estimates for 6MW steel hulls were obtained by a third-party offshore engineering firm for comparison purposes. Bids were solicited for both 2 hulls and for 86 hulls to evaluate scale-benefits.

Subtask 2.2: Cost Tradeoffs of Steel Versus Composite Towers

A cost study of steel versus composite towers supporting floating 6MW turbines was completed with NREL. A composite tower cost is compared to that of steel tower designs produced in the US, Germany, and China. Manufacturing and design improvements for the composite tower have led to an approximately 50% cost reduction, compared to the prior 50% FEED estimate. The US composite tower cost was found to be 13% less expensive than the least costly steel tower. Cost estimates for the composite tower was provided by one of the US top composite production companies. Composite tower manufacturing for a utility-scale project is expected to create 150 local jobs further increasing local content. As requested by DOE, our team has proceeded with the concrete hull design using a steel tower option to reduce the innovation risk on this project. At the same time, the UMaine team continued to work with the turbine OEM team to explore the opportunity to use the innovative lightweight composite tower.

Subtask 2.3 Cost tradeoffs of Concrete Versus Steel Hulls

At the request of the US Department of Energy, the University of Maine obtained independent cost estimates for both concrete and steel semi-submersible hulls from 3rd parties to verify internal cost estimates presented to the Department of Energy during the 50% FEED design review in April 2014. UMaine engaged two engineering firms to prepare engineering estimates and get initial bids from contractors. Nine independent cost estimates for steel hulls (7 from the US and 2 from Southeast Asia), and four US independent cost estimates for concrete hulls were obtained.

At commercial scale, the US concrete hull cost estimates were found to be considerably and consistently less than the US steel hull cost estimates. In volume production, the concrete hulls could be produced in the US at nearly half the cost of steel hulls, but also at less cost than steel hulls produced in Southeast Asia and transported to the US. The key observations for 6 MW hulls are:

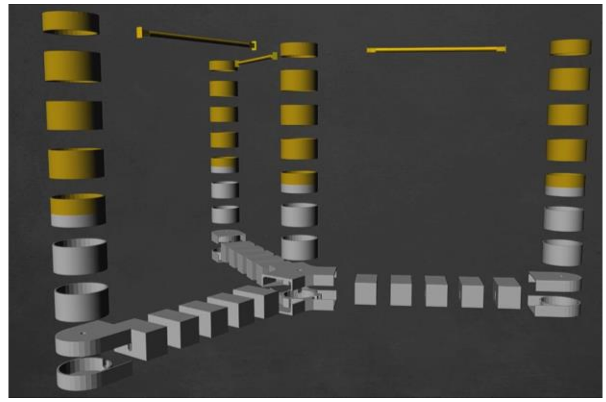

Figure 9 Modular Concrete Hull Construction

1. Due to modular segmental concrete construction methods (Figure 9), there are significant cost efficiencies for 83- and 166-units production volumes for concrete hulls: approximately a cost reduction factor of two to three as compared to the two-off demonstration project production volume. UMaine identified at least one oceanfront precasting facility on the US east coast able with approximately a 6-8 months' notice to begin large scale production at a rate of one 6MW hull per week. Modular precasting facilities can also be set up near project sites, as it is commonly done in segmental concrete bridge construction.
2. As opposed to concrete, there was little efficiency reported for large volume production for steel hulls. This was a surprising result, but this observation held consistently true for the 6 different steel fabricators who independently provided bids, as well as the engineering cost estimates.
3. The steel hulls will likely not be produced in the US. Steel hulls produced in Southeast Asia were found to be between 30-60% less expensive than US-produced steel hulls. Therefore, unless something dramatically changes, steel hulls will likely be imported from Southeast Asia to the US.
4. US Manufacturing: Concrete hulls produced in the US are less expensive than steel hulls produced in Southeast Asia. This will help to guarantee that manufacturing jobs related to concrete hull technology will stay in the US.

Subtask 2.4 Cost Tradeoffs of Light Wt. vs Normal Wt. Concrete

At the request of DOE, the costs of using a lightweight concrete mix to construct the hull were compared to costs for a normal-weight concrete mix. The light-weight mix is moderately more expensive due to the cost of the light-weight aggregates and mix processing requirements. However, by using a less dense mix, a smaller floating foundation with less concrete volume is possible which results in a significant cost savings.

2.5 Task 3.0: LCOE Analysis and US Impact for 6MW VolturnUS FOWTs

NREL performed an LCOE analysis for a total of four separate projects using the VolturnUS concrete technology, spanning small 12 MW (demo) and large 500MW (utility) wind farms, and New England (Atlantic) and west (Pacific) coasts. Please note that a later NREL report in 2020 was developed for larger 15MW WTGs which showed additional cost reductions. Please see the references section to access this report.

This report demonstrates the benefits of the economies of scale and the known challenge with financing a demonstration project. The steel project hull costs are based on estimates and bids obtained by an independent engineering firm. The following are the conclusions quoted from the NREL report:

"The LCOE shows that for the utility-scale projects, UMaine's concrete semi-submersible substructure could be effective at lowering the cost of offshore wind energy compared to the conventional steel hulls. In addition, given the ability for the concrete hull to be built anywhere, it can be installed on both the Atlantic as well as Pacific side economically and could be an important step in increasing domestic content for offshore wind in the United States."

"Finally, an analysis was conducted that determined the total offshore wind capacity for the United States comparing the fixed bottom and floating technologies. The analysis determined that water depth of about 45 m is a break point where floating substructures may become more economical than fixed-bottom to floating structures. Limiting the water depth to a maximum of 1000m, ***the analysis estimates that of approximately 2281 GW of available offshore wind energy supply, about 70% would be suitable for floating substructures, similar to the UMaine concrete floating semi-submersible hull."***

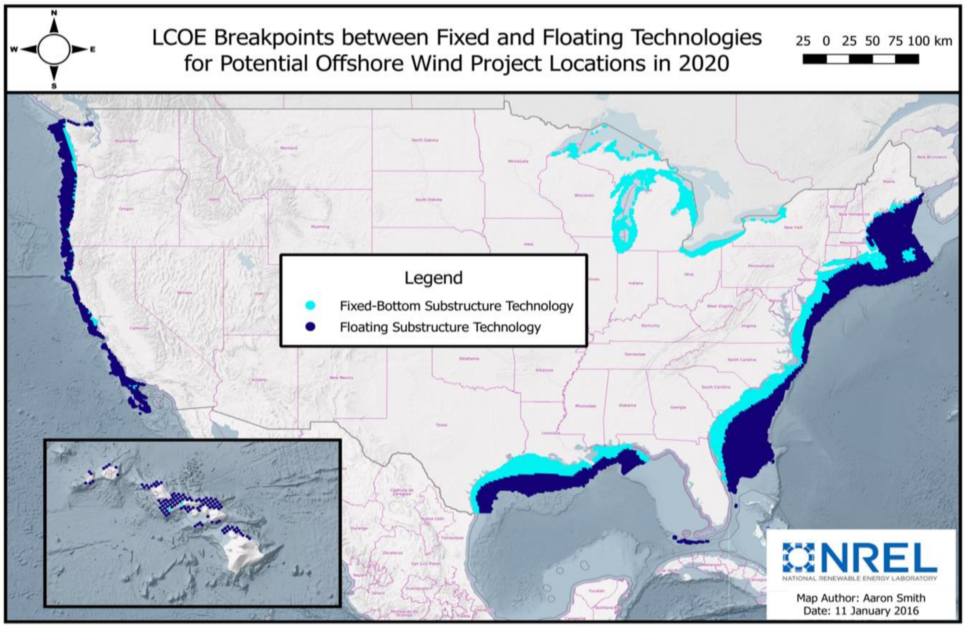

Figure 10 Economic Breakpoints for Fixed and Floating Offshore Wind Technology Showing that 70% of the U.S. Offshore Wind Energy Supply may be Suitable for Floating Technology (NREL Report Ref. 57)

2.6 Task 4.0: Disseminate project information through conferences and peer reviewed journals.

Results from this work were published in 3 refereed journal papers and presented at 5 conferences. Please see the list of publications at the end of this document in Chapter 5.

3. Budget Period 2

3.1 Introduction

This chapter serves as a technical summary of the work completed under Budget Period 2 for the US Department of Energy (DOE) award DE-EE0006713. This chapter follows the format of the Project Statement of Project Objectives (SOPO) which is also included for reference.

Award DE-EE0006713 represents one source of funding for the project from the DOE. This award achieved several critical design and development milestones including the design of a 100% FEED for a 6MW floating offshore wind turbine (FOWT) hull and support of technical due diligence reviews from project investors which led to development agreements between UMaine, Diamond/ Mitsubishi, and RWE representing approximately $100M in investment in NEAV I. During the course of this award, the Project originally consisted of a 2 turbine 12-MW floating wind farm, using two 6MW horizontal-axis turbines deployed in Maine state waters off the Coast of Monhegan Island as previously shown in Figure 1 and Figure 3. UMaine has completed the 100% FEED for these FOWTs and the design has been independently approved by the American Bureau of Shipping (ABS) under its guidelines for floating turbines.

Figure 11 The New England Aqua Ventus I Project will Demonstrate the VolturnUS Concrete Floating Hull

During the course of this award, turbine sizes have increased faster than anticipated, and US projects are now planning to use these larger turbines making the smaller 6MW turbines unavailable. For example, the Vineyard project in Massachusetts has announced that it will be using MHI-Vestas V164-9.5.0 MW turbines for installation in 2021. Therefore, the project team is now developing an alternate design for the NEAV floating demonstration project using a single 10-12 MW turbine rather than the planned two 6MW turbines.

Although the turbine size has changed, DE-EE0006713 still enabled significant advancement of the project and VolturnUS technology which will be directly leveraged to support the redesign of the project for a larger turbine. These deliverables achieved in this budget period are presented here and included in this final report.

3.2 Task 1 Hull Design Summary of Work Completed

The overall goal of this design effort was to complete all aspects of the design, a third-party review, and obtain revised cost information for the project. The following sections summarize the design work organized by the SOPO Subtask structure.

The hull consists of a corrosion-resistant, fatigue-resistant, prestressed concrete floating platform. Mass-production costs for the VolturnUS prestressed concrete hull are about 50% of that of a comparable semisubmersible steel hull and take advantage of known domestic construction techniques in the precast concrete building/bridge industry. The VolturnUS 100% hull FEED represents a culmination of 10-years of work. The design has been successfully tested at 1:50 scale in a wave-basin multiple times and 1:8 scale offshore Maine. The 100% hull FEED received an Approval in Principle by the American Bureau of Shipping (ABS) in 2014, has received a 3rd party review from a third-party engineering firm and received a positive ABS Design 3rd-party Classification in February of 2017 (ABS Classification Number YY252339). Figure 12 shows the VolturnUS floating wind hull supporting a 6MW WTG. The hull design consists of a central column with three radial arms each comprised of a concrete bottom beam, concrete radial column, and steel axial strut member/access way. Three chain mooring lines connect the structure to three drag embedment anchors. A lazy-wave electrical umbilical connects the turbines to the grid.

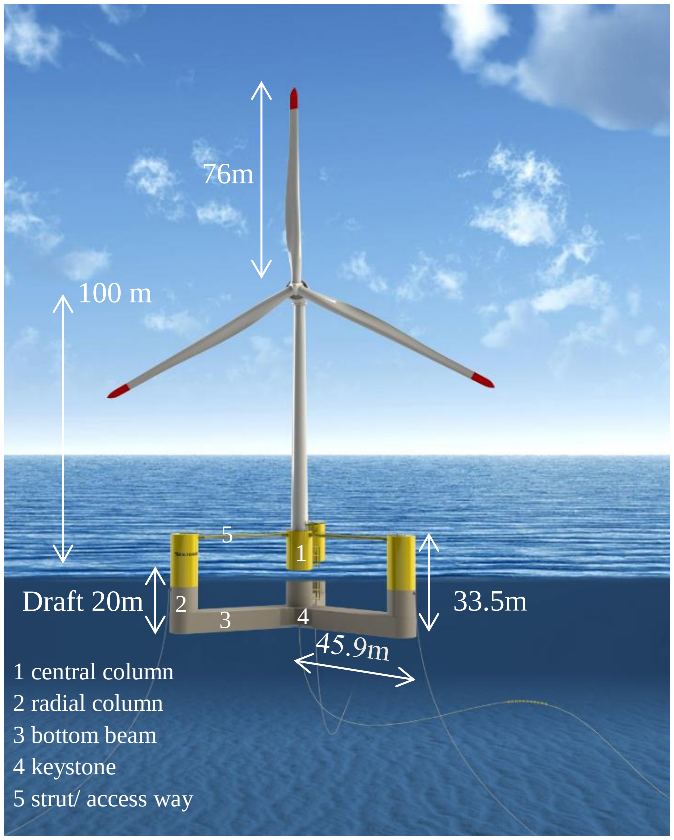

Figure 12 Gross dimensions of VolturnUS floating wind hull supporting a 6MW WTG

Subtask 1.1. Design management and system integration

This effort consisted of managing the entire design process and integrating all aspects of the project with particular attention to interfaces between all aspects of the design. The following design management deliverables were completed in this subtask:

- Day-to-day design management responsibilities and system integration activities with the project design team.
- DOE Regular Reporting Activities including bi-weekly teleconference calls with the DOE management team, monthly presentations to the DOE management team, quarterly written reports to meet DOE management requirements, and monthly project schedules submitted to the DOE Management team
- Coordination of all subcontractors to deliver project objectives and deliverables
- Interim Deliverable submission in June 2017.
- Management of a comprehensive project technical due diligence reviews completed as part of the project financing effort. This effort included development of a virtual data room (VDR) filled with all technical details of the project, answering detailed technical questions from the project investor's technical teams, and preparing additional technical reports and addendums to satisfy the project reviewers. A virtual data room was established to share over 300 documents (7,862 MB) of project documents and data. The information was shared with several project developers

  The technical reviews with the developers covered all aspects including project design, hull design, mooring system design, site data, electrical infrastructure, permitting, outreach, design management principles and other aspects. The goal was to assess all available project data to inform business and technical planning and relationships going forward. The effort informed an investment decision-making process for the project partners but required significant technical design support from UMaine to address all questions from technical experts employed by the developers.

  One developer was selected from the group of five and additional work surrounding turbine size evaluation, an Interim Development Agreement (IDA), and Joint Development Agreement (JDA) were completed. The selected developer was RWE and Diamond/ Mitsubishi.

- Preliminary evaluations of the size of the turbine determined that the 6MW turbine was not suitable due to lack of availability in proximity to the anticipated project execution date. A separate award (DOE AWARD DOE-EE0008965) will support the development of a complete design for a 9.5MW+ turbine.

Subtask 1.2. Metocean conditions

The goal of this task was to continue the deployment of the DeepCLiDAR buoy at the Monhegan test site to collect hub-height wind speeds and other metocean conditions for approximately 6 months.

The DeepCLiDAR was built by the University of Maine and first deployed off the Monhegan test site in December 2015. The wind data collected offshore was compared to wind data collected from a second LiDAR situated on Monhegan Island. An independent report was developed validating the offshore DeepCLiDAR data by AWS Truepower. The DeepCLiDAR data will be used to inform future energy production estimates. In addition, to support the 100% design of the floating platform, metocean conditions will be analyzed to update and verify environmental conditions required for design. In addition to wind speed measurement, the buoy also collected wave and current information necessary for design.

Figure 13 UMaine DeepCLiDAR buoy was deployed offshore Monhegan Island in December 2015 to collect hub-height wind speed. The buoy was validated by AWS True Power following the Carbon Trust Guidelines for Floating LiDARs It supplements 14 years of metocean data collected by an UMaine surface level buoy.

UL-AWS Truepower, an independent 3rd party, validated DeepCLiDAR's data recovery and measurement accuracy against

Carbon Trust's industry-standard performance criteria. With successful third-party validation complete, DeepCLiDAR is now available for commercial lease or purchase. DeepCLiDAR can help accelerate the development of the US offshore wind industry by providing high quality, low-cost offshore wind resource data, metocean monitoring, and ecological characterization capabilities in remote marine environments. The test concluded a robust, three-phase validation program that sequentially vetted the DeepCLiDAR's performance onshore, near-shore and offshore. The validation campaign was jointly developed by UL/ AWS Truepower and UMaine to characterize the floating LiDAR's measurements in the absence of an offshore meteorological tower. The basis for the system's evaluation and acceptance were the Key Performance Indicators and Acceptance Criteria defined by the Carbon Trust. DeepCLiDAR houses a WINDCUBE V2 Offshore LiDAR Remote Sensor, which has been adapted to a dynamic marine environment to measure wind conditions using laser technology up to 200 meters above the ocean surface.

Received: 2 March 2018 | Revised: 22 February 2019 | Accepted: 23 May 2019
DOI: 10.1002/we.2387

RESEARCH ARTICLE

WILEY

Validation of the first LiDAR wind resource assessment buoy system offshore the Northeast United States

Anthony Viselli[1] | Matthew Filippelli[2] | Neal Pettigrew[3] | Habib Dagher[1] | Nathan Faessler[1]

[1]University of Maine, Advanced Structures and Composites Center, Orono, Maine
[2]UL-AWS Truepower, Albany, New York
[3]University of Maine, School of Marine Sciences Physical Oceanography Group, Orono, Maine

Correspondence
Anthony Viselli, University of Maine, Advanced Structures and Composites Center, Orono, ME, USA.
Email: anthony.viselli@maine.edu

Funding information
State of Maine Maine Technology Institute, Grant/Award Number: DL-4006; United States Department of Energy EERE, Grant/Award Numbers: DE-EE0003278 and DE-EE0002981; AWS Truepower-UL; NRG Renewable Systems; University of Maine Physical Oceanography Group; University of Maine; Davis Family Foundation; Rockerfeller Brothers; National Science Foundation, Grant/Award Number: IIP-0917974

Abstract
The US offshore wind industry is maturing with several projects in various stages of development. These projects require site wind and environmental data before and during operation. Conventional techniques such as fixed-bottom meteorological towers present economical and permitting challenges for the US. Floating Light Detection and Ranging (LiDAR) buoys offer significant advantages including reduced costs, less permitting, and reusability. This paper presents the validation of the first floating LiDAR buoy in Northeast US waters. The buoy, named DeepCLiDAR, includes a LiDAR, ecological monitoring sensors, and metocean sensors. A three-phase LiDAR validation plan was executed, and its results are presented. The objective of the validation plan was to verify the accuracy of measurements made by the LiDAR buoy in wave environments against an unmoving reference wind measurement. Due to a lack of reference met masts, the use of a LiDAR on land as a baseline reference was implemented for validation. Comparison to a reference LiDAR instead of a traditional meteorological tower was a unique approach required in the Northeast US waters due to the absence of a reference fixed-bottom meteorological tower in the region at the time of this study. The testing included a comparison of wind speed measurements made by the buoy deployed 15 km offshore from the mainland and a land-based reference LiDAR located on a nearby island. This paper presents the methodology and results of this program, which indicate favorable agreement. This was the first such validation program in the Northeast USA which is now seeing rapid development of offshore wind.

Figure 14 Peer Reviewed Journal Publication Summarizing Validation of the First LiDAR wind resource assessment buoy system in the US, the DeepCLiDAR.

UL/ AWS Truepower, the third party who validated DeepCLiDAR, is one of the world's leading providers of renewable energy solutions to developers, investors, utilities, and governments. "DeepCLiDAR performed well during its validation, exceeding the Carbon Trust's acceptance criteria for wind speed and direction measurements," said AWS Truepower Principal Engineer Matthew Filippelli. "In spite of the inherent challenges of validating floating LiDAR in the U.S. – notably the absence of an offshore meteorological tower – the DeepCLiDAR has demonstrated a pre-commercial level of technical maturity. AWST considers this system valid for use in an offshore wind resource and design condition assessment campaign in similar metocean conditions."

In addition to the DeepCLiDAR measurements, UMaine continued to collect and analyze site wind, wave, current, and temperature data from buoy E01 near the project site to support design activities including the wind turbine loads analysis with turbine OEMs and electricity production estimates. Additionally, the following two journal articles were also developed using the data further establishing confidence in the data set:

1. Validation of the First LiDAR Wind Resource Assessment Buoy System Offshore the Northeast United States, Journal of Wind Energy**.**
2. Analysis of LiDAR Wind Speed and Shear Measurements Offshore in the Northeast to the US, Journal of Offshore Mechanics and Artic Engineering in Review

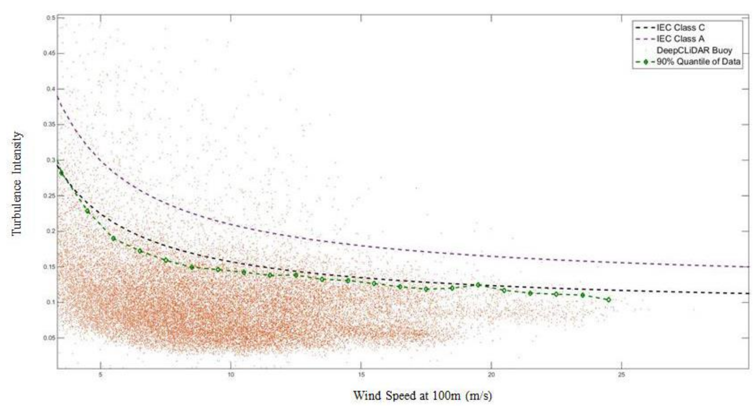

Figure 15 Comparison Between IEC 61400-1 Turbulence Intensity Class A and C with data and 90% Quantile DeepCLiDAR Measurements at 100m Elevation.

The Basis of Design was also revised including necessary updates resulting from metocean design parameters (revision of design load case list, etc.) needed to reflect updates in metocean data.

Subtask 1.3. Hull construction engineering

The goal of this task is to work with contractors, conduct constructability reviews including optimization of fabrication details to simplify construction and minimize costs and risks. Also, the effort includes calculating loads and stresses and hull support requirements based on proposed construction means and methods.

The following work has been completed under this task.

- Supported technical review of construction documentation as part of the developer due diligence process. This required the design team to answer questions, provide additional data and supporting documentation to satisfy the developer review teams. A major concrete design firm, Arup, was hired to complete the review of the hull constructability based on the 100% FEED design. Through this process, Arup provided the following review services:
    - Verification of the concrete hull structural design and concrete mix characterization
    - Verification of construction methods
    - Verification of material and structural testing.
    - Requested the design team existing guidelines/certification reviews in order to confirm the fit-for-construction/constructability.
- Evaluation of 3 proposed construction methods

Subtask 1.4. Hull electrical and communication design

This effort consists of electrical and data communication design to support the flowing functions: 1) turbine integration, 2) mechanical and safety systems, 3) hull instrumentation and testing, 4) data communication from the project site to the University of Maine, Maine Aqua Ventus and the turbine OEM.

A hull electrical integration package was completed for the turbine OEM 6MW turbine including layout of equipment, cable interface, cable hook up, and grid-interconnection. the turbine OEM provided integration documentation to which the UMaine design team adapted the hull design to accommodate. In particular the following design details were substantially developed:

- Detailed export cable attachment design and installation methodology. The layout of the subsea electrical cable was finalized working with cable hardware suppliers and installers. It was determined the subsea cable will approach the hull in a lazy wave configuration and proceed through an interface running from the keel of the hull to the main deck. The interface would terminate at the work platform and a portable winch would raise the cable during installation. The connection would be made using an industry connector in a junction box. From the junction box, the electrical system would be hard wired within the hull to provide power to the turbine equipment including the switch gear.
- The work platform has been designed to meet the turbine OEM requirements for size, load, and crane access.
- Arrangement of all the turbine OEM equipment within the VolturnUS hull was completed. the turbine OEM requested that switch gear be located within the hull. Access requirements for the switch gear to be removed and replaced were also adhered to.
- Integration of the turbine OEM systems with Mechanical and safety systems onboard the hull.
- Preliminary integration of the turbine SCADA system with the UMaine instrumentation system. See subtask 1.5 for more information.
- Data communication protocols and plans were developed for the major systems on board the hull.

The overall design approaches implemented in the 6MW version are readily expandable for larger turbine systems.

Subtask 1.5. Hull instrumentation and testing plans

The goal of this subtask is to design the hull testing program to validate design models, design assumptions, and to meet permitting requirements. Additionally, this task is intended to provide cost estimates for the acquisition and installation of the equipment, and for the operations of the equipment. This effort will coordinate with Subtask 1.4 to define electrical and communication requirements.

A test and instrumentation plan has been developed. This plan was originally developed by a consortium of testing team partners in 2013-2014 under DOE project DE-FOA-0000410, which included the University of Maine, University of Massachusetts-Amherst, AWS Truepower, and the National Renewable Energy Laboratory [1]. The team developed this data collection plan to provide data to support the following objectives for the end-uses of the data set:

- FOWT performance and design verification to support third-party certification efforts including the American Bureau of Shipping which has provided a classification for the VolturnUS floating hull (ABS Class No. YY252339).
- Validation of meteorological and ocean environments used in the design process
- FOWT numerical coupled model validation at a commercial scale to further the confidence in numerical tools used for design
- System health monitoring to support operations and maintenance

This original data measurement plan has been revised by the University of Maine in 2017 during DOE project DE-EE0006713 to reflect the current state of the project design and newly available guidelines from the DOE and NREL, while incorporating advances in instrumentation technology. Efforts have also been made to reduce redundant sensors and optimize the overall instrumentation system. The proposed instrumentation systems build off the successful testing of a 1:8 scale 6MW floating VolturnUS prototype funded by the US Department of Energy in 2013-2014.

The proposed equipment consists of instrumentation hardware to characterize the wind, wave, current, and tidal environment, as well as performance of the FOWTs during operation of the project. Environmental data will be provided from three sources: (1) a floating LiDAR buoy equipped with wave, current, and atmospheric sensors will be deployed upwind to the West of the two turbines, (2) a sub-sea acoustic current speed/ direction profiler, tide measurement, and directional wave system will be deployed in between and south of the two turbines, and (3) a look-ahead/ look-behind LiDAR will be deployed on one of the wind turbines to measure incoming or down-wind wind speeds. Data from the buoy and subsea acoustic device will be relayed via telemetry. The two 6MW FOWTs will be instrumented to collect turbine performance, structural loads, and system motion data. Figure 21 presents a conceptual layout of this instrumentation. The data on board the turbines will be communicated via a fiber optic cable connected to shore.

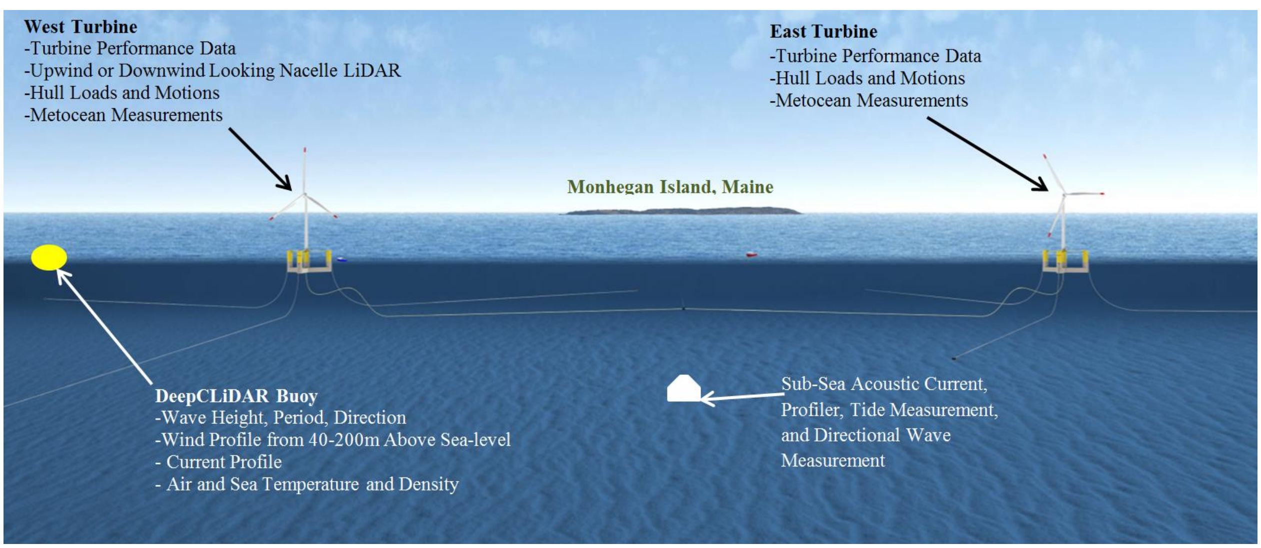

Figure 16 Instrumentation layout for the 2x6MW New England Aqua Ventus pilot project.

A draft of the instrumentation plan was submitted to DOE and DOE provided comments which were addressed by UMaine. A cost estimate cost estimate was provided for establishing a Data Archive and Portal (DAP) for 5 years with a variety of capabilities including, but not limited to:

- Provide user and operational support to automated methods to upload and download data

- Long-term preservation and access to all datasets identified by the PI
- Provide tools to monitor the data flow during the campaign and identify issues with data flows
- Process raw data to meet including standardizing variable names, units and applying quality checks
- Support methods to view videos in near real-time
- Participate in meetings with instrument mentors and operational team

Due to the anticipated unavailability of the 6MW turbine, additional work in this area will be completed for a larger turbine on a separate DOE award (DE-0008965)

Subtask 1.6. Mooring and anchors installation procedures and design

The goal of this task is to develop and refine the final designs for the mooring lines and anchors based on installation and testing methods working with contractors to a sufficient level of detail needed for producing bids. The following work has been completed:

- Mooring design has been reviewed during ABS review which resulted in the use of studless chain. ABS accepted the mooring design.
- An independent review of this system was completed by a subcontractor. The review resulted in a comparable bar diameter being required, effectively confirming the analysis originally completed by UMaine and increasing confidence in the result.
- Additional surveying of the test site may be required to evaluate the possibility of using more than three anchors.
- Revise design if needed based on installation procedures for construction.
- Due to the necessity of considering a larger turbine a preliminary sizing of the mooring took place using a limited set of load cases to support project planning, siting, and construction efforts.
- Budgetary costs for materials and installation were received and compared against previous cost estimates. Costs are considered comparable accounting for the reduced number of turbines and increased size of the mooring chain.

Subtask 1.7. Tow-out and installation of Floating Offshore Wind Turbine (FOWT)

The goal of this subtask is to design the tow-out and hull installation procedures. This includes FOWT tow-out from Searsport to Monhegan Island and installation at the test site. The following work has been completed to date:

- Development of a refined tow-out plan has begun for both the tow-out of concrete hull base (consisting of the three bottom beams and keystone) from the Hamden cofferdam to Searsport as shown in the figures below and for complete hull from Searsport to Monhegan.
- The tow-out plan includes a review of bathymetric data collected from the Penobscot river and Penobscot bay as well as tidal gauges and NOAA tidal data.
- Input from the Penobscot Bay Pilots Association and relevant subcontractors have been included in the plan.
- The plan will inform detailed design of towing connection hardware and attachments needed for design as well as be provided during the bidding process for the work.
- Two construction/launch workshops took place with UMaine, the detailed concrete designer, and the project developer in December 2019 and February 2020.
- Work for necessary tow-out engineering and support were discussed during the workshops.

Subtask 1.8. Turbine and tower integration

The goal of this effort is to complete all turbine and tower integration activities including development of the turbine controls, updated power curve for turbine, onboard electrical systems and electrical equipment layout, and final loads analysis check using an optimized controller and tower from turbine OEM. During the course of the award UMaine made substantial progress with the turbine OEM 6MW WTG Turbine. The following work was completed:

- Completion of a Design Loop 0 analysis and hull redesign. This include resizing the 6MW hull based on revised mass data from the turbine OEM for both the RNA and tower. The turbine mass has changed by 8.1% increase due to both increased blade and increased nacelle weights. The mass changes were explained by the turbine OEM to be due to lessons learned from the first test prototype installed in France and the 5-turbine Block Island wind project.

- Prior to the turbine OEM beginning the Design Loop 0, UMaine completed a design check to assess the impact of the increased turbine mass on the hull.
- The hull appears to require minimal changes to accommodate the increase in the turbine OEM turbine mass. This was determined through the following analyses.
- FAST coupled analysis of key load cases determined during 100% FEED effort
- Dynamic performance of hull acceptable for UMaine and appears also to meet the turbine OEM stated requirements for nacelle acceleration and maximum inclination angles during operation.
- Design loads for hull are increased slightly due to increase in turbine mass but no major hull design changes are expected. Overall hull geometry changes are not likely to be needed. Small reinforcement changes are likely sufficient to address the small increase in loads.
- The steel tower provided by the turbine OEM has a natural frequency which lies in the 3P range and may need to be addressed by the turbine OEM as they are designing this element either through a revision of the structural design or through a control strategy such as frequency hopping.
- Hull hydrostatic stability performance was assessed using General Hydrostatics Software (GHS). The analysis showed that the hull with the increased turbine mass still meets the ABS stability requirements in operation and in damaged conditions.
- With the UMaine hull initially confirmed, UMaine provided the turbine OEM an updated hull model for use in the turbine OEM's Bladed coupled modeling loop 0. the turbine OEM is developed a controller for the hull and ran an analysis of key design load cases (approximately 1000 load cases) and developed a project-specific turbine power curve which accounts for motions of the hull, to be used in the preliminary TSA offer and project Preliminary Investment Decision (PID).
- the turbine OEM completed Loop 0 analysis using Bladed (Figure 23 which was checked by UMaine using FAST). UMaine's check resulted in recommendations that the controller be modified to reduce the fatigue loading on the tower and other components—the turbine OEM indicated that an updated controller was being developed and would be used in future design Loops.
- A standard interface for the tower base was developed through collaboration between UMaine and the turbine OEM which mimicked land-based concrete foundation details.

Subtask 1.9. Electrical interconnection

This task consists of the following activities

1.9.1 Grid interconnection study and Small Generator Interconnection Application (SGIA) Cable route survey
1.9.2. Offshore subsea static cable design
1.9.3. Offshore dynamic cables and T-connection from Static to Dynamic cable
1.9.4. Offshore cable landing design
1.9.5. Grid interconnection design from offshore cable landing termination to CMP line, including grid interconnection equipment.
1.9.6. Land line design by CMP. This will be an upgrade to an existing CMP distribution line.

The following work was completed:

A 100% FEED report was produced by an electrical engineering subcontractor. This report addresses the SOPO work items 1.9.1-1.9.5. The New England Aqua Ventus project consists of two floating wind turbine generators, located approximately 2 miles south of Monhegan Island, Maine. In this report, an initial cable landing location was considered, and the subsea cable runs approximately 16 miles to a landing at harbor. From the landing point, the cable will be routed underground and overhead to the point of interconnect (POI) with a distribution line in the village. From the village it connects to a substation via existing 34.5 kV lines, and a newly rebuilt 34.5 kV line.

During the FEED phase, the electrical engineering subcontractor has maintained close communication with Project Owners, Project Operators, Engineering Firms, and other stakeholders to determine the project specific requirements. Front End Engineering has been completed and the design viability has been confirmed for primary options as well as alternatives under consideration by the owner.

Eleven additional landing options were considered based on several factors including ability to bury the cable, overall distance from test site, ecological impact of cable burial, environmental constraints of landing, access and proximity to land-side transmission infrastructure, and ability to avoid town-owned property or roads.

The eleven landing options were reduced to two sites. Either route option would result in roughly 22 miles of cable length. Cost estimates for landing alternatives were developed with the ultimate goal of minimizing impact. With the introduction of a developer to the project, the developer set up a series of meetings and workshops to validate cable landing site. Potential landing sites were analyzed using a cable landing matrix that included several factors, technical feasibility, distance/cost, land-based infrastructure, and local support. UMaine continued to work with stakeholders in the area to refine cable landing options. Developer and state representatives held positive meetings with town officials who have been supportive of landing the cable. An RFQ for a cable and geophysical survey has been prepared by developers RWE and Diamond which will be issued under DE-EE0005990.

Subtask 1.10. Laboratory testing

This task consists of laboratory testing as needed to support the project design review including: (a) Conduct final VolturnUS hull design verification through 1:50 scale wave-wind basin testing at the UMaine facility, (b) based on third party review comments and other design considerations, conduct additional materials and component testing as needed to support design and the third-party ABS review and documentation, (c) conduct testing as needed to answer construction contractors questions such as effects of creep and shrinkage or (d) conduct testing to evaluate proposed suppliers products such as strength and fatigue properties of supplier components. The following work has been completed:

In August and September 2016, a 1:52 scale model test of the VolturnUS 100% design was conducted at the UMaine Ocean Engineering Lab Wind-Wave basin (W^2). The objective of the model test was to confirm the performance of the VolturnUS floating platform supporting a 6 MW wind turbine. The data generated during the testing campaign was used to verify the design performance of the floating system and numerical tools for the final 100% FEED.

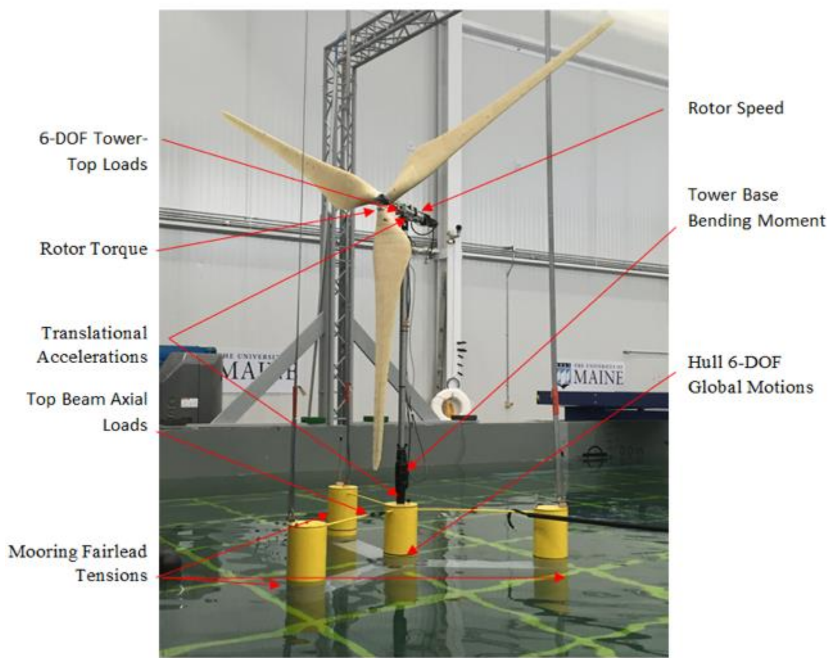

Figure 17 VolturnUS 1:52 Model Tested at UMaine W2 Wind-wave Facility

The testing campaign was conducted successfully over the course of several weeks and subjected the model to ABS defined environmental conditions which were found to be design-driving in the 100% FEED effort. Key system responses were recorded with the instrumentation package installed on the model (shown in Figure 26). Outputs from the turbine included measured rotor speed, rotor torque and 6 degree of freedom (DOF) forces and moments at the tower top. **The test confirmed the design, numerical model predictions, and that the system met the turbine OEM stated limitations for loads and motions.** Based on the project testing conducted in the laboratory at UMaine, the following papers were accepted for publication/ presentation:

- Validation of a Spectral-Based Structural Analysis Model Implemented in the Design of the VolturnUS 6MW Floating Offshore Wind Turbine, C. Allen, A. Viselli, A. Goupee, and H. Dagher. ISOPE 2017
- 1:52 Scale Testing of the First US Commercial Scale Floating Wind Turbine, VolturnUS: Testing Overview and the Evolution of Scale Model Testing Methods, Fowler, M., Goupee, A., Allen, C., Viselli, A., Dagher, H. OMAE 2017.
- Assessment of Wind/Wave Basin Capability for Emulating Active Blade Pitch and Generator Control Influence on Floating Wind Turbine Response, C. Allen, and A. Goupee. ISOPE 2017

UMaine also completed extensive laboratory structural testing of the concrete mix and post-tensioning elements as described in the conference paper titled "Experimental Verification of ABS Concrete Design Methodology Applied to the Design of the First Commercial Scale Floating Offshore Wind Turbine in the United States, M. Dwyer, A. Viselli, H. Dagher, and A. Goupee. OMAE 2017". Three commercial post-tensioning anchorages have been fabricated and tested with the project's concrete mix to qualify three suppliers following AASHTO structural testing guidelines and methods used by industry. Specimens were tested and found to pass the AASHTO post-tensioning anchor cyclic load transfer test crack width criteria for "moderately aggressive environments". UMaine and suppliers made changes to test specimen design based on supplier recommendations to meet "Higher Aggressivity Environment" crack width criteria. A second round of testing was conducted to address due-diligence work of developers. The results of the anchor testing were that two suppliers were qualified for supply of the anchors. The third supplier may be able to supply if they show successful testing results in the future. The key findings are summarized below:

- 1 anchor supplier met all the requirements for all four specimens tested.
- 1 anchor supplier met all the requirements for all but two of the four specimens tested. The other two specimens met the strength requirements but only the moderate durability crack width requirements. Our team believes that by working with the anchor supplier, slight modifications to the anchor details will address this issue.
- 1 anchor supplier met the strength requirements but did not meet the high durability requirements for any of the specimens.

Additionally, a third-party testing facility, was contracted to perform standard creep (per ASTM C512-15 Standard Test Method for Creep of Concrete in Compression) and shrinkage (per ASTM C157-17 Length Change of hardened Hydraulic-Cement Mortar and Concrete) testing at the recommendation of the concrete detailing subcontractor. The facility was also contracted to issue a report on the results. Specimens were cast by UMaine and delivered to the testing facility. Results will be used for the detailed design in DOE Award DE-EE0005990.

Subtask 1.11. Develop construction drawings and specifications

This subtask includes development of all final drawings and specifications provided to the contractors for the purpose of bidding and construction including: the hull construction, hull mechanical/electrical/safety/access systems, installation of mooring lines and anchors, hull tow-out and installation, installation of electrical cables and electrical infrastructure onshore and offshore, and installation of instrumentation and communication systems.

Subtask 1.12. Obtain final electricity production estimates

The subtask consisted of using updated metocean data collected from the DeepCLiDAR, and updated power curves from the turbine OEM which account for hull motions to obtain final electricity production estimates. Considerable site data has been collected including 18 years of surface level wind speed data and over 12 months of LiDAR data from a land-based and floating LiDAR system.

AWS Truepower reviewed all wind resource data and packaged data into a form that was transmitted to DNV for review and calculation of the AEP. DNV-GL wind resource modeling work and consolidation of AEP has been conducted considering both a fixed and floating power curves provided by the turbine OEM**.** Uncertainty of the AEP calculations for this project are considered in line with other US Offshore projects but reduced for availability uncertainty for floating foundations.

Subtask 1.13 ABS and other Project Reviews

The goal of this task is to complete a final project-wide third-party engineering review and certification through the ABS. This will augment the ABS hull FEED review currently in process and will include updates to the hull or turbine design based on OEM analysis and constructability reviews. The ABS review will be for design conformance with the ABS "Guide for Building and Classing Floating Offshore Wind Turbines (2020)". Design reports and drawings will be reviewed as part of the process and may include some independent ABS analysis.

The following work has been completed:

- ABS issued a successful 100% Hull FEED design review indicating that the VolturnUS (6MW) hull 100% FEED design is in compliance with the ABS requirements and standards for sound engineering practices. This effort built upon an Approval in Principle received in May 2014 from ABS. ABS has completed reviewing 30 new and updated design reports and 96 drawings per ABS Guide for Building and Classing Floating Offshore Wind Turbine Installations.

Subtask 1.14 Third-Party Review of Project Costs and Risk

This subtask consists of commissioning a third-party review of project costs and risk analysis, with the identity of the third-party reviewer and scope to be determined after consultations with equity and debt investors. The third party will be approved by DOE and could be the ABS who is already reviewing the project. This work will be completed under DOE Award DE-EE0005990.

Relating to the 6MW turbine, significant time and effort evaluating cost and risks was completed as part of the investor due diligence process.

Subtask 1.15 Develop updated bid packages and answer bidder's questions as needed

As needed**,** this subtask aims to develop updated bid packages to support the multi-contracting approach for the project. Some of these bid packages may be binding, but this will likely depend on the subcontractors' willingness to provide binding bids. These bid packages will build on existing work to the extent that it is required to finalize the project CAPEX. The following work was completed:

- Engaged with three primary contractors on scope and price definition
- Drafted and advanced discussion with the turbine OEM on commercial terms
- Initiated foundation coordination engineering with the turbine OEM
- Created new Cap Ex budget format to refine pricing and define risk allocation

Subtask 1.16 Develop updated design report

This task was started and will be completed in the future. The design report will encompass a detailed design issued for construction for a larger 10+MW wind turbine generator.

3.3 Task 2 – Permitting, Environmental Data Collection, and Outreach

This report provides a summary of permitting, environmental data collection, and outreach activity completed under DOE Award 6713 in support of the New England Aqua Ventus I Project off the Monhegan Island Maine. Final permits, environmental data collection and outreach activities will be completed on another active DOE Award, Award DOE-EE0005990.

The project already had site control through a State of Maine Legislative process, and the project site is within state waters. The Maine Department of Environmental Protection (DEP) is the designated state agency for project permitting and by statute has a 60-day period to respond to a completed General Permit application. The General Permit for the project was drafted and substantial environmental and ecological data was collected prior to this task.

As part of the SOPO, the goal was to work towards updating, completing, and submitting all required permit applications to be completed under DOE Award DOE-EE0005990, including updating environmental and ecological data as needed to support those applications. At the same time, the team aimed to conduct related public outreach in coordination with the DOE, including outreach required by the permitting statutes. There are four main geographic components to the permits based on location of construction activities:

1. Monhegan test site, where the units will be deployed
2. Construction sites
3. Assembly site and temporary mooring location
4. Electrical infrastructure: export cable, cable landing, land transmission line to interconnect point

Outreach activities consisted of strategic outreach coordination at the statewide level, as well as staffing for specific outreach related to the construction sites including Monhegan Island, the offshore and land-based cable routes, the offshore cable landing site, the construction sites, and the assembly site.

Support was provided to initiate the DOE NEPA process (complete a draft project description), DOE-led required consultations (i.e., Endangered Species Act, National Historic Preservation Act, Government to Government consultation, etc.), and NEPA processes required by other federal agencies. Activities include subcontracting with a NEPA contractor to develop a DOE EA under DOE direction. DOE directed EA content and the development of analyses and documentation needed for DOE to complete all required consultations. University of Maine and the NEPA contractor supported DOE-led public meetings (including providing subject matter experts), DOE site visits, agency meetings, and other stakeholder meetings including with potentially affected Indian Tribes if applicable.

The Task consisted of three subtasks (2.1, 2.2, and 2.3) as reported in the following sections.

Subtask 2.1 EA and/or other NEPA processes

The goal of this subtask was to initiate and complete the DOE NEPA process with DOE as the lead Agency as well as required coordination and consultations with other agencies, including the United States Army Corp of Engineers (USACE). This task also included the development of a complete project description to be used as the basis for permitting, NEPA and consultation documents. A NEPA contractor and subject matter expert was also set to be hired to support public meetings and development of an EA. The DOE NEPA process requires that the University of Maine and the permitting and NEPA teams engage actively with DOE to develop required materials, including support for agency meetings required to assist DOE in completing required consultations including compliance with the Migratory Bird Treaty Act and Bald and Golden Eagle Protection Act.

During the course of this award, progress was made to update permitting efforts, re-engaging agency consultations, supporting NEPA processes and assembling, updating, and completing the remaining analyses and field studies that are required to characterize project sites and complete permitting and NEPA analyses. Work towards this task was accomplished as required by 38 Maine Revised Statutes (M.R.S.) §480-HH, the Maine legislation that allows for the establishment and permitting of the Test Site, and by relevant local, state, and federal agencies. This included stakeholder engagement and outreach support for all regulatory review processes. All studies were conducted per state and federal permitting requirements and in close consultation with state and federal agencies.

Specifically, the following work was completed during the course of the DOE Award 6713:

- University of Maine and the NEPA contractor have conducted weekly conference calls with DOE, had several programmatic meetings in Maine, and undertook DOE-led scoping sessions in the winter of 2017. A meeting of state and federal regulators with DOE NEPA staff and UMaine representatives took place in early May of 2017, and a number of follow-up calls and meetings have continued to take place with agencies. Subsequently, a new NEPA contractor was retained, and continued all of the NEPA-related work as well as some State permit preparation work was also done by the Contractor and UMaine.
- Two separate NEPA-scoping sessions were held in 2017. Subsequently, two more scoping sessions were conducted in 2020.
- A Project Description was prepared that was used for scoping, and a more detailed Project Description was updated for the EA as design details continued to be firmed up (including the decision by the Monhegan community not to have a cable from the turbines providing free electricity as provided for in the Maine PUC Term Sheet).
- The Maine Department of Transportation continued its design work at the Searsport facility and was to be responsible for permitting construction activities at that site.
- For a potential concrete and hull fabrication site, approval was obtained for the marine archaeological survey, which was conducted in May 2017. The site was not ultimately used due to the presence of shallow bedrock.
- Additionally, consultants were retained for sound and visual impacts, including preparation of scopes of work that were been reviewed and commented upon by DOE NEPA staff; these scopes were modified and provided to DOE NEPA staff. The consultants completed reports that were shared with the DOE.
- Also, a terrestrial architectural and archaeological impacts firm was retained, their scopes of work were shared with DOE NEPA staff; comments were received, and the scopes were adjusted accordingly.
- Work progressed on the EA, including development of an EA outline and updated project description. Additionally, a Biological Evaluation for the geophysical survey was drafted and submitted to DOE.

Milestone 2.1.1 Develop complete project description that will be used as the basis for permitting, NEPA and consultation documents.

As noted above, a Project Description was prepared and approved by DOE NEPA for use in the scoping process for two 6MW turbines. The Project Description was updated based on the Monhegan vote not to use a cable on the island; the project decision not to proceed with a cofferdam due to shallow bedrock, but rather to use an existing construction facility; rescoping of work at Searsport, such that a man-made berthing or mooring structure that extends above water level would not be built by MDOT; and a decision to explore 2 alternative cable routes from the Test Site to the mainland. Additional updates to the project description were completed working with the project developer and the NEPA contractor and it will be completed under DOE award DE-EE0005990.

The NEPA contractor also made progress on a permitting gap analysis and other areas of NEPA-related work. The impacts of COVID-19 to the NEPA process were multi-faceted including the inability to engage with community stakeholders in Boothbay (the potential cable landing site) in a way that ensured success. Progress was still made towards coordination of soil sampling for cable landings being coordinated between the NEPA contractor and the DOE NEPA team.

Milestone 2.1.2 In coordination with the DOE, hold agency update meetings and/or conference calls.

Regular teleconferences were held with the DOE NEPA team and the permitting and outreach teams throughout BP2 as needed. Following scoping, DOE NEPA asked the NEPA contractor to prepare the agendas and to lead the calls, and they did so. Also working with DOE NEPA staff, we held an update meeting for state and federal regulators, on May 4, 2017 in Augusta, Maine. A second comprehensive update session was held in the spring 2020, virtually. We also held follow-up discussions or meetings with agencies such as the Coast Guard, NOAA, National Marine Fisheries Service (NMFS), and the Maine Historic Preservation Office, Department of Environmental Protection (DEP) and Department of Maine Resources (DMR) and kept DOE NEPA apprised of those interactions. Additional calls were conducted with Maine DEP and HPO, Army Corps, Monhegan and Port Clyde officials. Calls also took place with NOAA NMFS and the Coast Guard.

Milestone 2.1.3 Assist DOE with public scoping meetings and/or other outreach, as applicable. Scoping Meeting Activity

As summary of specific activity for scoping meetings and outreach is provided below:

- Assisted by the Project team, the DOE conducted scoping sessions both in a possible cable landing area and on Monhegan Island, on back-to-back days. UMaine helped DOE with a number of logistical issues for scoping, and also worked with the DOE on analyzing and summarizing the comments received from the public during scoping, which has now closed. The same was done in 2020, on Monhegan Island and separately for people on the mainland. The latter was conducted on Zoom given the pandemic restrictions and to allow for more people to participate.
- A webinar for tribal government representatives about the project scope and possible impacts was conducted by UMaine and DOE NEPA as part of the NEPA and Section 106 work.
- UMaine worked with the DOE NEPA team to plan the updated NEPA activities that feed into the schedule and conduct the NEPA process with COVID-19 limitations and identify potential activities we can work in the interim to minimize delays.
- Project partners, including the state and developers agreed on the preferred cable route. Work to engage with an outreach team started. The Boothbay Board of Selectmen are supportive of the project.
- We also conducted outreach activities in relevant towns and at the Maine Legislature, as well as with a variety of mainland groups and individuals interested in the project.

Fishermen Outreach

An updated and improved fishermen outreach strategy was developed with the following end goals:

- New England Aqua Ventus development team to be accessible to the community but not burdensome
- Concerns within the fishing community will be heard; a rapid response system is in place to keep key leaders/voices informed of project developments; project decisions are adjusted where feasible to align with concerns
- Project messaging remains optimistic for a future where fisheries and the fishing industry in Maine are stronger than they are today
- Press has been focused on the opportunity to Maine and coexistence with fishing
- Fishing associations agreed that their membership is best served by being engaged and informed with accurate and timely information relating to offshore wind, and that their membership interests aren’t served when misinformation is spread
- Work with Fishermen that expressed an interest in being directly involved with the project

A Fisheries Advisory Committee (FAC) was proposed to the Maine Coast Fishermen’s Alliance and Maine Lobstermen’s Association with the intent of establishing an official interface with fishing organizations. In addition, a local fisheries leader was identified to serve as a neutral Fisheries Liaison (FL) to help identify key voices in the fishing community who can influence other fishermen (positive or negative). Larry Knapp was hired to fill this role, having served as Chairman of the Zone E Lobster Council and Vice-Chairman of the Lobster Conservation Management Team. Subsequently this role has been filled by Genevieve McDonald, a former commercial angler, and State Legislator.

Cable Landing Outreach

Meetings were held to discuss potential cable landing locations. Negotiations started towards the end of 2018 with a possible landing site identified. Moving forward, 3 cable landing sites in were considered.

Work with local land stakeholders on the refinement of the cable landing site selection continued. Discussions with town government officials took place with the goal of refining the landing location and developing a public outreach strategy. Landowner engagement was initiated following a town meeting, which was delayed due to COVID-19 State orders, concerns with zoom-bombing of town meeting sessions, and concerns about rushing the approvals through in the middle of the pandemic. This work will continue under DOE Award DE-EE0005990.

Outreach with New Developers RWE/ Mitsubishi-Diamond Offshore Wind

A new project developer was brought after extensive negotiations. On Wednesday, August 5, 2020, UMaine announced the investment and collaboration with NEAV, a joint venture between Diamond Offshore Wind, a subsidiary of Mitsubishi Corp., and RWE Renewables, the second-largest offshore wind developer globally, who would be in charge of developing the demonstration project. RWE and Diamond intend to invest collectively $100 million in Aqua Ventus. The announcement gained significant local and trade media coverage (see Recharge article, right). The following also occurred following the addition of the project developer:

- A call was held with the Monhegan Energy Task Force (METF) on Thursday, August 6, the day following the developer announcement, between UMaine and NEAV in order for METF to meet the developers.
- A virtual public event co-hosted by NEAV and METF on Tuesday, August 18, at 5:30 p.m. provided an opportunity for the Monhegan community to meet the new project developers and ask questions in a virtual Q&A session.
- NEAV and UMaine engaged with the State of Maine on a weekly basis regarding the project communication plan and community outreach.
- A supply chain portal on the NEAV website was created and a Zoom webinar was held on November 18 to introduce the project and portal to potential vendors, many of whom are based in Maine. Approximately 70 potential vendors attended the webinar.
- Genevieve McDonald, then a Maine State Representative, and commercial fisherman in Stonington was retained by NEAV as the fisheries liaison.
- Continued efforts with the Town of Boothbay on cable landing and route. Positive follow-up meetings with the landowners regarding cable landing and O&M facilities.
- Worked with the NEPA team on confirming the durations of NEPA activities. 4-party NEPA agreement executed in September.
- The NEPA contractor was fully engaged by NEAV and the DOE NEPA calls resumed.
- Eelgrass study completed; survey supportive of a cable landing at two locations.
- Additional soil sampling conducted in the area regarding proposed cable landings were conducted. Results were similar to previous soil testing results and require no further actions. USACOE and Maine HPO approval received. HSE reviewed and confirmed.
- The location of the O&M facilities was being evaluated, and owners were engaged.

2.1.4 Complete any data collection efforts, analysis of data, and develop assessments/reports required to support the NEPA evaluation and required consultations

We worked with DOE NEPA staff to review and modify as needed scopes of work for marine and terrestrial archaeological, visual and noise impact assessments. Site historic data work was conducted in May of 2017. The visual and noise assessment work updated some assessments previously undertaken and provided to DOE and took place in June of 2017. A terrestrial archaeological and architectural historic impacts consultant was retained in May/June of 2017 to work in coordination with the visual impact firm on Section 106 and related issues. A wetlands survey was conducted and was planned to be conducted in June of 2017 on Monhegan. A Biological Evaluation was prepared for the geophysical survey work and shared with DOE NEPA staff. For the Maine DEP General Permit, the 3 required plans—Fish and Wildlife Monitoring Plan, Navigation and Safety Plan, and Decommissioning Plan—were drafted.

The following work was completed, and reports were generated:

- Threatened and Endangered Species and Essential Fish Habitat analysis - provided to DOE for comment prior to development of submittals to NMFS and USFWS requesting concurrence regarding project effects to T&E species and EFH.
- Area of Potential Effects - prepared and shared with Maine HPO and DOE NEPA
- Preliminary inspections– completed as to terrestrial historical impacts and consulted with Maine HPO and DOE NEPA.
- Sound Impact - completed for possible impacts on Monhegan from the Test Site.
- Marine archaeological assessment of the proposed fabrication site - completed.
- Contamination survey –completed and the analytical results were shared.
- Eelgrass study - completed and the final report was supportive of a cable landing at two locations.
- Visual Impact - Onsite visual impact data collection on Monhegan Island (see context map and select photo-simulations below)

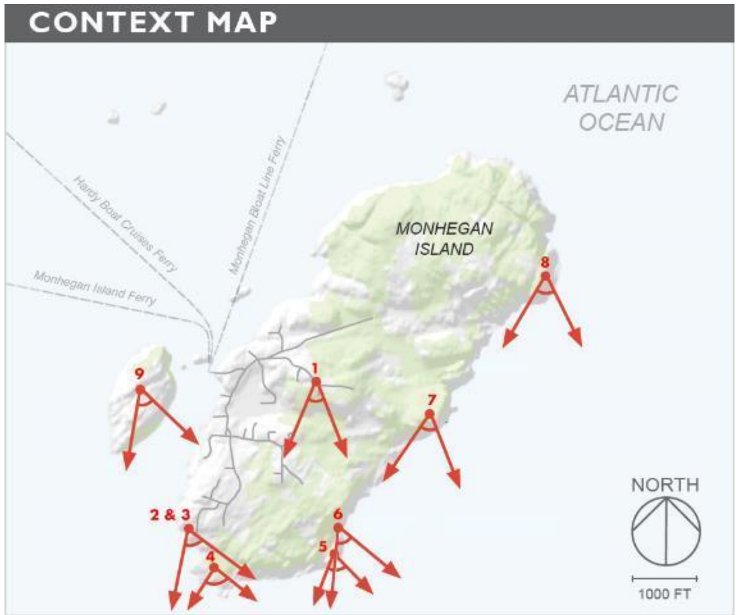

Figure 18 Context Map for the following 9 panoramic visuals

Figure 19 Panoramic view looking southeast to southwest from the top of Monhegan Island Lighthouse. Two turbines will be visible at a distance of approximately 3.4 miles from this viewpoint.

Figure 20 Panoramic view looking southeast to southwest from a point near the Sarah Kent Cottage (visible on left side of the image). Two turbines will be visible at a distance of approximately 2.9 miles from this viewpoint.

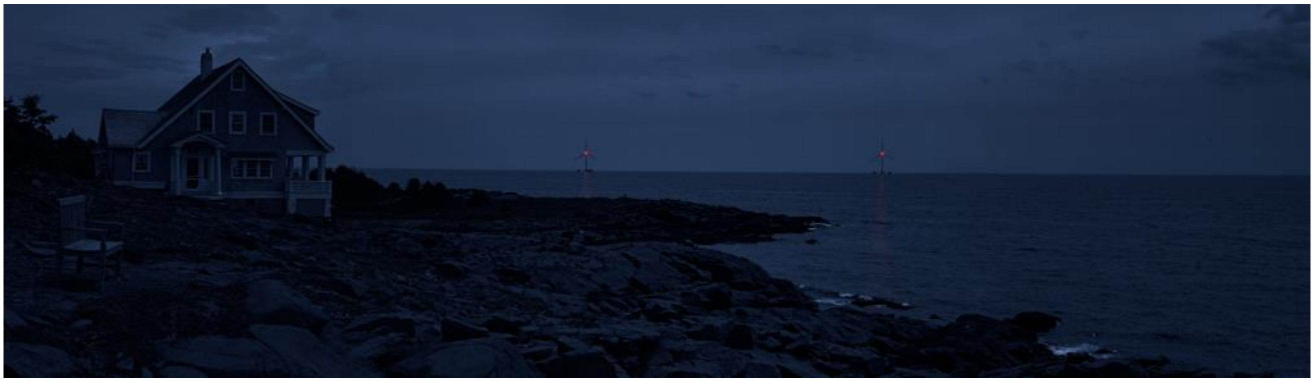

Figure 21 Panoramic view looking southeast to southwest from a point near the Sarah Kent Cottage (visible on left side of the image). Two turbines will be visible at a distance of approximately 2.9 miles from this viewpoint. The photograph has been darkened to reflect nighttime conditions.

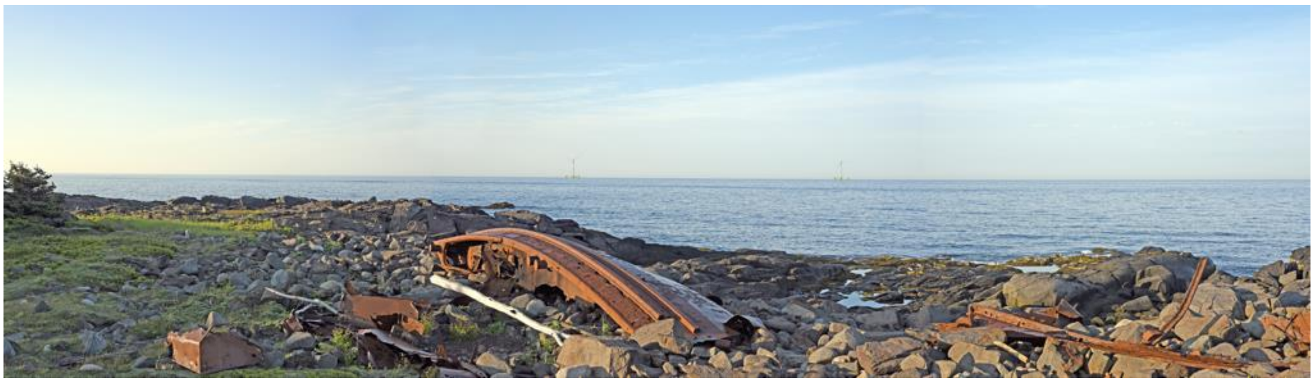

Figure 22 Panoramic view looking southeast to southwest from the shipwreck of the D.T. Sheridan. Two turbines will be visible at a distance of approximately 2.8 miles from this viewpoint.

Figure 23 Panoramic view looking southeast to southwest from Gull Rock. Two turbines will be visible at a distance of approximately 2.8 miles from this viewpoint.

Figure 24 Panoramic view looking southeast to south from Burnt Head. One turbine will be visible at a distance of approximately 3 miles from this viewpoint.

Figure 25 Panoramic view looking southeast to southwest from Whitehead. Two turbines will be visible at a distance of approximately 3.2 miles from this viewpoint.

Figure 26 Panoramic view looking southeast to southwest from Black Head. Two turbines will be visible at a distance of approximately 3.7 miles from this viewpoint.

Figure 27 Panoramic view looking southeast to southwest from Manana. Two turbines will be visible at a distance of approximately 3.3 miles from this viewpoint. The Manana Island Fog Signal Station is visible on the right side of the image.

Figure 28 Panoramic view at sea looking southeast from the Hardy III ferry. Two turbines will be visible at a distance of approximately 6.8 miles from this viewpoint.

Figure 29 Panoramic view looking south to southeast from a point near Pemaquid Lighthouse. Two turbines will be visible at a distance of approximately 12.4 miles from this viewpoint.

Figure 30 Panoramic view looking south to southeast from a point near Pemaquid Lighthouse. Two turbines will be visible at a distance of approximately 12.4 miles from this viewpoint. The photograph has been darkened to reflect nighttime conditions.

Potential sea bottom contamination near thecable landing site was identified as an issue. Plans to conduct a Vibracore sampling survey were initiated, causing a postponement of the offshore cable survey. Five possible providers for the Vibracore work were identified, and they provided cost estimates. Following this, soil sampling in the area regarding cable landings was conducted. Results were similar to previous soil testing results and no further actions were required.

Milestone 2.1.4 – Update Preliminary and final draft EA, final EA in response to public review comments

Updates were made to the preliminary draft EA considering major changes including the Monhegan vote not to proceed with the cable to Monhegan Island; the project decision not to proceed with a cofferdam but rather to use an existing construction facility; rescoping of work, such that a dolphin will not be built by MDOT; and a decision to explore 2 alternative cable routes from the Test Site to the mainland.

Subtask 2.2 Local/State/federal permitting and consultations for site, hardware, and cable, as well as related agency consultations.

An updated permitting and NEPA GANTT schedule was maintained through the program.

Regular DOE Program and NEPA calls involving DOE staff and select people from the UMaine team took place as needed. Discussions also continued with MDEP, MDMR, MHPO, municipal officials and with other federal agencies as needed. Primary schedule drivers were determined to be selection of the turbine supplier and the cable landing site.

The team held calls with U.S. Fish & Wildlife, National Marine Fisheries Service, Army Corps, Maine Dept. of Marine Resources, Maine Dept. of Inland Fisheries and Wildlife, Maine Historic Preservation, and Dept. of Environmental Protection. DOE NEPA will initiate recontact with the Tribes.

UMaine worked with the DOE NEPA team on confirming the durations of NEPA activities. The 4-party NEPA agreement was executed in September of 2020. UMaine also continued to engage with the State of Maine on a regular basis regarding the project communication plan.

Milestone 2.2.1 – Updated Maine DEP application package

In September of 2017 the permitting subcontractor worked towards updating the Fish & Wildlife Monitoring Plan, the Navigation and Safety Plan, and the Decommissioning Plan. The project description developed for NEPA was adapted for use in the DEP application package. More work was undertaken in 2020 on the components of the Maine DEP requirements.

Milestone 2.2.2 – Update United States Army Corps of Engineers (USACE) permit application

We have consulted with the USACE staff, who is very familiar with the project, and began work on the application for approvals under Section 10 of the Rivers and Harbors Act and Section 404 of the Clean Water Act. USACE was working as an active participating agency with DOE under the NEPA process, with a representative on the weekly conference calls. USACE indicated the possible need for a summary of alternatives, and one will be included in the USACE permit application package.

Milestone 2.2.3 – Update Maine Department of Conversation submerged lands lease application

This will be handled as part of Milestone 2.2.1 above. Per 12 MRS Section 1268, once the Section 480-HH General Permit is issued, no separate submerged lands lease will be issued for the turbine site and the cable to shore.

Milestone 2.2.4 – Federal Energy Regulatory Commission (FERC) process for electrical infrastructure, as needed

The Federal Energy Regulatory Commission process is not needed for the duration of this project due to its small size. If required, this will be addressed in the future.

Milestone 2.2.5 – Update U.S. Coast Guard (USCG) Private Aids to Navigation and Navigation Safety Plan materials, which were previously drafted

Communications occurred with the USCG, as per 2.2.1, above, including in regard to the Navigation Plan and potential marking of cable ways. Further conversations in this area will occur in the future.

Milestone 2.2.6 – Onshore cable, hull assembly site (Searsport) and temporary hull mooring site (Searsport) permitting processes started for any required local approvals, and application packages drafted.

The permitting processes for this Milestone were not addressed during BP2 of this award other than on a preliminary conceptual level. This will be completed in the future as the project progresses.

Milestone 2.2.7 – Develop draft application materials for Hampden site, if any permits are deemed necessary to apply for following consultations with regulators

The draft application materials for this Milestone were not required as this site was not selected.

Milestone 2.2.8 – Coordinate with Federal Aviation Administration (FAA) to obtain No Hazard to Air Navigation Determinations for turbines.

Initial conversations were held with the FAA during BP2 of this award. This will be addressed in a separate DOE award.

Milestone 2.2.9 – Develop and execute plan to apply for and receive all requisite regulatory approvals.

The following work was completed for this subtask:

- Corps consultation regarding site selection for turbine assembly and section 408 (temporary use of a part of the federal navigation channel)
- Corps, Maine Department of Environmental Protection, and US Coast Guard consultation to provide general project update and schedule
- Public meetings with Town Selectmen to update cable landing sites and information
- Consultation with Maine DMR regarding marking of cable ways on Maps
- FAA obstruction review submitted to FAA
- The Visual Impact Report for the two turbines off Monhegan Island was completed and submitted to DOE.
- The Sound Report for the two turbines off Monhegan Island was completed and submitted to DOE.
- A revised Project Schedule was provided to DOE NEPA staff.
- Cable survey discussions with Developer and the State, as well as negotiations for turbine selection, were held.
- 3 possible cable landing sites were reviewed.

Subtask 2.3 Complete remaining analyses and field studies

The following work was completed for this subtask:

- A wetlands survey was conducted on a potential fabrication site..
- **Marine archaeological field work at the potential fabrication site** was completed on May 31, 2017; no issues

were found, only hard-packed gravel and some boulders. Site ultimately not used to cost of removing bedrock.

- **Cable route survey:** Bids were received from five different survey vendors. It was decided to proceed with a limited survey in June 2017 to cover the permitting needs for the project. The team worked to commission a focused historic survey of the charted cableway from test site to shore to meet permitting requirements and gain engineering data to improve cost estimating. The survey was set to include a multi-beam echo sounder, side-scan sonar, magnetometer, and sub-bottom acoustic profiler and possibly a boomer to evaluate prehistoric sites. A biological impact report was developed for the survey and submitted to the DOE NEPA and US Fish and wildlife for consent. The team discussed the survey with Maine SHPO, NMFS, and DOE NEPA. Two preliminary surveys were conducted by the State of Maine as discussed previously.
- All work related to selection of the possible cable routes was completed with minimal impacts to the environment and competing use in mind. Preliminary survey of the cable route bathymetries was conducted by the State of Maine in Q3 of 2019. A preliminary plan for the cable route was developed in Q4 of 2019. Following this, a preliminary RFP was prepared by the developers. The State of Maine completed surveys and environmental data collection analysis for two cable routes.
- The State analyzed the bathymetry data from the two routes and compared the data to the NOAA tide charts.
- **Scenic impact assessment:** Completed. Visuals from this report are included in Subtask 2.1.4 for 2 6MW turbines.
- **Land Archaeology:** The scope of work for terrestrial architectural and archaeological impacts was submitted to DOE NEPA and vetted with Maine SHPO.
- Marine archaeological assessment of a potential fabrication site was completed, and the report was provided to DOE
- **Sound studies** were updated and related modeling work was completed for possible impacts on Monhegan from the Test Site.
- A wetlands survey was conducted on Monhegan for the potential cable routes; the Monhegan voters decided not to pursue the option of energy from the project.

Milestone 2.3.1 – Marine and riverine historic resource surveys will be conducted

The goal of this milestone was for surveys to be conducted as needed 1) along portions of the cable route to Monhegan Island that had not been previously surveyed, 2) along portions of the cable route to the mainland that have not been previously surveyed, 3) in relevant areas in the Penobscot River.

Additionally, terrestrial historic resource surveys were intended be conducted as needed along the 1) cable route on Monhegan Island and 2) along the cable route leading to the grid connection with the existing overhead transmission lines These surveys were expected to consist of pedestrian surveys and digging of selected shovel test pits.

Work to complete this milestone included:

- The marine historic resource survey at the potential fabrication site was completed.
- A marine survey company completed survey of potential work areas in early December 2017 and nothing of significance was reported.
- The terrestrial architectural and archaeological impacts subcontractor did a preliminary inspection of terrestrial historical impacts and consulted with Maine HPO and DOE NEPA.

Milestone 2.3.2 – Update visual impact parameters for two 6MW turbines

The visual impact parameters were captured in the scenic impact data collection on Monhegan Island and the report was shared with DOE.

Milestone 2.3.3 – Update existing sound/vibration model parameters for two 6MW turbines

Sound impact analysis was completed for possible impacts on Monhegan Island from the test site for the initial two-turbine project. An updated study is being done for the single-turbine project as part of DOE Award DE-EE0005990. Key results are provided in the Table and Figure below. The following excerpt summarizes the conclusions:

“Ambient sound levels were measured on Monhegan Island in 2014 and 2016 to determine the current sound level ranges.

Sound levels from the two offshore turbines were modeled based on the full rated sound power output of the turbines using established standards for sound propagation with conservative modeling assumptions. Comparing current ambient sound levels with the modeled sound output, turbine sound levels are expected to be at or below current ambient sound levels under conditions required for full rated turbine operations. In addition, the hourly sound levels and long-term noise exposure from turbine operations will be below Maine regulations, FERC regulation, and USEPA and WHO guidelines for community noise exposure for all noise sensitive land uses and most vulnerable segments of the population."

Table - Comparison of Sound Level Predictions with Noise Standards and Guidelines Source	**Metric**	**Lowest Standard**	**Modeled Worst Case (SEPA Method)**	**Comparison**
Maine DEP regulation[1]	Hourly LAeq	42 dBA	36 dBA	6 dBA below standard
LUPC regulation[2]	Hourly LAeq	45 dBA	36 dBA	9 dBA below standard
FERC regulation[3]	24 Hour Ldn	55 dBA	42.4 dBA	12.6 dBA below standard
EPA guideline for Outdoor Areas[3]	24 Hour Ldn	55 dBA	42.4 dBA	12.6 dBA below standard
WHO guidlines[4]	Annual LAeq (Lnight, outside 11 pm to 7 am)	40 dBA	36 dBA	4 dBA below standard

[1]This limit would be 5 dBA less if SDR or tonal sounds are present at the protected location, which is not anticipated.
[2]Maximum permissible sound of continuous source of sound assumed to be the rated LAeq of turbine.
[3]Effective outdoor sound limit for continuous sound source is 48.6 dBA as 10 dBA added between the hours of 10 pm and 7 am.
[4]Annual sound level expected to be 5 dBA below model prediction based on evaluation of annual sound levels from Maine Wind Project per Section 6.3 of this report.

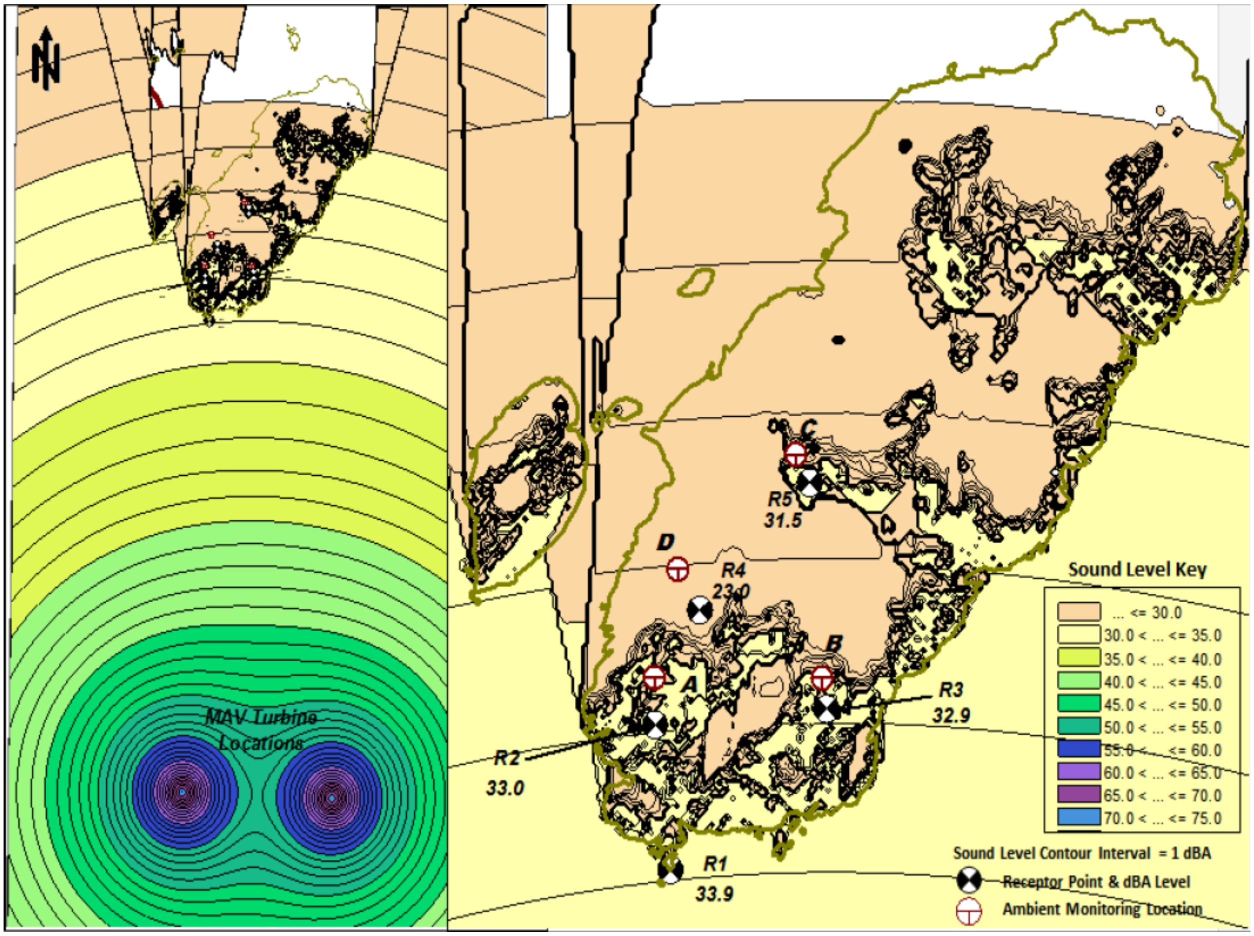

Figure 31 Predicted Sound Levels from Full Turbine Operations per ISO 9613-2

Milestone 2.3.4 – A view shed effects analysis will be conducted.

As reflected in Milestone 2.1.4 above, a visual impacts assessment was conducted. An architectural historian worked with the company developing the visual impact model to evaluate viewshed effects of the turbines to historic properties located on Monhegan Island (there are historic properties, and the whole island is eligible to be an historic district). The architectural historian will determine where the turbines would be visible, look at the characteristics that make the area significant, and characterize the effects to those characteristics.

The terrestrial architectural and archaeological impacts subcontractor was contracted to do this work and worked to prepare a draft report. The primary APE study area for the VIA included an eight-mile radius surrounding the Project site, which is located approximately 2.7 miles south of Monhegan Island and 13 miles southeast of Pemaquid Point in Bristol. This APE area was based upon standard professional practice for developing VIAs for onshore wind energy Projects in Maine. The eight-mile radius was established by the Maine Wind Energy Act, which determined that the visual effects of wind turbine generators at distances greater than eight miles from a scenic resource of state or national significance would be considered insignificant. The viewshed mapping and scenic resource identification was limited to Monhegan and Manana Islands because they are the only inhabited land masses within the 8-mile radius of the turbines. The proposed turbines would be located 2.7 miles off the southern end of Monhegan Island. The next closest land mass is Allen Island in St. George, located 9.6 miles north of the Project site in the southeastern end of Muscongus Bay. On the mainland, the closest point is Pemaquid Point in Bristol, at a distance of 13 miles from the nearest turbine. The southern end of Port Clyde is 14.1 miles from the nearest turbine.

Photo simulations (computer-altered photographs, see 2.1.4 in this report) were prepared to illustrate the anticipated changes to the visible seascape and onshore scenic resources caused by the presence of the turbines. Photo simulations were not prepared for the temporary visual impact associated with turbine erection in Searsport, or terrestrial impacts associated with onshore electrical facilities (e.g., transmission lines, STATCOM electrical structure). A total of nine key observation points (KOPs) where the project would be likely to be seen were selected to illustrate the potential visual impact on scenic resources (see Table below).

#	Key Observation Point	Distance to closest turbine
1	Manana Island Fog Signal Station, Manana	3.3 miles
2	Rockwell Kent House, Monhegan (day + night views)	2.9 miles
3	D.T. Sheridan Shipwreck, Lobster Cove	2.8 miles
4	Gull Rock, Monhegan	2.8 miles
5	White Head, Monhegan	3.2 miles
6	Burnt Head, Monhegan	3.0 miles
7	Black Head, Monhegan	3.7 miles
8	Top of Lighthouse, Monhegan	3.4 miles
9	Pemaquid Point Lighthouse, Bristol	12.4 miles
10.	View from Hardy III Ferry, Muscongus Bay	6.8 miles

The permitting gap analysis identified that this study would have to be updated for the larger turbine.

Milestone 2.3.5 – A sampling program will be conducted for contaminant testing of soils that will be excavated or dredged as part of the construction of the cofferdam in Hampden

Borings were taken at the Hampden site in October of 2017 and testing was completed at an independent lab. No contaminants were found; however, the Hampden site will not be used for a cofferdam or other structure. The Boothbay contamination survey was conducted by Stantec, and the analytical report was shared with DOE.

Milestone 2.3.6 – Wetland delineations, rare plant surveys, and northern long ear bat habitat surveys (if tree clearing is necessary) will be conducted along the 1) cable route on Monhegan Island and 2) along the cable route in Port Clyde leading to the grid connection with the existing overhead Central Maine Power transmission lines.

A wetland survey took place in these locations and found little of concern. However, no cable will be run to Monhegan Island per the vote of the residents. A wetland delineation along the final cable route in Boothbay will be conducted as part of DOE Award DE-EE0005990.

Subtask 2.4 Develop updated environmental and permitting process report illustrating a clear and realistic path to regulatory compliance and project completion.

Milestone 2.4.1 – Complete updated environmental & permitting process report

This report will be provided at the conclusion of DOE Award DE-EE0005990.

3.4 Task 3 – Construction, Operations and Maintenance (O&M) Plans

The goal of this task was to make progress towards developing an updated construction plan and schedule, as well as an updated Operations and Maintenance plan based on the turbine OEM requirements for the New England Aqua Ventus I project. Much of the work developed focused on a two 6MW turbine project configuration which will be leveraged to complete the construction, operations, and maintenance plans for the new single 10+MW turbine configuration under DOE Award DE-EE0005990. The fabrication of the floating offshore wind turbine is comprised of several key activities including concrete facility site preparation, platform hull and column concrete segment construction, floating transportation of the units from the fabrication area to the final assembly site in Searsport, Maine, and platform hull and floating wind turbine generator (WTG) assembly and installation The fabrication of the platforms will take place in Maine at one of several potential sites and assembly including the wind turbine and tower will be in Searsport, ME.

The task was broken into three subtasks as follows:

3.1 Start Updating of the Construction plan to be finalized under DOE award DE-EE0005990:
3.2 Update the O&M Plan. Initiate the planning of the O&M in conjunction with the turbine OEM and finalize under DOE Award DE-EE0005990.
3.3 Update the construction and O&M report for submission at the end of DOE Award DE-EE0005990 BP2 to enable the next phase of construction to begin.

Subtask 3.1 – Update the Construction Plan

The objective of this task was to make progress on the final details of the construction plan. An overview of the progress made in these details and next steps are presented in this report.

Hull concrete fabrication and assembly options

The concrete VolturnUS hull is designed to be constructed using segmental bridge industry production methods readily in use. The hull consists of about 50 concrete segments which are post-tensioned together to form the floating hull. In this demonstration project, the segmental construction method is a key feature to demonstrate along with the hull design itself.

Multiple options for specific construction logistics for the concrete hull production and assembly were developed and advanced under this award.

Installation of the Wind Turbine Generator and Tower

During the course of this award, the selection of an assembly process of the wind turbine generator and tower on top of the VolturnUS concrete hull required careful consideration given the large cranes required to erect the turbine.

Offshore Installation

The offshore operations were further defined in this award through engagement with project partners and industry suppliers of marine vessels, equipment, and services. A summary of the current approach is now discussed for two 6MW wind turbines.

<u>Health Safety and Environment</u>

The project will execute works in line with applicable law and International Guidelines and Standards. In view of the potential hazards for this type of work and in addition to the project related procedures (developed in the Safety Management System – see more information regarding Safety Management System development in section 0), special attention is drawn to, but not limited to, the following:

- To arrange, provide and maintain safe systems of work for employees at all times:
    - Areas of HSE responsibility will be clearly defined;
    - Adequate and proper facilities, equipment and apparatus will be provided, and its correct use will be ensured;

- Adequate training, instruction and information regarding HSE and hazards on workplace will be provided (training, toolbox talk, permit to work for specific activities);
    - Incidents will be regarded as preventable and the follow-up of the HSE standard will be ensured;
    - Each installation procedures will be developed with regards to include input from HIRA (hazard identification and risk assessment);
    - Management of change (MoC) process will be clearly defined.
- Responsible personnel involved in the work will observe the following basic working rules, amongst others:
    - Relevant Personal Protective Equipment (PPE) will be issued and used prior to the commencement of the work;
    - PPE shall be worn at all times on site with exception of the dedicated safe area(s) and welfare facilities;
    - Proper training and induction in the various roles for the type of activity will be performed;
    - Experienced and active supervision will be in place at all work times.

Risk Assessment

Risk assessments will be carried out before the development of the procedures to identify and control hazards to the activities and to associate the risk and/or reduce it to ALARP levels (As Low as Reasonably Practical). For every phase of the operation, a separate Method Statement will be prepared, and an associated Hazard Identification and Risk Assessment of all the activities will be conducted.

Prior to the start of any operation, the Method Statement and associated Risk Assessment shall be presented to all key personnel involved in the operation. Detailed Task Plans and Work Instructions shall be prepared, describing in a step-by-step approach all the tasks that need to be executed to safely complete the works. Job Safety Analysis will be conducted whenever necessary by the Superintendents in charge of the operations, with the assistance of the HSE Advisors on site.

These are live documents that can be modified and improved during the preparation and execution stages of the project. Revisions of approved documents shall be submitted to the Proponent for review through an appropriated management of change system and shall only be implemented once approved by Client.

Vessel related operations will be addressed in vessel specific procedures, and these shall be managed by the Master (or Barge Master) of the vessels.

Equipment

Operations are performed by the following marine spread:

- Medium Anchor handling tug (AHT) used to performed operations that requires power, stability and maneuverability for chain handling facilities and chain storage capacity, large storage deck capacity.
- Assist tugs to maintain FOWT station during hook-up and escort the tow during transit.
- Harbor tug assistance (if required): to support maneuvering near shore.

Operational Requirements

Weather risk management strategy

Installation planning is based on relatively short operation sequences, following one another, and implementing safe-state stages between two consecutives sequences. Overall operation can be split into several weather windows, to mitigate the impact of regular occurrence of short adverse weather episodes.

Prior to work commencing a suitable weather window for FOWT installation will be approved by the Client representative, Marine Warranty Surveyor (MWS), Offshore manager, AHT Master and Project engineer. If the Client representative, Offshore Manager, AHT Master and project engineer are satisfied that a suitable weather window exists, then the final decision lies with the MWS to proceed.

Prior to set up on site the weather patterns will be known to the AHT Master and the offshore manager from two independent twice daily weather forecasts.

Personnel

The following personnel will be involved for the installation:

- Project management staff (various levels of participation throughout project):
  - Project Manager
  - Project Controller
  - Project Scheduler
  - Project Engineer
  - Document Controller
  - Project Procurement/Logistics
  - Subcontracts Manager
  - Contract Administrator
  - Project crew (including offshore manager, superintendent)
- AHT crew
- Assist tug crews
- ROV Operators
- Marine Warranty Surveyor
- Anchor tensioning system supplier representatives/experts
- Mooring anchors representative/experts
- Potentially, a certification body representative (to ensure the installation survey as a part of the project certification).

Method Statement

Drivers

Our approach is driven by:

- Safety and reliability of operations
  - Safe environment work, High HSE standards
  - Minimum offshore work performed by operators, no diving operations
- Cost-efficiency
  - Limited marine spread made out of light class vessels (limited mobilization costs, out of toughest vessel spot markets)
  - Reduction of permanent mooring item procurement costs and floater outfitting's (operations are mainly performed with assets boarded on vessels. No use of specific or exotic tools to guarantee a good availability and reliability of means and limit CAPEX).
  - Streamlined installation process: limited number and duration of offshore operations.
  - Optimized utilization rate of expensive assets. Marine spread strategy is based on a cost-efficient combination of AHT vessels and assist tugs

- Flexibility and liability of solutions
    - o Considered operating solutions can accommodate several mooring design changes and site condition modifications (likely to occur before FID)
- Independence of operating contractor
    - o Clear and simple operation breakdown
    - o Simplicity of offshore operations
    - o Use of common and conventional installation means (vessels and installation aids)
- Innovation
    - o Leverage innovating solutions
    - o Keep door open to technical opportunities that may come, by limiting operation complexity and interdependency

<u>Summary of the Installation Principles</u>

The following depicts the main characteristics of the proposed solution:

- Mooring items are mobilized at port
- FOWT (ready for installation) delivery is taken at port
- 2 sequential installation phases:
    - o Mooring system installation: Anchor and chain installation (including anchor test load).
    - o FOWT installation: FOWT stevedoring, Transit to site, Hook-up operation, (Ballasting operation: out of scope), Mooring line pre-tension adjustment, Final survey.
- No diving operation is required, minimum offshore work, limited use of ROV
- No personnel access is required to perform the hook-up and limited equipment demobilization needs.
- Towing operation is performed by the same vessel as used for anchor installation and hook-up operation.

3.1.4 Balance of Plant (BOP): Electrical interconnection including offshore export cable, dynamic cables, and cable landing into sealed junction box onshore or into Pole onshore.

The following section describes the most likely installation scenario that is planned to be used for the project developed during this award that will be further refined in DOE award DE-EE0005990.

The export cable and dynamic cables installation sequence is outlined in the following steps and detailed in the next sections:

1 Route preparation and pre-lay inspection
2 Barge and equipment mobilization
3 Cable loading / transpooling
4 Transit to site
5 First dynamic cable initiation
6 Fist dynamic cable pull-in
7 Second dynamic cable initiation
8 Second dynamic cable pull-in
9 Recovery of both subsea ends and connection to hub
10 Hub deployment and export cable initiation
11 Main cable lay
12 Shore-landing
13 Post-lay survey

The following vessels are envisioned for these operations.

Cable Laying Barge

The main equipment used for the installation of the submarine export cable is the Cable Laying Barge (CLB).

Figure 32 Typical Cable Laying Barge

For the purpose of the operation a standard cargo barge will be mobilized and fitted with 2 off deck mountable azimuth propellers. During mobilization the barge will also be fitted with necessary equipment required to cable laying operation. This Cable Laying Barge will be very likely mobilized from a port on East Coast, from the USA or Canada to minimize the mobilization cost: a various panel of cable landing suppliers operates in this zone and will be able to propose the most suitable means (more cost effective than big cable supplier vessels coming from Europe).

<u>Note:</u>

- Instead of a CLB, a Cable Laying Vessel could also be used. The choice will be done based on vessel availability and vendor quotes. In this case, the same methodology than the one described below for the CLB will be used except that no ocean tug will be necessary anymore.

Figure 33 Cable laying vessel

The typical lay spread equipment will be as follow:

- Cable carousel of sufficient capacity (to load the full length of the export cable).
- Loading arm and cable highways in line with product Minimum Bending Radius (MBR);
- Linear Cable Engine of sufficient capacity;
- Saddleback or equivalent load monitoring equipment;
- Cable laying chute in line with product MBR;

- Echoscope

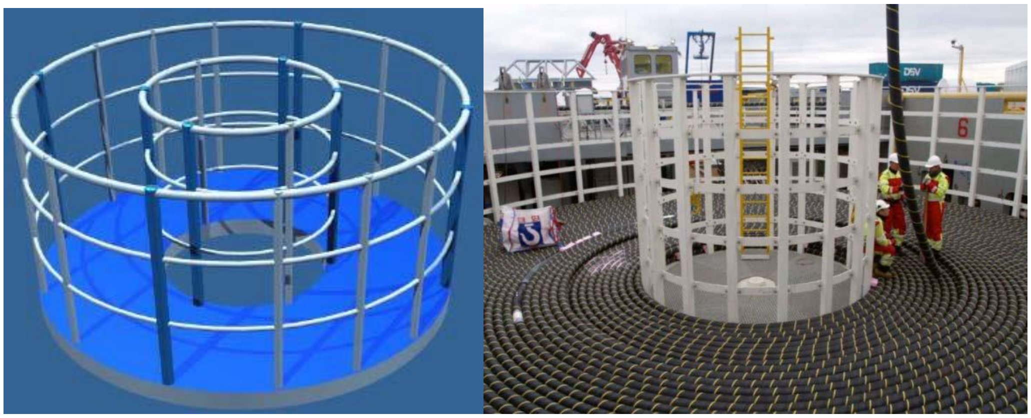

Figure 34 Typical basket carousel

Subtask 3.2 – Update the O&M Plan

The goal of this subtask was to update the O&M plan in conjunction with the new turbine OEM to provide sufficient details to develop final O&M pricing for the project. It consisted of three steps:

3.2.1 Develop updated detailed O&M plan
3.2.2 Develop final O&M pricing for the project
3.2.3 Execute a Long-Term Service Agreement (LTSA) or similar with the turbine OEM (M9).

Preparation of Plan and Key Inputs

Two workshops were conducted with the turbine OEM about O&M activities (that are highly governed by turbine O&M tasks). An overall project O&M philosophy was also developed based on the workshop with the turbine OEM.

In preparation of this plan, the proponent worked with leaders in the offshore wind industry to assist in identifying the important elements of Operations and Maintenance (O&M) for floating wind WTG in the Gulf of Maine. While there are many important variables to consider, the following themes are consistent based on European offshore wind experience and the experience of maritime operations in the Gulf of Maine:

- Crew Transfer operations from shore to WTG access represents one of the highest risk activities that the O&M team will undertake. It is critical to develop a plan that minimizes the number of required trips to site, incorporate best-in-class technology on crew transfer equipment design, and includes stringent operational constraints and procedures to ensure personnel safety.

- Weather conditions on site will prevent site access for extended periods of time during parts of the year. Designing for an un-manned vessel in mind with the necessary robustness and redundancies is critical to minimize trips to site and increase plant availability.

- Predictive maintenance, including condition monitoring, is an important tool to minimize trips to site and increase plant availability.

- Development of a comprehensive safety management system (SMS) is critical; a plan that will identify and assess hazards, including methods to control and mitigate hazards. A complete emergency response plan will provide the last defense to ensure personnel safety at sea.

<u>O&M Philosophy</u>

In developing this plan, we have considered the human and equipment resources required, and a strategy to leverage local resources to the extent possible to improve the economics of offshore O&M for a small project. Future O&M needs were a constant consideration in design efforts to date. Examples include redundancy in key systems, instrumentation to support condition monitoring, and tower door sizing/hatchways/overhead rigging points to accommodate replacement of internal components.

This maintenance philosophy includes:

Preventive maintenance and associated frequency

- Supervision of the floater from shore.
- Annual maintenance
- Intermediate maintenance
- Special Periodic Survey

Corrective maintenance:

3 levels of corrective maintenance are considered:

- Level 3: Small corrective maintenance tasks
- Level 2: Large corrective maintenance tasks without return to harbor.
- Level 1: Large corrective maintenance tasks with return to harbor.

Plan Objectives

The objectives of this plan are to demonstrate a thorough understanding of:

- The important aspects of operations and maintenance of floating WTG.
- The scope of maintenance activities including the human and equipment resources required.
- The important elements and process for finalizing an operations and maintenance plan.
- Project specific aspects relevant to *the PROJECT*.

Each procedure developed will place significant emphasis on safety, environmental awareness, and operational efficiency.

O&M Facilities and Transportation

Crew Transport Vessel

Transport of crew from shore to project site is a necessary requirement of any offshore facility and represents one of the highest risk activities that the O&M team will undertake. Vessel specifications, transfer systems from vessel to hull, and weather condition constraints are all critical elements that should be properly assessed to ensure that maintenance preventive tasks and corrective actions could be performed properly and without important delays.

The recorded data in the Gulf of Maine for more than 10 years by UMaine will be used to study the accessibility and plan the preventive maintenance at suitable periods during the year. These data will also be used to evaluate for the cost model the standby duration in case of necessary corrective actions. At the end, it will be of course the local weather forecasting combined to the local buoy measurement on-site that will be used to decide if accessibility of FOWT is possible. Weather forecasting will be crucial to provide the operations team with site specific information to plan trips to site. There are private companies that offer private forecasting services, such as Locus Weather in Camden, ME who has provided specialized marine forecasting for over 20 years.

All vessels involved in support of offshore WTG shall meet with the applicable sections of 46 CFR (Code of Federal Regulations) per USCG. Dependent on mission and number of passengers, most vessels will fall under passenger vessels (subchapter H, K, and T), cargo and misc. vessels (subchapter I) and offshore supply vessels (subchapter L). Annual USCG inspections of these vessels determine that all safety requirements for equipment and operations, including SOLAS, are being supported for the area of operations listed on Certificates of Inspection for these vessels.

A navigation safety plan will be developed in coordination with the USCG to determine geographical project limits, additional navigation aids (buoys) required, and lighting for floating structures to meet requirements of applicable sections 33 CFR.

Air Transport:

Given the distance from shore to project site, we do not intend to utilize helicopters for crew transport. At this time, air transport is planned for emergency response only.

Emergency Response:

USCG operates a port facility in Portland, ME, located 40 nautical miles from the project site. Both vessel and helicopter emergency response teams are located in Portland and will be the primary responder for emergency events on site.

During BP 3-5, the Proponent will work with USCG to develop specific emergency response and raining plans.

3.5 Task 4 Planning for connection of floating offshore wind turbine (FOWT) to Maine-State Electrical Grid

The goal for this task was to develop the grid interconnection design and advance regulatory processes necessary to realize an offtake agreement for a 20-year Power Purchase Agreement (PPA)approved by the Maine Public Utilities Commission, the project will interconnect with the Central Maine Power (CMP) grid.

In DOE award 6713, this task was begun and will be completed under DOE award DE-EE0005990. The overall goal of the project is to negotiate a final power offtake contract from the Maine PUC and CMP, as well as complete grid interconnection studies and Small Generator Interconnection Agreement (SGIA).

Since interconnection will be through an existing Central Maine Power owned distribution line, a generator application through the ISO New England is not needed. The existing CMP distribution line will be upgraded to accept the 10+MW power project output after the EA/NEPA review are completed.

Subtask 4.1 Complete Small Generator Interconnection Agreement (SGIA) with CMP

The goals of this task were as follows:

(a) Completion of the Grid interconnection study which precedes the SGIA, and which would be completed under design subtask 1.9 before the EA/ES.

(b) Negotiation and execution of the grid interconnection agreement (IA). A requirement should be added to the IA that ensures any funding for the identified interconnection work scope and work scope execution are suspended until completion of the DOE NEPA process and that if needed, the interconnection point/upgrades would be revisited upon conclusion of the DOE NEPA. The Grid Interconnection Study and the SGIA are part of the FERC requirements.

(a) Completion of the Grid interconnection study which precedes the SGIA, and which would be completed under design subtask 1.9 before the EA/ES.

The project will interconnect with the CMP grid owned distribution line and a generator application through the ISO New England was not needed. Since interconnection will be through an existing CMP owned distribution line, and the total power is less than 20 MW, the project falls under 65-407 PUBLIC UTILITIES COMMISSION, Chapter 324: SMALL the turbine OEMNERATOR INTERCONNECTION PROCEDURES, § 1. LEVEL 4 SCREENING CRITERIA AND PROCESS: ALL the turbine OEMNERATORS NOT SUBJECT TO FERC JURISDICTION. Under Chapter 324, the application is made to CMP. Upon consultation with ISO New England, the System Impact Study will be delegated to CMP. This delegation avoided the lengthy ISO Study Que process.

During the course of this project many alternative cable routes have been considered. Interconnection studies for all three locations were completed by an engineering firm

Subtask 4.2 – Negotiate the final offtake agreement with the Maine PUC and CMP

Critical Milestone 4.2.1 – Obtain approved offtake agreement from the Maine PUC

On June 19, Governor Janet Mills signed LD 994, a bill requiring the approval by the PUC of a proposal for a long-term contract for deep-water offshore wind energy. According to statute, LD 994 becomes effective 90 days after the Legislature adjourns, which was on or about September 18, 2019. Negotiations between MAV and PUC staff began in advance of the October 2019 deadline to submit a revised contract in order to accelerate deliberations and the overall timeline. The Maine PUC voted unanimously to approve the 20-year PPA on November 5th, 2019, and no appeals were filed in the 21-day appeal period. On December 9, 2019, MAV and CMP executed a 20-year power purchase agreement (PPA), making it the first DOE-funded offshore wind demonstration project to reach this milestone. This milestone made the project financially viable and allowed remaining work with Developer and various development aspects of the project to proceed.

3.6 Task 5 Advancement of Project Financing Documentation

The New England Aqua Ventus I demonstration project requires a financing plan consisting of equity, debt, tax equity, and federal awards to enable the construction of the project. During the course of this award under Task 5, the team worked to prepare a financial plan in parallel with the design and other technical scope.

The specific goals of this effort were to obtain updated energy production estimates, integrate updated CAPEX, OPEX, energy production estimates, estimated financing structure including tax equity, into a financial model to be used as the basis to initiate discussions with investors and lenders. This Task was initiated on DOE Award DE-6713 (6713) and will be completed under a separate DOE Award DE-EE0005990. This report provides a summary of the work completed only on award DE-EE0006713.

Task 5 consisted of the following six subtasks and associated milestones:

Subtask 5.1 **Bankable energy production estimates**. Obtain updated energy production estimates (using a fixed-bottom turbine) from credible third-party experts that are known to be accepted by the lending community.

- **Milestone 5.1.1 –** Obtain preliminary energy production estimates report from DNV using fixed-bottom and Loop 0 floating power curve. (Further update using final floating turbine power curve under DE-EE0005990).

Subtask 5.2 **Start identifying risks and develop an initial risk mitigation plan**. This plan will evaluate a multi-contracting approach, to include design, contracting, and construction risks and will explicitly be drafted to address the need for a lender-investor acceptable risk wrap.

- **Milestone 5.2.1 –** Develop an initial risk registry**.** (Complete risk plan under DE-EE0005990).

Subtask 5.3 **Start working on final CAPEX.** Finalize overall construction methodology as a basis for completing design. Under DE-EE0005990, start issuing RFPs and soliciting bids for designated packages consistent with acceptable lender risk management philosophies. Update budgetary CAPEX using this new construction methodology.

- **Milestone 5.3.1 -** Obtain preliminary updated CAPEX using a combination of internal estimates and some industry budgetary estimates (final CAPEX under DE-EE0005990).

Subtask 5.4 **Develop updated financial model** incorporating the updated CAPEX and all applicable tax and incentives plans.

- **Milestone 5.4.1 –** Refine financial model**. (**Complete financial model under DE-EE0005990).

Subtask 5.5 **Initiate process to obtain commitment letters from debt and equity partners**, including any tax equity partners required for project financing, leading to financial close, specifically in this phase, hire a financial advisor to commence a process to develop an independent financial model and identify qualified lenders.

- Critical Milestone 5.5.1 - Retain financial advisor.

Subtask 5.1 – Bankable energy production estimates

The goal of this task was to make progress on obtaining bankable energy production estimates in cooperation with the debt and equity investors, turbine OEM, and using services of a qualified third-party analyst acceptable to all parties.

A third party was hired to complete the Annual Energy Production (AEP) report. The initial work on this report was completed using a power curve associated with a 6MW the turbine OEM WTG Wind Turbine on a fixed bottom foundation. The report was updated using an estimate for a floating turbine power curve.

Subtask 5.2 – Identify risks and develop a risk mitigation plan

The goal of this task was to develop a risk mitigation plan to evaluate a multi-contracting approach, to include design, permitting and construction risks and other project risks. Ensure that all risks are properly assigned and accounted for, eliminating double counting of risks.

A third party was commissioned to complete due diligence work including an assessment of risks and mitigation plans which was completed as of December 2017. The risk assessment was completed for a 2x6MW project using the 100% Front End Engineering and Design (FEED) documentation and construction methodology and consisted of technical, programmatic, and execution risks.

Subtask 5.3 – Obtain final CAPEX

Using the multi-contracting approach, the goal of this task was to develop and issue final bid documents with clearly identified risk allocations, review bids, and carry out final contract negotiations. This task was intended to include execution of a binding Turbine Supply Agreement (TSA). This would also be reviewed by a 3rd party approved by the DOE.

During the course of award 6713, progress was made towards obtaining final CAPEX numbers. Primarily this work consisted of obtaining cost-estimate for the hull construction, deployment, and operation working with the project partners for 2 6MW floating wind turbines supported atop the VolturnUS hull.

Subtask 5.4 – Develop updated financial model incorporating the updated CAPEX and all applicable tax and incentives plans

Significant work was completed to develop a robust financial model.

Subtask 5.5 – Obtain commitment letters from debt and equity partners, including and tax equity partners required for project financing leading to financial close

Significant work towards this goal was completed under award 6713. The following work was completed:

- Detailed conversations took place with five prospective investors-developers including in-person visits, due diligence review of project documents, and continued discussions. The due diligence effort was narrowed to five potential developers.
- Joint Development Agreement UMaine and NEAV, a joint venture of RWE and Diamond, was signed July 2, 2020. On Wednesday, August 5, 2020, UMaine announced the collaboration with NEAV.

The team will build upon this success and complete final execution of commitment letters under award DE-EE0005990 for the revised project consisting of a single 10+MW wind turbine.

Figure 35 Signing of LD 994 by the Maine Governor Mills Administration

4. Conclusions

This project enabled significant progress in the development of the New England Aqua Ventus I (NEAV) project, which is currently on track to be the first floating offshore wind commercial demonstration effort in the US. The project will demonstrate a unique prestressed concrete semi-submersible floating hull technology, called VolturnUS. The technology is applicable to harness nearly 60% of the US offshore wind resource within 50 miles of the coast. The hull will be demonstrated at full-scale with a commercial scale wind turbine connected to the grid in the Northeast US off Monhegan Island, Maine for 20 years. In this award, the following key achievements were made:

1. Completion of the design of a 100% FEED for a 6MW floating offshore wind turbine (FOWT) hull which successfully passed a 3rd Party Review by the American Bureau of Shipping
2. Collection of cost estimates for concrete and steel hulls showing that concrete hulls are significantly less expensive and have the opportunity for increased local content.
3. Completion of a cost-trade-off analysis of a light-weight composite tower versus a traditional steel tower that showed the composite towers can help to reduce overall weight of the system and cost. Local content is also increased as well for the composite tower as production facilities can be set-up locally to produce large diameter tower sections using existing tools.
4. Completion of technical due diligence reviews from project investors which led to development agreements between UMaine, Diamond/ Mitsubishi, and RWE representing approximately $100M in investment in NEAV I.
5. Execution of a Power Purchase Agreement with the State of Maine
6. Continued permitting, outreach, and environmental data collection efforts relevant for the project.
7. Completion of preliminary construction and operations plans
8. Development of financial plans and models needed to finance the project

Award DE-EE0006713 represents one source of funding for the project from the DOE and significant progress has been made towards the construction of the project and will be directly leveraged to support the completion of the effort.

5. Related Publications

5.1 Peer Reviewed Conference Papers

1. Dwyer M, Viselli AM, Dagher HJ, Goupee AJ (2017). Experimental Verification of ABS Concrete Design Methodology Applied to the Design of the First Commercial Scale Floating Offshore Wind Turbine in the United States. OMAE2017-62461. Proceedings from the American Society of Mechanical Engineers 36th International Conference on Ocean, Offshore and Artic Engineering, Trondheim, Norway.
2. Allen CK, Goupee AJ, Viselli AM, Dagher HJ, (2017). Validation of a Spectral-Based Structural Analysis Model Implemented in the Design of the VolturnUS 6MW Floating Offshore Wind Turbine, No. 2017-TPC-0828 041017, The International Society of Offshore and Polar Engineers, ISOPE-2017, San Francisco, USA.
3. Fowler M, Goupee AJ, Allen C, Viselli AM, Dagher HJ (2017). 1:52 Scale Testing of the First US Commercial Scale Floating Wind Turbine, VolturnUS: Testing Overview and the Evolution of Scale Model Testing Methods, OMAE2017-61864. Proceedings from the ASME 36th International Conference on Ocean, Offshore and Artic Engineering, Trondheim, Norway.
4. Viselli AM and Dagher HJ (2016), Federally funded W^2 Wind Wave-Basin to Support the Offshore Wind Industry, Presentation given at the Offshore American Wind Energy Association Conference, Baltimore, MD.
5. Fowler, MJ, Goupee, AJ, and Viselli, AM (2016), Advances in Model Scale Testing of Floating Offshore Wind Turbines Utilizing the W2 Wind/Wave Basin, Proceedings of the 2016 Offshore Technology Conference, Houston, Texas, USA.
6. Allen CK, Goupee AJ, Viselli AM, Dagher HJ, (2015). Validation of Global Performance Numerical Design Tools Used for Design of Floating Offshore Wind Turbines, OMAE2015-41437. Proceedings from the ASME 34th International Conference on Ocean, Offshore and Artic Engineering, St. John's, Newfoundland, Canada.
7. Viselli AM, Dagher HJ, Tomlinson SM, Young AC, Goupee AJ, Hettick SA (2014). Design Fabrication and Testing of a Composite Tower for Floating Offshore Wind Turbines. CAMX- The Composites and Advanced Materials Expo, October 13-16, Orlando, FL.

5.2 Conference Presentations

1. Viselli AV (2019), "VolturnUS Concrete Floating Wind Turbine and New England Aqua Ventus I Project Update". US Offshore Wind Conference. Boston, Massachusetts.
2. Viselli, A, Filippelli, M, Faessler, N (2019). Analysis of Wind Speed Shear and Turbulence LiDAR Measurements to Support Offshore Wind in the Northeast United States. International Offshore Wind Technical Conference, San Francisco, USA.
3. Viselli AV (2018), "Harold Alfond W2 Ocean Engineering Facility". French American Innovation Day Conference. Northeastern, University, 2019.
4. Viselli AV (2018), "VolturnUS Concrete Floating Wind Turbine and New England Aqua Ventus I Project Update". Pacific Ocean Energy Trust Conference. Portland, Oregon.
5. Viselli AV (2018), "Briefing on Advanced Model Testing for US OSW Innovation & Cost Reduction". Session Chair. International Partnering Forum for Offshore Wind. Princeton, New Jersey.
6. Viselli AV (2017), "Federally Funded Wind-Wave Basin to Support US Offshore Wind Industry". POWER US Technology workshop Partnership for Offshore Wind Energy in the United States hosted by NREL. Boulder, Colorado.
7. Viselli AV (2017), "VolturnUS Concrete Floating Wind Turbine and New England Aqua Ventus I Project Update". Pacific Ocean Energy Trust Conference. Portland, Oregon.
8. Viselli AV (2017), "Offshore Wind Program Update". Camden Yacht Club Summer Presentation Series. Camden, Maine.
9. Dagher HJ, Viselli AM, Hadlock P, Wissemann C (2017). "New England Aqua Ventus I Project Update, Offshore Wind Partner's Forum, Annapolis, Maryland.

5.3 Peer Reviewed Journal Papers

1. Viselli, A, Filippelli, M, Pettigrew, N, Dagher, H, Faessler, N (2019). Validation of the First LiDAR Wind Resource Assessment Buoy System Offshore the Northeast United States, Journal of Wind Energy. 2019;1–15. DOI 10.1002/we.2387.
2. Viselli, A, Filippelli, M, Faessler, N (2022). LiDAR Measurements of Wind Shear Exponents and Turbulence Intensity Offshore the Northeast United States. Journal of Offshore Mechanics and Artic Engineering. 2022.
3. Young A, Goupee AJ, Dagher HJ, Viselli AM (2017). Methodology for Optimizing Composite Towers for Use on Floating Wind Turbines, Journal of Renewable and Sustainable Energy 9, 033305, DOI:10.1063/1.4984259.
4. Friedland KD, Methratta ET, Gill AB, Gaichas SK, Curtis TH, Adams EM, Morano JL, Crear DP, McManus MC and Brady DC (2021) Resource Occurrence and Productivity in Existing and Proposed Wind Energy Lease Areas on the Northeast US Shelf. Front. Mar. Sci. 8:629230.doi: 10.3389/fmars.2021.629230

5.4 Technical Reports

1. Musial, W, Beiter, P, Nunemaker, J. (2020), "Cost of Floating Offshore Wind Energy Using the New England Aqua Ventus Concrete Semisubmersible Technology", NREL/TP-5000-75618, National Renewable Energy Laboratory, January 2020.

2. Mone, C, Stehly, T, and Musial, W (2016). Levelized Cost of Energy Analysis using a Floating Concrete Semi-Submersible Foundation for the University of Maine. NREL/TP National Renewable Energy Laboratory, 2016.