Meteorological Tower Placement Report to the Virginia Offshore Wind Development Authority (VOWDA)

Virginia Department of Mines, Minerals, and Energy

December 7, 2010

The Virginia General Assembly, in 2010, established the Virginia Offshore Wind Development Authority (VOWDA) to facilitate the development, either by the Authority or by other qualified entities, of the offshore wind energy industry, offshore wind energy projects, and associated supply chain vendors. One specific duty that VOWDA may undertake is collecting relevant meteorological and oceanographic (metocean) and environmental data. The enabling legislation requires DMME to prepare a report on "the appropriate placement of meteorological towers and necessary renovations to existing structures" (Reference 1). This report fulfills that requirement.

- Section I of this report describes the types of metocean data needed to inform and accelerate offshore wind project development off Virginia.

- Section II catalogues the various metocean data sources that are now available on Virginia's outer continental shelf (OCS).

- Section III describes the state-of-the-art in offshore wind resource assessment to achieve a "bankable" project and recent results from Denmark that suggest how calibrated and traceable ground-based vertical-profiling LIDAR (LIght Detection And Ranging) can reduce uncertainty in estimating annual energy production, thereby improving project financing terms.

- Section IV describes the existing uses and present status of the Chesapeake Light Tower (CLT), and summarizes the opportunities and challenges posed by refurbishing it as a metocean and environmental data collection platform. The CLT is the only "existing structure" on Virginia's OCS to which the VOWDA enabling legislation applies

- Section V recommends a phased development approach whereby outfitting the CLT with appropriate instrumentation will enable Virginia to begin characterizing its offshore wind resource at a fraction of the cost of a new met tower in the initial phases of this work. This will enable data analysis and resource characterization in a public process subject to peer review, with wider dissemination of results more quickly than if such metocean measurements were left entirely to commercial project developers. Additionally, this will encourage more rapid growth of Virginia's offshore wind industry. Moreover, the recommended instrumentation will be key assets for a proposed National Offshore Wind Technology Center (NOWTC) based in Hampton Roads, which will be a foundational enterprise to grow and attract offshore wind businesses and more quickly create new jobs and capabilities in Virginia's offshore wind supply chain.

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I. Metocean Data Needs for Offshore Wind Turbine Selection and for Project Financing, Design, Construction, and Operation

Urgent Need for Offshore Wind Data to Inform Turbine Selection

Wind developers and government agencies need metocean data to design, construct, and operate offshore energy projects and for the attendant federal regulatory process. According to an analysis by the Virginia Coastal Energy Research Consortium (VCERC; Reference 2), the federal process for an offshore wind project developer to obtain a non-competitive lease is estimated to take between 10 and 21 months, while the competitive lease process could require 21 to 36 months. Thus, commercial wind projects in federal waters on Virginia's OCS might need 1-2 years to obtain a non-competitive lease, or 2-3 years to obtain a lease if a competitive lease auction is required. Note that these times may be shortened by the December 2010 changes to the Bureau of Ocean Energy Management and Reclamation Enforcement (BOEMRE) leasing process.

Once a commercial lease has been awarded, VCERC estimates that 3 to 5 years will be needed for development activities (acquisition of met-ocean & geological/geophysical data for design, acquisition of baseline environmental data, and securing an interconnection agreement, a power purchase agreement, and project financing commitments). Ordering of long-lead items such as turbines and submarine power cables, as well as securing offshore vessel charters, should occur well before installation is scheduled to start and key permits should be in place before such large binding orders are made.

Assuming that the BOEMRE decides to issue its Virginia Request for Interest (RFI) by the end of 2010, the date when a developer can expect to have a lease for a commercial offshore wind project in federal waters off Virginia will depend on whether or not a competitive lease auction must be held to resolve competing interests and the success of BOEMRE's regulatory streamlining.

Backing up from a project commissioning date of year-end 2018, long-lead items such as wind turbines and submarine power cables should be supplied by year-end 2016, meaning that firm orders for these major components should be placed no later than year-end 2014. As detailed in Reference 2, having turbines supplied from an assembly plant in Hampton Roads rather than from Europe could reduce the cost of an offshore wind project by $480 per installed kilowatt and lower the cost of energy by $15 per MWh. In order for serial production from a new plant to begin by year-end 2014 for turbine delivery by year-end 2016, a turbine manufacturer's decision to invest in such a plant and qualify its supply chain should be made by year-end 2011. This implies that key turbine design parameters, such as rotor swept area per unit generator capacity and total tower-top mass per unit capacity, should be known as early as year-end 2011 to meet an aggressive development schedule.

Metocean Data Needed for Project Financing, Design, Construction, and Operation

It is commonly thought that to obtain offshore wind project financing, a meteorological tower must be erected within the project footprint, to measure wind speed and direction at multiple

elevations above sea level, up to a "best practice" elevation of at least 2/3 of turbine hub height for at least one year in order for such data to be "bankable" (Reference 3).

One U.S. merchant project developer (Reference 4) estimates the cost of such a dedicated tower to be $4 - $7 million, depending on location, type of foundation and the instrumentation that is included. Another U.S. merchant developer (Reference 5) has documented offshore met tower costs ranging from $2.5 million for the Cape Wind project (5-m water depth, 60-m height, with three anemometer elevations) to over $10 million for the FINO-1 platform offshore Denmark (30-m water depth, 100-m height, with eight anemometer elevations).

Because obtaining such project-specific measurements is so costly, an increasing number of European offshore wind farms are being financed based on revenue projections derived from numerically modeled weather data, which have been validated by physical measurements near, but not within, the project site (Reference 6). In responding to DMME's questionnaire soliciting stakeholder input for this report, Virginia's incumbent electric utility has stated (Reference 7):

> At this point in time, upgrading the CLT [Chesapeake Light Tower] should be a priority, not to provide financing in preparation for a specific project, but to provide more detailed information on the wind resource in order to prepare Virginia for the offshore wind industry… Using the CLT to validate less costly measurement devices in lieu of project-specific met towers provides useful data for scientific evaluation, policy development, and initial project development.

Recent presentations by representatives from banks that have financed European offshore wind projects have suggested that a much bigger revenue risk than uncertainties in the hub height wind resource, *per se*, is the risk of lost revenues due to turbine inaccessibility for service visits caused by poor weather (References 8, 9 and 10). This is particularly true considering that inaccessibility is more likely to occur during high-wind periods when the output (and earned revenue) of a properly functioning turbine would be greatest. The five key metocean parameters governing offshore wind access are:

- Wind speed;
- Wave height;
- Wave period;
- Surface current speed; and
- Visibility.

Optimizing offshore maintenance strategies requires *a priori* knowledge of these conditions in order to design a project for least risk of revenue loss (Reference 11).

Metocean conditions also affect the design (e.g. appropriate floating equipment selection), scheduling, and safe conduct of offshore construction activities: staging, transport and installation of foundations, towers, turbines, and submarine power cables. Indeed, representatives from banks who finance offshore wind projects suggest that one of the best ways to mitigate against offshore wind project construction delays and cost-overruns is to develop

accurate metocean forecasting capabilities (References 6 and 7). The same five metocean `parameters that govern offshore access for maintenance also govern the design, scheduling and safe conduct of offshore construction activities (Reference 9).

Finally, reliable days-ahead forecasting of offshore wind conditions would improve the ability of projects to operate cost-effectively in the PJM regional transmission market. In particular, accurate wind speed forecasts reduce fees for load balancing and other ancillary services that PJM would charge against interconnected offshore projects.

Based on the above considerations, this report recommends a metocean data collection and environmental monitoring program that will attract lower-cost financing terms for offshore wind projects on Virginia's continental shelf. This is based on evaluation of existing metocean data sources (next section), the availability of the Chesapeake Light Tower as an existing platform of opportunity (third section), and the long timetable before project developers will be able to measure site-specific data on their commercial leases.

II. Existing Metocean Data Sources on Virginia's Outer Continental Shelf

There are three basic types of metocean data sources publicly available to offshore wind turbine manufacturers, commercial project developers, and federal regulatory and permitting agencies: measurements, forecasts, and hindcasts. Measured data sets may be relatively recent, with only a few years of archived measurements. In some cases measurement archives may cover two or three decades, which is comparable to the service life of an offshore wind project.

Existing operational metocean forecast products typically have a forecast horizon of one to two days, although "Wavewatch III" operational wind and wave products have a forecast horizon out to 180 hours (7.5 days). Some forecasts retain archives of their "nowcast" products (which are based on present-time analysis and thus the most accurate), but such archives have been maintained for just a few years. In some cases "nowcast" products are routinely discarded, which represents a lost opportunity.

For estimating extreme storm conditions that might occur during the service life of an offshore wind project, two to three decades of numerical model "hindcast" results are needed. Hindcast products estimate what metocean conditions would have been like based on actual past measurements of driving parameters such as atmospheric pressures and temperatures, while forecast products are based on predicted estimates of driving parameter values in the future.

Existing metocean measurement stations off Virginia are not suitable by themselves to meet the measurement needs of a "bankable" offshore wind resource assessment. They can however provide data points for physically validating any numerical metocean simulation models such as hindcasts and forecasts or any future metocean model that might be developed specifically for offshore wind development.

There are three operational metocean measurement stations on Virginia's OCS, which are mapped in Figure 1. Access to near-real-time data for all three stations is available through the main Web site of the National Data Buoy Center (NDBC), although the wave measuring buoy off Virginia Beach is actually owned and operated by the Coastal Data Information Program (CDIP) of Scripps Institution of Oceanography.

Figure 1: Existing metocean measurement stations on Virginia's Outer Continental Shelf.

NDBC station CHLV2 is part of NOAA's Coastal-Marine Automated Network (C-MAN) and is located on the Chesapeake Light Tower 24 km (13 nmi) east of Cape Henry in 12 m (39 ft) water depth. It has been measuring winds and non-directional wave spectra since August 1984, archiving 10-minute average wind speed every hour. Starting in June 1989, 10-minute average wind speeds have been archived continuously. Wave measurements ceased in December 2004, and sea surface temperature measurements ceased in August 2003. The following metocean instruments still operate: wind speed and direction at an anemometer height of 43.3 m (142 ft) above mean sea level (AMSL), atmospheric pressure at 23.4 m (77 ft) AMSL, and air temperature at 22.3 m (73 ft) AMSL.

NDBC station 44099 is a Scripps Institution of Oceanography Waverider buoy located 18.5 km (10 nmi) east of Cape Henry in 19 m (62 ft) water depth. It has been measuring directional wave spectra and sea surface temperature since June 2008. Air-sea temperature difference is an important input parameter for numerical modeling of the wind shear profile near the sea surface, and this can be calculated using the air temperature measurement at CHLV2.

NDBC station 44014 is a 3-meter discus buoy moored near the continental shelf edge in 47.5 m (156 ft) water depth, 120 km (64 nmi) east of False Cape. It has been measuring winds, waves, air temperature, sea surface temperature, and atmospheric pressure since October 1990. The wind sensor ceased functioning in March 2010 and will be repaired or replaced during NDBC's next service visit. This station also has an acoustic Doppler current profiler (ADCP) that has been measuring mean water velocity 3.8 m below the sea surface since March 2010. Short-range visibility data (out to 1.6 nmi from buoy) were archived from July 1991 to December 1994.

III. State of the Art in "Bankable" Offshore Wind Resource Estimation

Types of Wind Measuring Instrumentation

A typical anemometry mast will have several anemometers (devices to measure wind speed) installed at different heights on the mast, and at least two wind vanes (devices to measure wind direction). These will be connected to a data logger, at the base of a mast, via screened cables. In the absence of an alternating current power supply (as is the case at most offshore sites), the wind measuring system is battery operated, with battery charging via solar panel or small wind turbine.

For some systems, particularly in cold climates, the measurement of the temperature is important to assist with detection of anemometer icing. Temperature also factor into the calculation of air density for wind power density estimates. Temperature also should be measured at multiple levels in order to calculate heat flux, which is an important factor in applying numerical models to extrapolate wind speed at elevations higher than the anemometer.

Remote sensing techniques are being developed rapidly, and such devices are expected to become more widely used in the near future. These are ground-based upward-looking or outward-looking devices that can measure wind velocities at a range of elevations without the need for a conventional mast. There are two main sorts of devices:

- SODAR (SOund Detection And Ranging), which emits and receives sound and from this infers the wind speed at different heights using the Doppler shift principle; and
- LIDAR (LIght Detection And Ranging), which also uses the Doppler shift principle, but emits and receives light from a laser.

Although vertical-profiling SODARs are three to four times less costly than vertical-profiling LIDAR units, they suffer from poor performance in the rain and at high wind speeds. They also are too large to be mounted on buoys. Therefore this report focuses on the remote sensing applications of LIDAR units.

Signals that would typically be recorded for each anemometer (or at each target elevation for a LIDAR unit) are as follows:

- mean (ten-minute average) wind speed;
- maximum (moving three-second average) gust speed;
- true standard deviation of wind speed; and
- mean wind direction.

In recent years, it has become standard practice to download data remotely, via either radio modem or a satellite link. This approach has made managing large quantities of data more efficient and less costly than manual downloading by service personnel. It also has the potential to improve data availability, since failed or faulty sensors can be detected in near real time.

The key analyses to be performed on the mean wind speed and direction data is to develop a long-term (20- to 30-year) probability distribution of wind speeds and a wind direction rose. Other meteorological inputs to a project's annual energy production analysis are the long-term

site air density and site turbulence intensity (as characterized by the standard deviation of wind speed during a 10-minute averaging period). While still important, these are of secondary influence on the estimated energy production of a wind project, and their derivation is not considered further in this report. It should be noted, however, that the turbulence intensity is very important in determining the aerodynamic loading regime on the rotor and drive train of a turbine and influences the life expectancy of the rotor blades and gearbox.

Using Short-Term Measurements to Develop a Long-Term Resource Estimate

Even on land there is a general lack of wind data measured directly within a project site at the hub height of the turbine. This is because wind projects have a service life of 20- to 30-years, while developers only have a 1- or 2-year window of opportunity to undertake site-specific measurements. Such a short measurement period does not necessarily represent the long-term wind climate in which a project must operate.

As described in the previous section, the NDBC meteorological station on the CLT has been measuring wind speed and direction at 43 m above sea level since 1984. This represents more than 25 years of quality-controlled data at a fixed location. One may well ask if these data can be directly used for offshore wind project development off Virginia.

This would require two spatial extrapolations, as shown in Figure 2: a vertical extrapolation from the anemometer height of 43 m to the expected turbine hub height which is likely to be 90 or 100m above sea level, and a horizontal extrapolation from the CLT location to the wind project site, which is likely to be a few tens of kilometers (in the range of 10 to 50 km) east of the CLT.

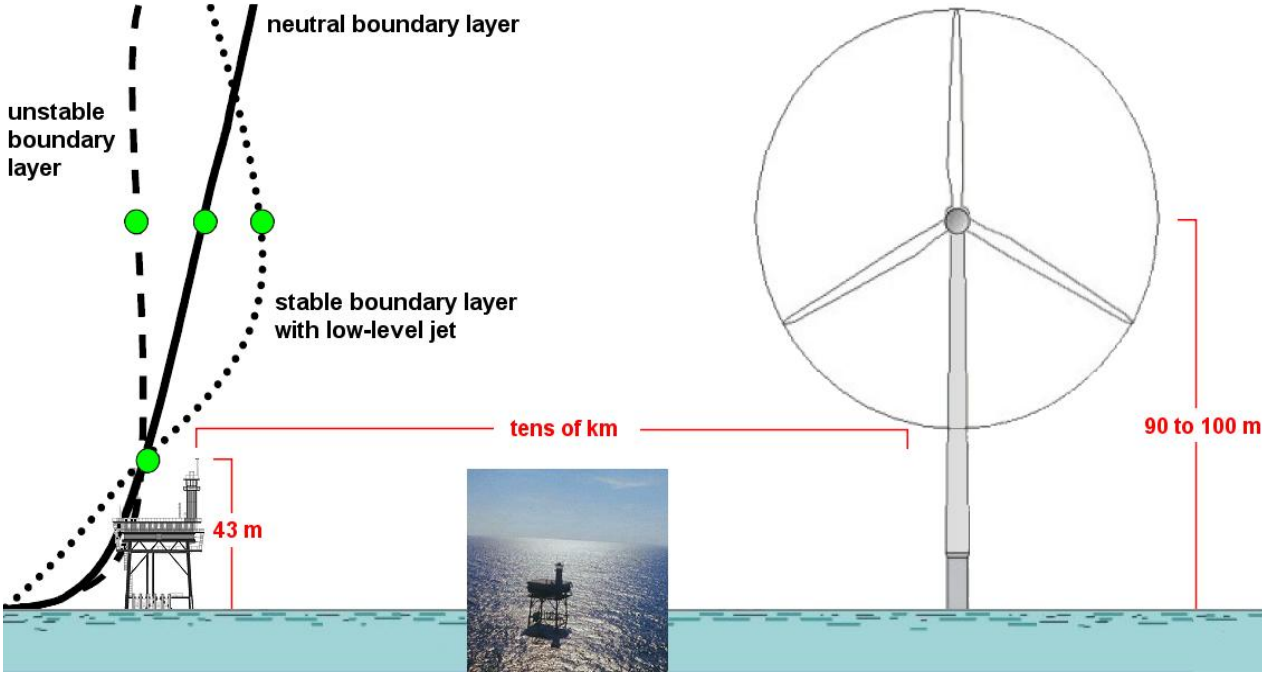

Figure 2: Uncertainties introduced by direct extrapolation of Chesapeake Light Tower data to likely commercial offshore wind turbine sites off Virginia. See text for explanation.

For feasibility-level analyses, a wind speed profile governed by a simple power law ratio or logarithmic ratio between one elevation and another is assumed, as was done by VCERC for its initial wind studies (Reference 2). Such an estimate is not bankable and VCERC analysis suggests that the uncertainty in this type of simple extrapolation is in the range of 20% to 25% (Reference 12). A more sophisticated approach would be to use meso-scale or micro-scale numerical models to simulate the vertical profile of wind speeds above the sea surface, which factor in sea surface roughness, heat flux, and the height of the boundary layer. As shown in Figure 3, however, comparison between such models and tall mast measurements at the FINO-1 met tower off Denmark suggest they still are not sufficiently accurate for project financing.

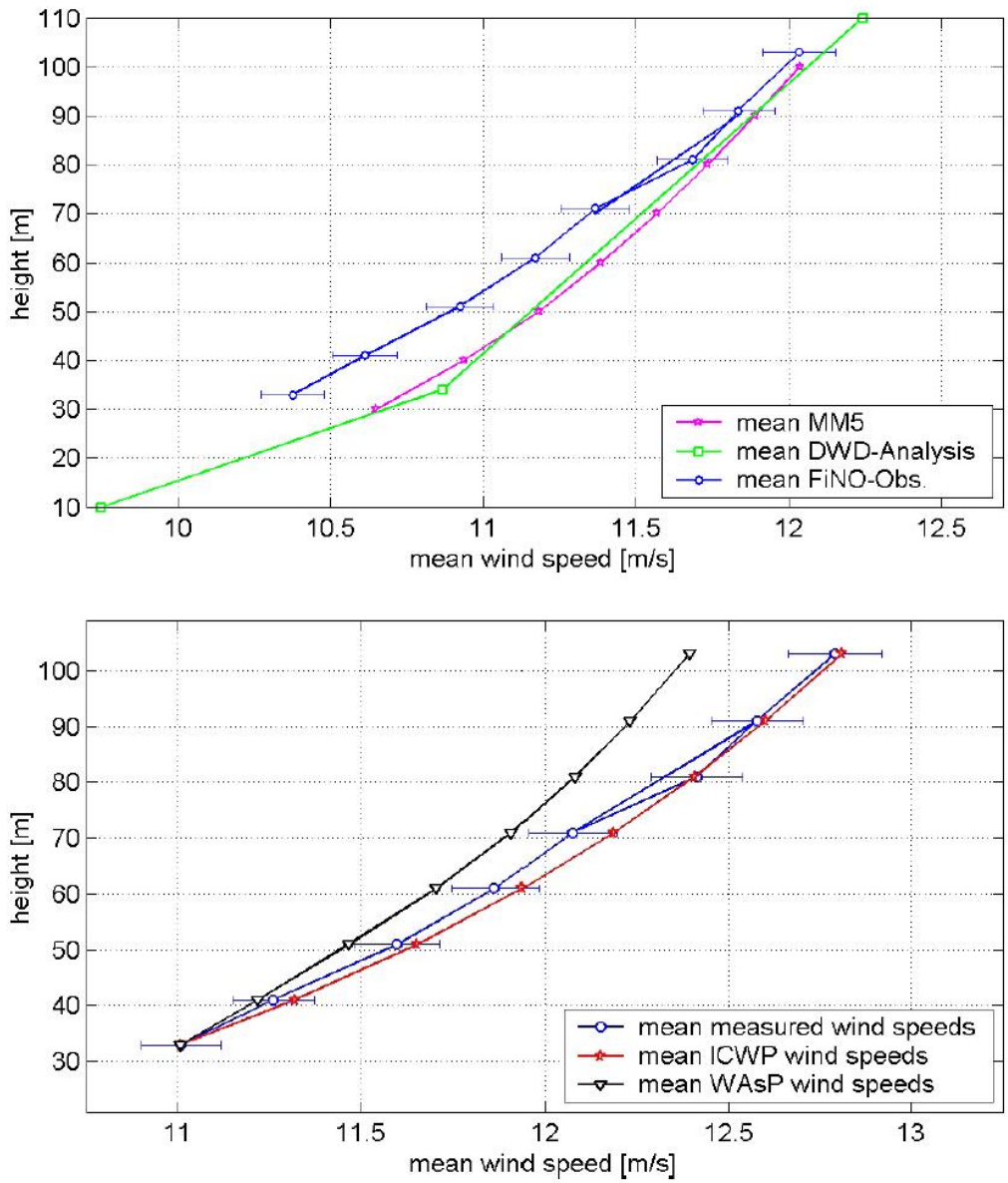

Figure 3: Comparison between the average wind speed profile measured at FINO-1 and numerically simulated profiles using two different meso-scale models (upper graph) or a commercial micro-scale model (WAsP in lower graph). The research micro-scale model, ICWP, shows promise but is not validated for project financing purposes (Reference13)

The aerial photograph of the CLT in Figure 2 suggests that this ocean area is a homogeneous environment and that horizontal extrapolation of the CLT anemometer data might be possible. Conceptually, it might appear that offshore wind resources ought to be relatively easy to predict, due to the lack of topography and obstacles. Again, however, research in Denmark suggests that wind resource estimation at offshore sites is more complex than usually believed.

Variable sea surface roughness under different wave conditions, atmospheric stability, and the growth of the boundary layer with increasing distance from shore complicate the situation, but also the land–sea discontinuity can have affects far offshore. In this flow regime, the wind speed increases more rapidly with height than predicted by boundary layer theory. It should be noted that these deviations, although caused by the coastal discontinuity, have been observed as far offshore as 100 km (Reference 14).

The width of the coastal influence zone, and the wind's vertical (shear) and horizontal gradients within that zone, depend on atmospheric stability, with wind speeds adjusting more slowly (creating a wider zone of coastal influence) under stable atmospheric conditions. Modeling suggests that within the coastal influence zone, wind speeds at typical turbine hub-heights can change by up to 2 m/s over the horizontal extent of a large wind farm, depending on atmospheric stability (Reference 15).

Finally, meso-scale phenomena such as sea breezes, low-level jets, and roll circulations, also affect the wind speed and turbulence experienced by wind turbines in the offshore coastal zone. Reference 12 describes research at Rutgers that shows the zone of sea-breeze influence can extend up to 50 km offshore. Of particular concern is divergent, weak-wind zones associated with sea breeze circulation cells that develop along the Mid-Atlantic coast during warm afternoons, which are most prevalent during summer months of peak power demand. Although the long-term wind measurements at the CLT cannot be used directly, they represent an excellent reference archive that can be used in the so-called "Measure-Correlate-Predict" (MCP) method that is used to predict long-term wind speed distributions at a project site when only short-term measurements are available at that site.

The MCP procedure as it might apply off Virginia is illustrated in Figure 4. On-site data is would be measured for a short term (1- to 3-years) on a proposed project site using calibrated and traceable LIDAR equipment on either a fixed platform or a buoy. This type of equipment provides wind speed measurements on the project site and across the entire span of the turbine rotor swept area, including directly at hub height, so no vertical extrapolation would be needed.

If it can be established that there is good correlation between the short-term site data and data measured concurrently during the same period at the reference station (the CLT), then a linear regression or other statistical relationship (see Reference 16 for analysis) can be used to re-create (or "predict") what the long-term history of wind speeds would have been at the project site during the archive period of the reference station (since 1984 at the CLT).

Note that the MCP procedure assumes that the offshore wind climate for the past two decades will not change substantially during the next two decades. This is a matter of some debate and beyond the scope of this report. The general consensus among the scientific literature is that offshore wind speeds off the Mid-Atlantic are likely to increase in coming decades (for example, see References 17 and 18), such that MCP would yield conservative results off Virginia.

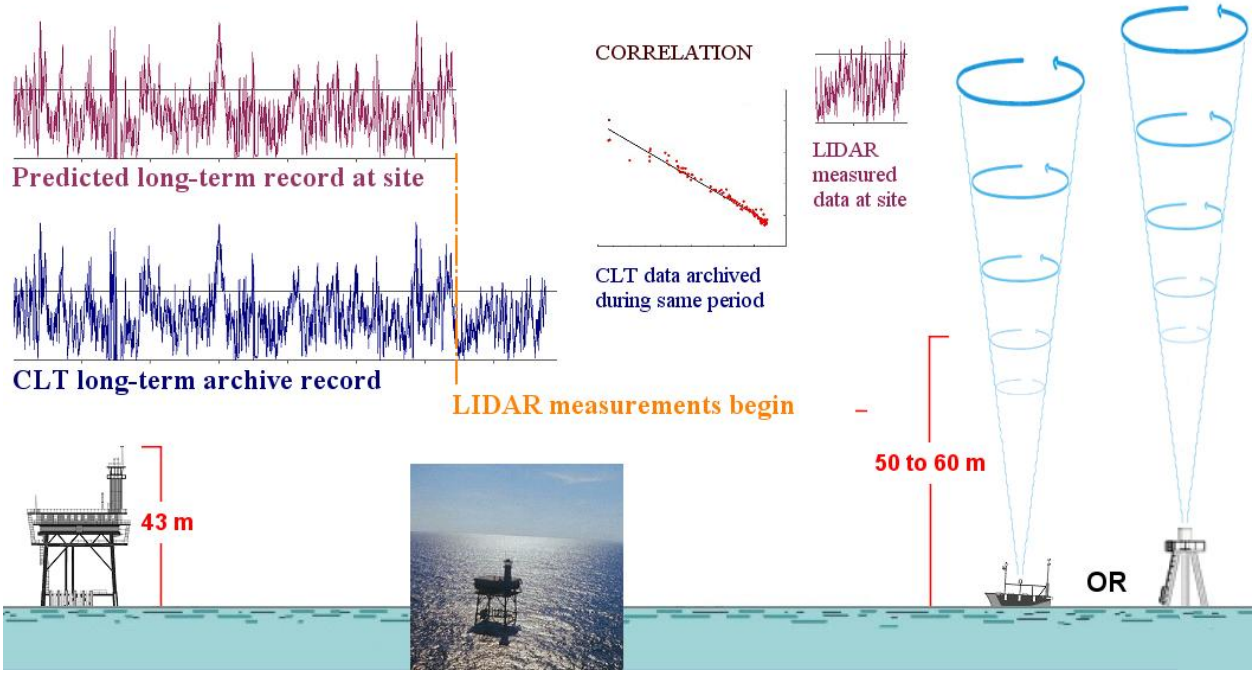

Figure 4. Measure-Correlate-Predict (MCP) resource assessment procedure as it might apply to commercial offshore wind project development off Virginia. The lowest elevation scanned by the site-based LIDAR (either on new fixed tower or moored buoy) should be used for correlation purposes, as this would be closest in elevation to the 43 m anemometer height at the CLT. Since the LIDAR units measure additional elevations up to 150 m and higher, there would be no need for vertical extrapolation to turbine hub height. See text for additional explanation.

Necessary conditions for a suitable long-term reference station described in Reference 19 are:

1. The archived reference data set includes data which has at least a one-year overlap in time with the short-term measurements on site
2. It can be demonstrated that the data has been recorded using a consistent system over the period of both the concurrent and longer-term data. This should include consideration of the position and height of the mast and the consistency of equipment used, all of which have been well maintained at the CLT by the National Data Buoy Center.
3. No potential changes to exposure of the reference station met mast. It is for this reason that wind turbines (demonstration or commercial) should be excluded from within a 5 km radius circle around the CLT. Any changes to the measurement equipment or surrounding exposure will render it useless as a reference site.
4. The Pearson correlation coefficient (r^2) between the short-term measured data at the project site and the archived data at the reference station from the same concurrent period should be at least 0.8.

Use of Fixed Vertical-Profiling LIDARs to Improve Project Financing Terms

As mentioned previously, there are four commercially available vertical-profiling LIDAR units. Given the relative newness of this technology as compared with conventional anemometers that use cups or propellers, this section examines the use of vertical-profiling LIDARs to improve the "bankability" of a wind project by significantly reducing the uncertainty in hub-height resource assessment.

As exemplified by the FINO-1 platform off Denmark, to construct an offshore anemometer mast that extends fully to the optimal hub height of modern offshore wind turbines, which is likely to be 90 or 100 m, would cost more than $10 million. This is because substantial mast structure is required to prevent swaying of the mast top. Because of the small platform deck area, the mast must be cantilevered from the platform base without guy wire support. For this reason, it has become accepted practice to construct offshore masts to 2/3 of hub height, as has been done for the Cape Wind project in Nantucket Sound, where the meteorological mast extends to just 60 m, whereas the proposed turbine hub height is 90 m.

A comprehensive field evaluation of cup anemometers and vertical-profiling LIDARs in flat coastal terrain has been reported by the Risoe National Laboratory in Denmark (Reference 20). This study compared the annual energy production (AEP) estimate of a 2 MW turbine with a hub height of 100 m, as derived from four different measurement sources, with the following results for uncertainty in the 90% confidence intervals for AEP estimates of Annual Energy:

- Class 1 cup anemometer at 100 m elevation (hub height measurement). AEP uncertainty: ±0.5%
- Cup anemometer at 80 m elevation, with measurement-driven extrapolation to hub height using WAsP micro-scale numerical model with either default heat flux or site-specific measured heat flux. AEP uncertainty: -1.7% to -2.8%
- Cup anemometer at 60 m elevation, with measurement-driven extrapolation to hub height using WAsP micro-scale numerical model with either default heat flux or site-specific measured heat flux. AEP uncertainty: -8.1% to -8.5%
- Vertical-profiling LIDAR (Leosphere WindCube) traceable to calibrated Class 1 cup anemometer, measuring at 100 m target height. The largest source of error for such LIDARs is the range estimate to the target height, causing the greatest wind speed error when the vertical gradient in wind speed (i.e. shear) is greatest (stable atmospheric conditions). AEP uncertainty: ±2.5%

The cup anemometers were all Class 1 calibrated and well maintained, supported on a guyed mast at the coastal Risoe field test center in Denmark. These results indicate that calibrated and traceable WindCube vertical-profiling LIDARs in flat terrain yield AEP uncertainties for 100 m hub height comparable to those from cup anemometers at 80 m elevation, and significantly better than those from cup anemometers at 60 m elevation.

German field tests of the ZephIR continuous wave LIDAR and the WindCube pulsed LIDAR have yielded similar results. The WindCube also was shown to be remarkably accurate in measuring turbulence (standard deviation of wind speed) when compared with turbulence measured by cup anemometers at an elevation of 135 m (Reference 21).

A critical question is whether or not vertical-profiling LIDAR data will be acceptable for commercial project financing on the same terms as cup anemometer data. Until formal standards for LIDAR-based resource assessment are developed (see Reference 22 for status), projects must be assessed on a case-by-case basis. As stated in Reference 20:

> It is very likely that with coming improvements well-documented LIDAR measurements for hub-heights above 60 m in flat terrain will be similar in precision to many "in field" cup anemometer set ups. Furthermore, the avoidance of vertical extrapolation is likely to reduce the overall AEP estimate uncertainty.

To understand how reduced uncertainty translates into improved project financing terms, it should be noted that resource assessments include Monte Carlo simulation-based statistical analyses that incorporate a relatively small number of key uncertainties, which area assumed to each have a normal probability distribution. The resulting AEP has an overall probability distribution that associates energy production levels with a probability of those levels being exceeded during a specified time period, such as one year, ten years, or the service life of the project (see Figure 5). For example, a P90 of 110 GWh/year means there is a 90% probability of the project producing an annual average of 110 GWh during the specified time period. From the perspective of a bank or investor, this means that there is only a 10% risk that the project will produce less than this amount.

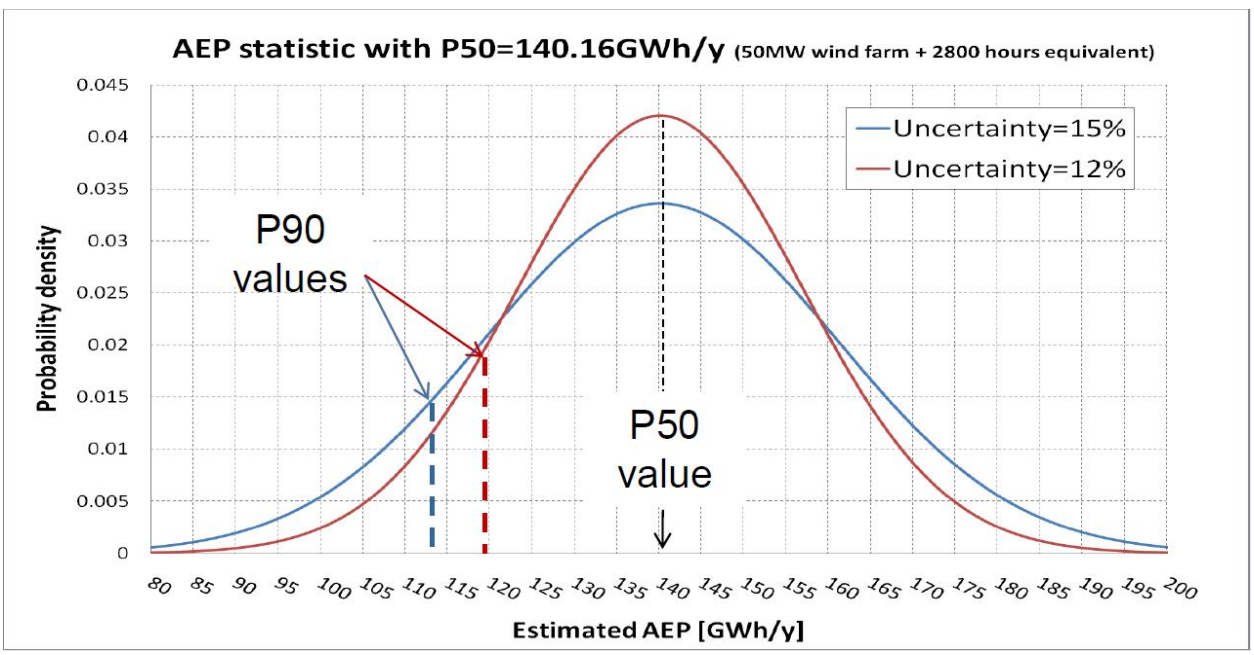

Figure 5. Annual Energy Production (AEP) probability distribution for a hypothetical 50 MW wind project with two levels of overall uncertainty, which include resource uncertainties (the primary focus of this report) as well as uncertainties in turbine performance and long-term reliability. The objective of any VOWDA-facilitated metocean measuring program off Virginia will be to reduce uncertainties associated with vertical extrapolation of wind speed profiles to hub height and horizontal extrapolation of wind speed data from the CLT or a project-centered met tower due to spatial variability across an offshore lease at different turbine locations. Source of graphic: Reference 23 .

Based on such a statistical approach, Figure 5 illustrates how reduced uncertainty yields a larger value of P90 energy production, which thus translates into a higher revenue stream. Both cases have the same mean (P50) annual energy production, but when the uncertainty around that value decreases from ±15% to ±12%, the annual energy production increases by more than 5 GWh annually. This represents an increase in the guaranteed revenue stream against which a project can secure debt financing, and this reduces the amount of required equity investment (which costs more than debt and is not tax deductible).

Note that the uncertainty analyses presented in typical wind energy resource assessments assume that the turbines will perform according to the manufacturer's power curve and will have a minimum availability. The turbine's power performance and availability are usually covered by specific warranties from the turbine manufacturer. Any consideration of the uncertainty contributions from these parameters requires third-party review of the turbine performance curves and the turbine supply contract, both of which are generally outside the scope of a 'standard' wind energy resource assessment.

Wind energy in general and offshore wind in particular is fundamentally different from other generation in its risk profile, in both resource and non-resource aspects. A fossil fuel or conventional hydro generation plant involves a well behaved resource exploited by a small number of turbines in an interior space close to operation and maintenance infrastructure. In contrast, as stated in Reference 22, "wind power entails the exploitation of a highly variable and intermittent resource which has characteristics that cause stress and damage by a large number of highly dispersed assets in locations that present access challenges." This is particularly true of offshore wind.

As stated in the previous section of this report, physically validated numerical metocean models can be used to reduce uncertainties associated with construction cost overruns due to "waiting on weather" during installation, accumulated fatigue damage, offshore access for timely maintenance and repairs, and extreme event survival. Existing measurement station on Virginia's OCS can be used to validate some aspects of such models, and the metocean measurement equipment recommendations made in this report also can support such physical validation. The primary focus of the next two sections, however, is the establishment of metocean measuring equipment that will facilitate offshore wind resource assessments to support annual energy production estimates and the associated guaranteed revenue stream that developers can offer to secure low-cost project financing.

Buoy-Based Vertical-Profiling LIDARs and Volume-scanning LIDARs

In addition to the three fixed vertical-profiling LIDARs already discussed, there is a fourth LIDAR profiling unit, manufactured by "Catch the Wind" of Manassas, Virginia, which has been incorporated in the WindSentinel buoy marketed by AXYS Technologies in British Columbia. This LIDAR unit was originally developed for near real-time turbine control using a nacelle-mounted LIDAR measurement of incoming wind speeds 300 to 500 m upwind of the turbine. Because it also has been used for wind shear sensing aboard helicopters, its motion correction algorithms have been adapted for use on buoys.

Initial sea trials of the WindSentinel buoy off Vancouver were conducted in November and December of 2009. Buoy-mounted LIDAR wind speeds were compared with readings taken

from a stationary LIDAR located 750 meters away on Race Rocks Island (Reference 24). To the principal author's knowledge, results from these trials have not been published. Fishermen's Energy has proposed to use a WindSentinel buoy for resource assessment on its project off the coast of New Jersey (Reference 25).

The British company that developed the ZephIR vertical-profiling LIDAR also has developed a buoy-based version called the SeaZephIR. According to Reference 26, Deepwater Wind will employ a SeaZephIR to measure the wind resource of Block Island, Rhode Island. Deepwater Wind also has proposed to use a SeaZephIR for its New Jersey project (Reference 25).

The U.S. Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE) has approved the use of these buoy-based vertical-profiling LIDARs on their interim-policy leases off New Jersey, and the New Jersey Board of Public Utilities has determined that these systems will qualify for the rebate that the state granted these developers for offshore wind measurement, even though fixed towers were envisioned when the rebates were first awarded (Reference 25).

If the LIDAR range-finding height uncertainty introduced by buoy motions can be minimized by heave-pitch-roll correction algorithms to the point where these vertical-profiling LIDARs have the same accuracy as their fixed counterparts, then buoy-based LIDARs can make two key contributions to reducing the overall AEP uncertainty for offshore wind projects. First, they can reduce the uncertainty caused by vertical extrapolation of cup anemometer data to turbine hub height from a shorter-than-hub-height mast. Second, being moored by moveable anchors, the buoy can be redeployed around a large offshore lease area, to "map" the horizontal variability of the wind resource. In order to have a sufficiently long measurement record for MCP algorithms and account for seasonal variability, each buoy mooring site should be occupied for at least six months, ideally up to a year.

The biggest advantage of buoy-mounted vertical-profiling LIDARs is their low cost relative to a fixed offshore met tower. As noted earlier in this report, a new offshore met tower is estimated to cost in the range of $4 million to $7 million. For this same cost, two or three buoy-based LIDARs could be purchased. Moreover, in the 2- to 3-year period that would be required to obtain permits and geotechnical data for a fixed met tower, followed by a year's operation each buoy could occupy 6 to 8 different turbine sites for six months per site. This would give a fairly good picture of horizontal wind variability across a large offshore lease area, provided that the short-term buoy data records are correlated with a nearby reference station, such as the CLT. Note that BOEMRE does not require leases for any buoy deployment less than twelve months' duration, and this represents another large advantage of a buoy-mounted LIDAR profiler.

Rather than moving buoys around for six months at a time, better coverage can be obtained by a LIDAR that scans a three-dimensional volume. The stationary Galion vertical-profiling LIDAR also can be used in volume-scanning mode, but only out to a range of 2 km (Reference 27). This is adequate for viewing the velocity deficit in the wake downwind of a nearby turbine (as shown in Figure 6), but not sufficient to map a large offshore lease area.

The only commercial LIDAR unit for long-range volume scanning is the WindTracer offered by Lockheed Martin. Originally developed for wind shear monitoring at airports (Figure 7), the WindTracer has demonstrated clear-air effective ranges of 15 to 25 km (Reference 28).

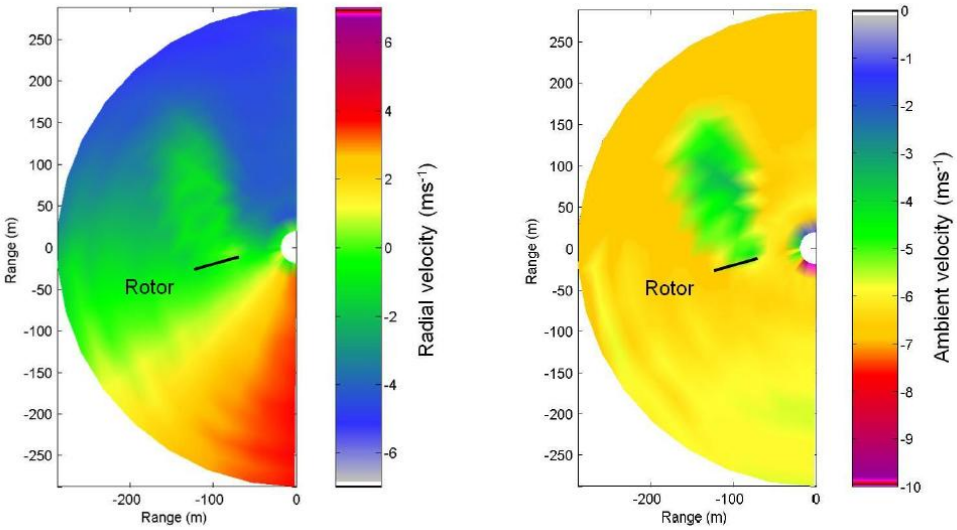

Figure 6. Horizontal slice through a Galion volume-scanning LIDAR measurement image showing a distinct wake downwind of a wind turbine rotor. Source: Reference 27.

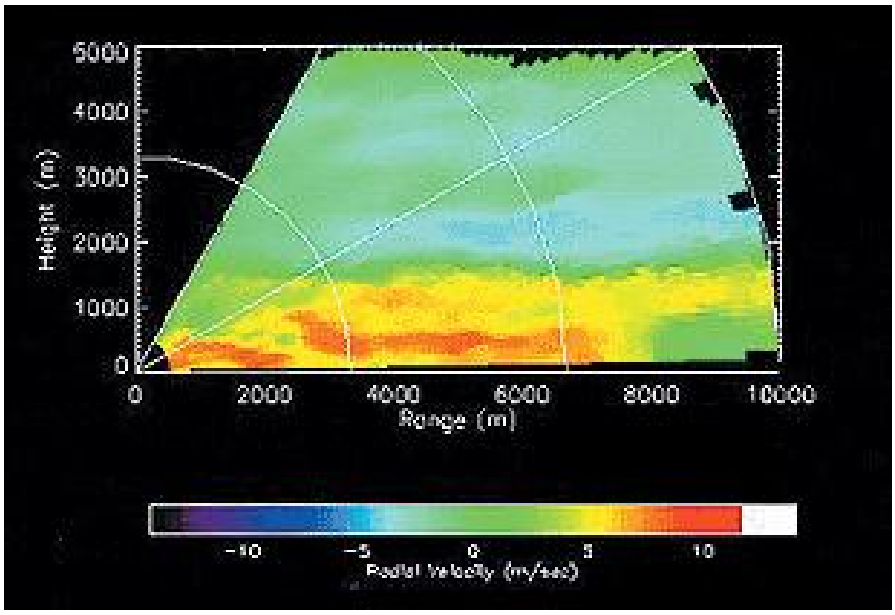

Figure 7. Vertical slice through a WindTracer volume-scanning LIDAR measurement image along an airport runway, showing radial velocity relative to the measurement origin. Orange represents 10 m/sec away from the origin, violet represents 10 m/sec towards the origin. Source: Reference 29.

IV. Existing Uses and Present Status of the Chesapeake Light Tower

On 17 March 2010, the U.S. General Services Administration (GSA) issued a notice of surplus property determination for the CLT, which is located approximately 24 km (13 nautical miles) east of Virginia Beach. The structure consists of a light tower, an upper helicopter landing deck,

a middle deck of enclosed machinery and living quarters covering approximately 1,000 square feet, and a lower, open maintenance deck, supported by four main pilings on a shoal area where the local water depth is 12 m (39 ft). An outboard profile is shown in Figure 8.

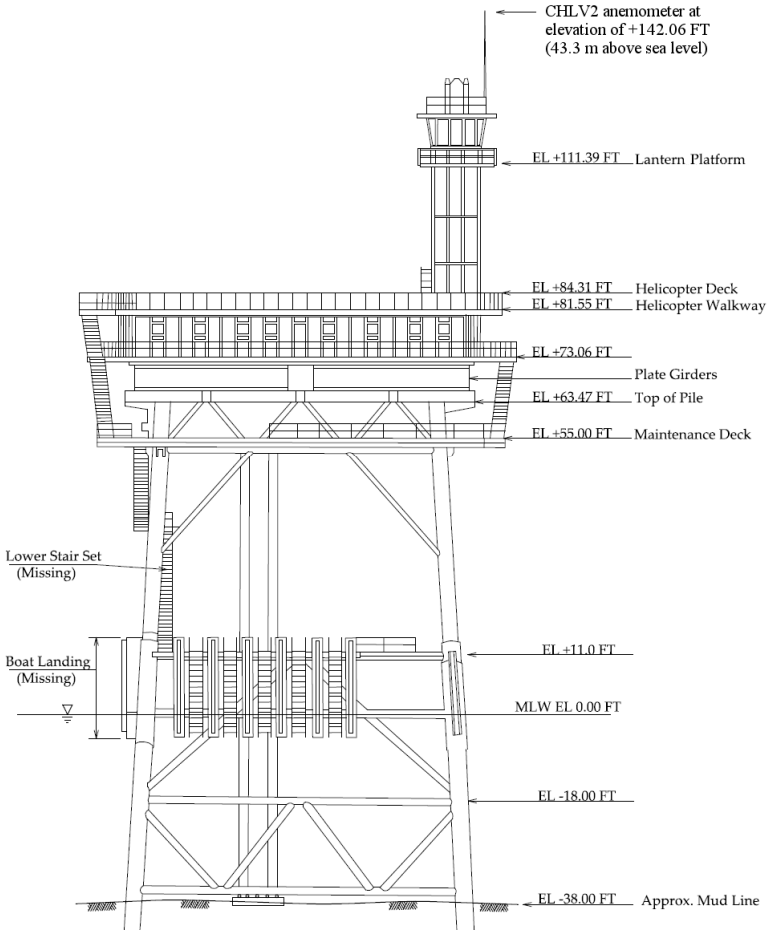

Figure 8. Outboard profile drawing of Chesapeake Light Tower structure elevations.

The U.S. Coast Guard will continue to maintain its aids to navigation and access for such maintenance, and the National Data Buoy Center will continue to maintain its Coastal-Marine Automated Network (C-MAN) metocean station, which included an anemometer that has been measuring wind speed and direction at an elevation of 43 m above sea level since 1984.

The CLT also serves as an instrumented validation site for satellite measurements of cloud and aerosol microphysics by NASA Langley Research Center (LaRC). The platform is small enough that its "island effect" is negligible, which makes it an excellent site for ground-truth validation of satellite measurements over the ocean (Reference30).

Until now, the Coast Guard has contracted structural inspections every two years at an estimated cost of $50K per inspection. DMME and the City of Virginia Beach have on file the two most recent inspection reports from 2006 and 2008, as well as the most recent underwater survey from 2004. NASA-LaRC performs annual inspections for health and safety and undertakes minor repairs to railings and footings as necessary, roping off any unsafe areas.

Boat access was disabled when the landing and stairwell were carried off by Hurricane Isabel in 2003. As of September 2009, the Coast Guard was understood to have budgeted funds to replace the boat landing and stairwell.

Access is now possible only by helicopter. Due to deterioration of some supporting structure found in the Coast Guard's 2008 inspection, only helicopters lighter than 9,000 lb are permitted to land. The cost of structural repairs in 2008 was estimated to be $1.2 million.

On April 7, 2010, NASA-Langley researchers and representatives from DMME, VCERC, and the City of Virginia Beach discussed that the City was in the best position to move forward with beneficial public use of the CLT. Under 40 U.S.C. 545 (b) (8), the GSA is negotiating sale of the CLT to the City of Virginia Beach. The City's intended use of the platform for possible location of an air traffic control radar repeater ("gap filler") station is entirely compatible with our recommended outfitting of the CLT as an offshore wind research platform for possibly hosting a wide variety of different instruments, including not only metocean instrumentation but also avian detection and tracking radar, shipping vessel traffic monitoring radar, and lightning detection sensors. The City is in ongoing discussions with GSA on the surplussing of the CLT and with the Department of Defense on use of the CLT for gap filler radar.

It appears that the governing regulation for construction and operation of the CLT (including subsequent modifications by the Coast Guard) has been the "Rivers and Harbors Appropriation Act of 1899". Section 10 of this Act (33 U.S.C. 403) delegates authority to the U.S. Army Corps of Engineers (ACOE) for review and regulation of certain structures and work that are located in or that affect navigable waters of the United States. The OCS Lands Act extends the jurisdiction of the ACOE, under Section 10, to the seaward limit of Federal jurisdiction.

It also appears that the GSA statement about ACOE regulatory jurisdiction of new uses is derived from this authority. Therefore, any modifications to the CLT, such as installation of a tall anemometry mast, or research activities adjacent to that structure (such as mooring a buoy-based vertical-profiling LIDAR to be calibrated by the tall anemometry mast), could be regulated by the ACOE and may require a Section 10 permit.

Given this regulatory status, BOEMRE will not require that Virginia obtain a right-of-use and easement (RUE) under Subpart J (Rights-of-Use and Easement for Energy and Marine-Related Activities Using Existing OCS Facilities) of the "Renewable Energy and Alternate Uses" rule.

BOEMRE's statutory authority for Subpart J is paragraph 8(p)(1)(D) of the OCS Lands Act (43 U.S.C. 1337(p)(1)(D)). Under this authority, as delegated by the Secretary of the Interior, the then-MMS (now BOEMRE) "may approve activities that use, for energy or other marine-related purposes, facilities that are currently or were previously used for other activities authorized under the OCS Lands Act." The BOEMRE rule also states that Subpart J does not apply to those activities authorized by another statutory authority or other applicable law. We believe that the CLT falls in this latter category, based on its history and original primary function as a Coast Guard aid to navigation, and therefore Subpart J would not apply. BOEMRE has confirmed this interpretation and will not impose any other requirements beyond the regulatory jurisdiction already held by the Corps of Engineers.

V. Recommended VOWDA Metocean Data Collection Program

Phase I: Conventional Anemometer Mast and Fixed Vertical-Profiling LIDAR on the CLT

Phase I would install a new self-supporting mast on the Chesapeake Light Tower (CLT) to measure wind velocities with both mechanical and ultrasonic conventional anemometers at 45m, 60m, and 75m above sea level. This would be contingent on determining that the existing CLT structure can accommodate such a tall mast. The ability to conventionally measure winds up to notional turbine hub heights of 90 or 100 m will be constrained by having no ability to guy the tower (due to helicopter landing requirements). The new mast will have to be self-supporting, based on either the helicopter deck (which is 84.3 ft or 25.7 m above sea level) or the lantern platform (which is 111.4 ft or 34.0 m above sea level).

Rough-order-of-magnitude cost estimates for this multi-level anemometry system range from $300K (to reach 75 m) to $500K (to reach 105 m). Note that the cost of a fixed vertical-profiling pulsed LIDAR, such as the WindCube or Galion, is roughly the same as the cost difference between a 75 m mast and a 105 m mast. Based on European test results that show good accuracy and repeatability for these pulsed LIDAR profilers (References 19, 20, and 26), we recommend that Phase I consist of installing a shorter met mast on the CLT with conventional anemometers (individually calibrated and traceable) at 45 m, 60 m, and 75 m above sea level. In addition and at the same time, we recommend also installing a pulsed vertical-profiling LIDAR adjacent to the mast, measuring winds at targeted heights of at least 45 m, 60 m, 75 m, 90 m, and 105 m. If the LIDAR unit is not restricted to just five target heights, then measurements also should be made at 120 m, 135 m, and 150 m above sea level. If the LIDAR unit has a great enough range, then targeted heights of 165 m and 180 m also should be measured, giving a total of ten heights, which is within the capability of at least one commercial system.

This Phase I setup will give Virginia a vertical profile baseline to begin correlating with the climatological archive at the NOAA C-MAN station that has been measuring winds at 43.3 m above sea level since 1984. After six months of operation, this should be enough to perform an analysis of optimal rotor swept area to identify appropriate turbine makes and models well matched to the vertical profile of offshore wind speeds on Virginia's OCS. Phase I should be targeted for installation on the CLT in the second quarter of 2011, such that six months of data would be available for analysis in the last quarter of 2011.

Phase I also will serve as a fixed baseline set of conventional and fixed LIDAR vertical profiles for verifying the accuracy of floating buoy-based vertical-profiling LIDARs and also verifying the accuracy of fixed volume-scanning LIDAR at large horizontal offset ranges. These would be major steps that have not yet been taken, which would greatly advance industry's ability to accurately assess the offshore wind resource at many locations around an offshore project site.

Recall that the WaveSentinel buoy-based vertical-profiling LIDAR was compared with a fixed vertical-profiling LIDAR located 750 m away. It is unknown what type of fixed LIDAR was used for this comparison and whether it had been calibrated with cup anemometers before and after these trials. Phase I will give Virginia a calibration site in waters immediately adjacent to the CLT for supporting the development of new buoy-based vertical-profiling LIDARs as well as customer acceptance testing of existing systems such as the WaveSentinel and the SeaZephIR.

Phase II: Installation of a Fixed Volume-Scanning LIDAR on the CLT

Volume-scanning WindTracer performance has been verified only at inland locations. These have shown effective ranges of 15 to 25 km in the clear mountain air of Colorado, although many details of these tests have not been published.

Sea haze and humidity provide more aerosols for light reflection and a strong signal-to-noise ratio, they also increase the atmospheric extinction coefficient for the laser beam. The head of the LIDAR group at NASA-Langley suggests that 10 km (rather than 25 km) be considered as our likely effective mapping range for volume-scanned wind velocities. This is very close to the 11 km monitoring range of avian radar operating in the marine S and X bands..

Even if the effective range for bankable accuracy proves to be only 10 km, this would still give Virginia an affordable asset for measuring offshore wind turbine performance in an actual ocean environment. Virginia can apply to BOEMRE for a Section 238 research lease located at a range of 6 to 8 km southeast of the CLT. These could be used as test pads for the National Offshore Wind Technology Center (NOWTC) under a proposed being developed for the U.S. Department of Energy's Advanced Technology Demonstration Project solicitation, expected to be issued in the first quarter of 2011.

Test pad instrumentation will be needed to measure the incoming wind velocity immediately upwind of the turbine rotors, across the entire span of the rotor swept area. An identical set of measurements will be needed downwind of the turbine rotors, such that the turbine wake and velocity deficit can be characterized at different downwind distances. These data are critical for determining the optimal spacing between turbines in commercial projects and the wake-induced turbulence that rotors and drive-trains must be designed to withstand. As shown in an aerial photo of the Horns Rev 1 wind project off Denmark (Figure 9), wake-induced turbulence can impact turbines at least five rows downwind of the leading upwind row at high wind speeds.

Figure 10 illustrates the two types of instrumentation that could be used to meet the above objectives for the NOWTC test pads. One alternative is to use two calibrated and traceable buoy-based vertical-profiling LIDARs. Based on a recent quote from AXYS Technologies, the cost of a single WindSentinel would be $1.3 million. This does not include ship time or personnel to deploy the buoy, which would bring the cost to $1.5 million. Given a single ship mobilization, two WindSentinel buoys could be purchased and installed for a total estimated cost of $2.8 million.

By comparison, the purchase of a WindTracer is estimated to cost $1.2 million per year, plus $150K per year annual service contract (Reference 31**)**. Installation on the CLT is estimated to cost $200K to $300K. Thus, a fixed volume-scanning LIDAR would cost much less than two WindSentinel buoys. More important for NOWTC operations, such a volume-scanning LIDAR on the CLT could characterize the wakes of multiple test pad turbines at various downwind distances, whereas a WaveSentinel buoy would have to be continually relocated, at considerable cost for ship mobilization and crew time. Regardless of its ability to generate bankable wind resource assessments at extended ranges of 15 to 25 km, a volume-scanning LIDAR on the CLT that can demonstrate such accuracy at ranges of 5 to 10 km would be a key asset for Virginia, giving us a unique advantage in competing for NOWTC funding from DOE and other sources.

Figure 10. Wake turbulence visualized by natural contrail formation at Horns Rev 1. Wind speeds here are much higher, and the wakes correspondingly longer, compared with the ambient velocities shown in the volume-scanning LIDAR image of Figure 6.Source: Reference 32.

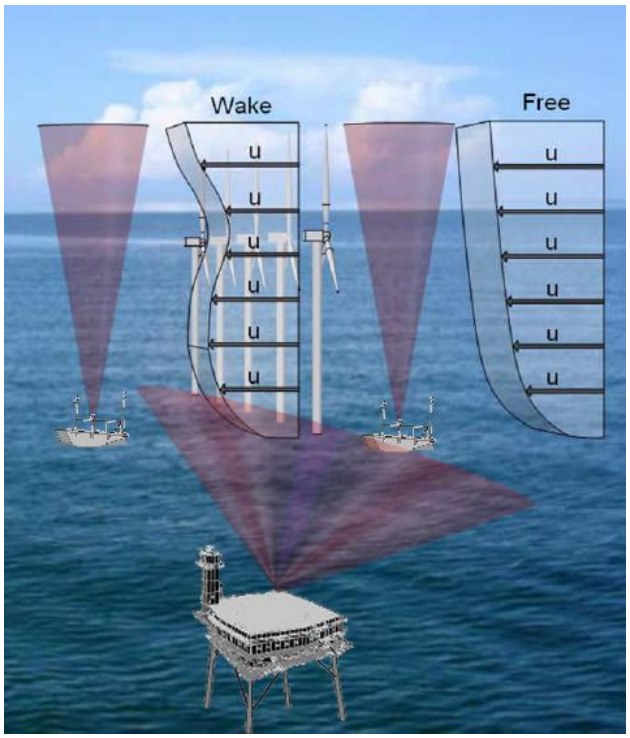

Figure 11. Conceptual illustration of LIDAR instrumentation alternatives for testing offshore wind performance and characterizing velocity-deficit in turbine wakes at NOWTC test pads.

The WindTracer can scan up to ten vertical elevations with a resolution of 10 m for a given horizontal range sweep. NASA LaRC researchers also have developed a volume-scanning LIDAR that is sufficiently light and compact that it can be flown aboard a DC-8 aircraft for characterizing three-dimensional wind fields in a hurricane or severe thunderstorm at a safe stand-off distance (Reference 33).

A budgetary cost estimate has been requested from NASA LaRC for the cost to fabricate a prototype volume-scanning LIDAR for offshore wind mapping to a range of 25 km. Pending receipt of this estimate, such a prototype is assumed to have the same cost as a commercial WindTracer, based on the fact that NASA LaRC already has built similar volume-scanning LIDAR prototypes for its DC-8 field trials and needs to undertake little additional development work for offshore wind application (Reference 34).

Any new design of a volume-scanning LIDAR unit (as well as vertical-profiling LIDARs used in Phase I) should consider survivability and operability during hurricanes and tropical storms, since reliable monitoring of wind speed and direction during these events is critical to effective offshore wind turbine design in the Atlantic Ocean and Gulf of Mexico.

An important aspect of Phase II would be the field testing of a volume-scanning LIDAR unit on the roof of an oceanfront hotel in Virginia Beach. A leading candidate for this might be the Wyndham Hotel at 57th Street and Ocean Front Ave, which has an unobstructed line of sight to the CLT (range 24.6 km, bearing 82.8°) and the existing conventional anemometer masts on the first (range 14.6 km, bearing 308.8°) and third islands (range 18.8 km, bearing 334.1°) of the Chesapeake Bay Bridge Tunnel (Figure 11). This is a 17-story structure surrounded by the residential housing neighborhood, which also gives it unobstructed lines of sight to coastal anemometer masts at Little Creek Amphibious Base, Lynnhaven Fishing Pier, Cape Henry, Dam Neck, and Sandbridge (Figure 12), as well as two inland masts at Norfolk International Airport and Naval Air Station Oceana.

Adding such testing to the cost of a Lockeed-Martin WindTracer or a NASA LaRC prototype unit, paying for installation and initial testing on the roof of the Wyndham Hotel, together with subsequent installation of the same unit offshore on the CLT, the cost of Phase II is estimated to be in the range of $3 million to $3.5 million.

Onshore field testing of a volume-scanning LIDAR unit should begin by the end of the second quarter of 2011, after the Phase I met station has been established on the CLT. Rooftop field tests should be undertaken for nine months, with the unit then being moved to the CLT during the second quarter of 2012, such that it can be established on the CLT by the end of June 2012. This would be followed by mapping and monitoring of the NOWTC test pad area.

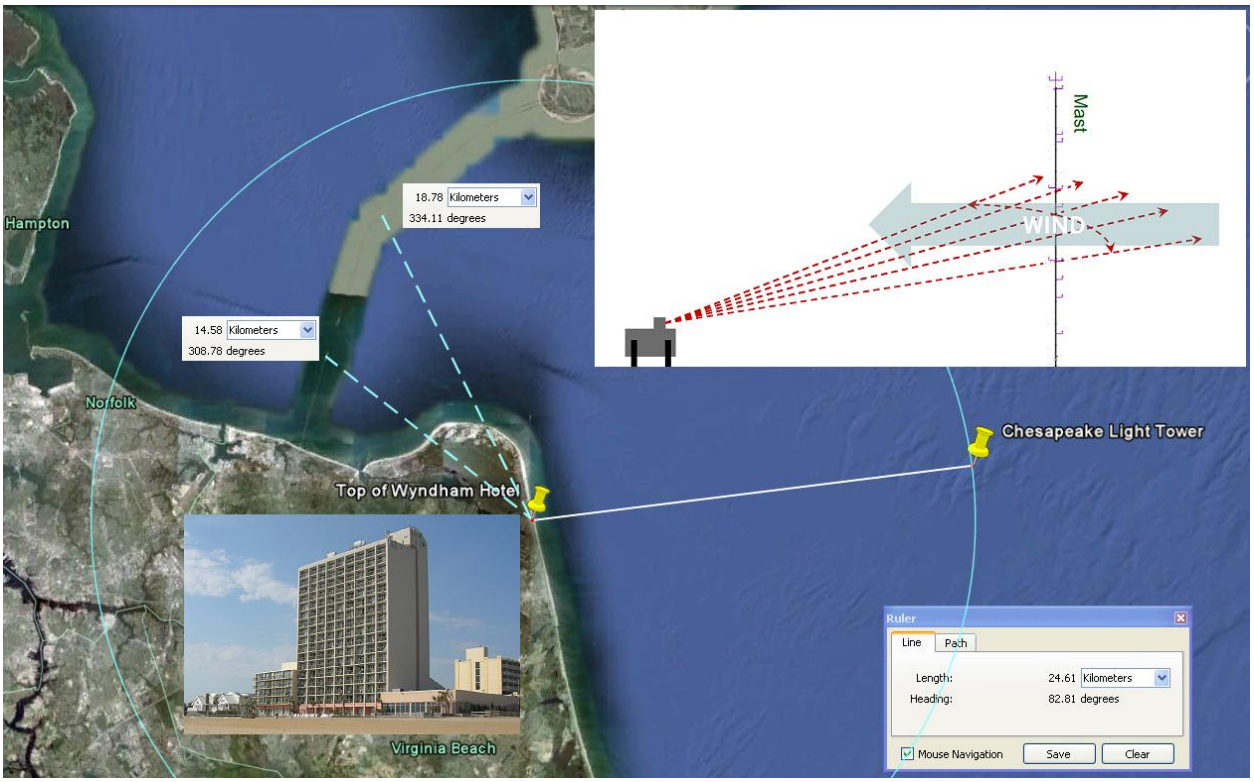

Figure 11. Ranges and bearings from the oceanfront Wyndham Hotel to the CLT and to the first and third islands of the Chesapeake Bay Bridge Tunnel.

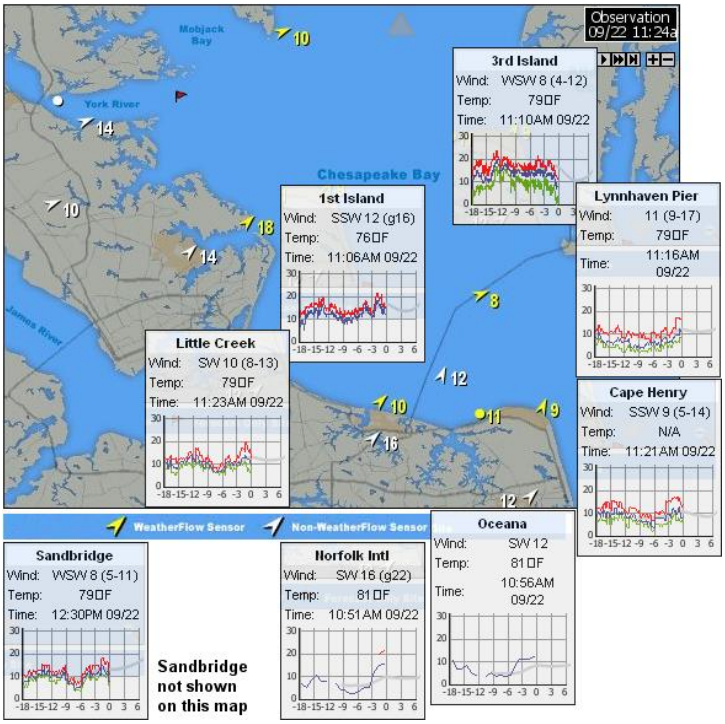

Figure 12. Nine offshore, coastal, and inland anemometer masts within volume-scanning LIDAR range of the Wyndham Hotel roof. In addition, James Madison University has installed a 50 m met mast on the coast at Dam Neck Combat Training Center in south Virginia Beach.

Phase III: Installation of a New Met Tower or Buoy in the Virginia Commercial Lease Area

By early 2012, there should be at least six months of data from the oceanfront hotel field tests of the Phase II volume-scanning LIDAR units, sufficient to determine the range to which they can provide bankable offshore wind measurements for both resource mapping purposes and for turbine field validation of performance curves (power output vs. wind speed plots). At this point Phase III can take the form of two possible scenarios, as follows:

Scenario A: Volume-scanning LIDAR produces bankable wind speed data out to 10 km, and results from tests by others (e.g., Fishermen's Energy) indicate that buoy-based vertical-profiling LIDAR have sufficiently accurate and repeatable motion-correction algorithms that these can provide bankable wind speed data when moored on a project site or adjacent to a test turbine.

> Activities: Move the volume-scanning LIDAR to an appropriate onshore installation site for use at the onshore and near-shore test pads of the NOWTC. Purchase two buoy-based vertical-profiling LIDARs and begin calibrating in waters immediately adjacent to the CLT. Once calibrated, begin moving both buoys around the Virginia commercial lease area, occupying potential project sites for six months at a time to provide bankable offshore wind resource assessments and scientific validation data for numerical metocean models.
>
> Cost: $2.5 million to $3.5 million for purchasing two buoys, installing at calibration site next to CLT, and then moving to four other site locations (two sites per buoy per year).
>
> Timetable: Calibrate buoys the second quarter of 2012. Offshore lease area mapping at four buoy mooring sites (two per buoy) takes place from mid-2012 to mid-2013, at which point buoys are ready for use as NOWTC instrumentation to monitor offshore test pads.

Scenario B: Volume-scanning LIDAR produces bankable wind speed data out to 10 km, but results from tests by others (e.g., Fishermen's Energy) indicate that buoy-based vertical-profiling LIDAR are not sufficiently accurate to provide bankable wind speed data.

> Activities: Move the volume-scanning LIDAR to an appropriate onshore installation site for use at the onshore and near-shore test pads of the NOWTC. Begin permitting process and design activities for a fixed met tower to be sited along the western boundary of Virginia's commercial lease area.
>
> Cost: $4 million to $7 million, depending on type of foundation and the instrumentation that is installed.
>
> Timetable: Begin tower design and permitting activities in the first quarter of 2012. Anticipate installation 12 to 18 months later, such that six months of data would be available for MCP analysis by end 2013.

Note that under Scenario A, the first six months of offshore wind mapping data would be available by December 2012. This should be in time to inform any competitive lease auction that might occur, assuming that Virginia issues its Request for Information (RFI) for commercial offshore lease interests and nominations by the end of 2010. Scenario B could not yield six months of data until the end of 2013. This still would provide bankable data at least one year before any commercial developer could permit, design, and install a tower on a commercial lease and collect six months of data under a competitive leasing process.

Although Scenario A provides the lowest-cost and most quickly available bankable wind resource assessments, neither of them provides a fixed structure within Virginia's commercial lease area. It has not yet been determined whether such a structure will be needed for avian monitoring with S-band or X-band marine radar, which have an effective range of only 11 km (References 35 and 36). Discussions with avian experts and regulatory agencies will be required to determine if marine or other types of radar on the CLT would provide sufficient data to characterize avian activity over commercial lease sites located tens of kilometers farther east.

If the best available science indicates that avian activity is relatively homogeneous across this stretch of ocean area off Virginia, then avian data collected by marine radar on the CLT may be adequate for obtaining permits, particularly with the condition that additional marine radars would be installed in the actual project site for post-construction avian monitoring. Typically, such radars have been installed on offshore substation platforms (for example, see Reference 37).

Phase IV: Installation of a New Met Tower at the Eastern End of Virginia's Lease Area

This phase would have a cost of $4 million to $7 million, depending on the type of foundation and instrumentation that is installed. This would enable Virginia to have a more complete offshore wind map of its commercial lease area. Figure 13 shows the recommended Section 238 research lease that VOWDA could obtain to implement the program recommended in this report. These possible Section 238 leases are identified to the nearest aliquot, which is 1/16 of a lease block and the smallest unit that BOEMRE will lease. The three recommended research leases mapped in Figure 13 are as follows:

- The three aliquots located southeast of the CLT would be for NOWTC Stage III turbine test pads.
- The single aliquot at would be the site of a fixed, horizontal-scanning LIDAR for Stage III, Scenario B, which would provide real-time imaging of the wind velocity field in the western portion of Virginia's commercial lease area, as well as a fixed platform for avian monitoring via S-band or X-band marine radar.
- The single aliquot at would be the site of a fixed, horizontal-scanning LIDAR for Stage IV, which would provide real-time imaging of the wind velocity field in the far eastern portion of Virginia's commercial lease area, as well as a fixed platform for avian monitoring via S-band or X-band marine radar.

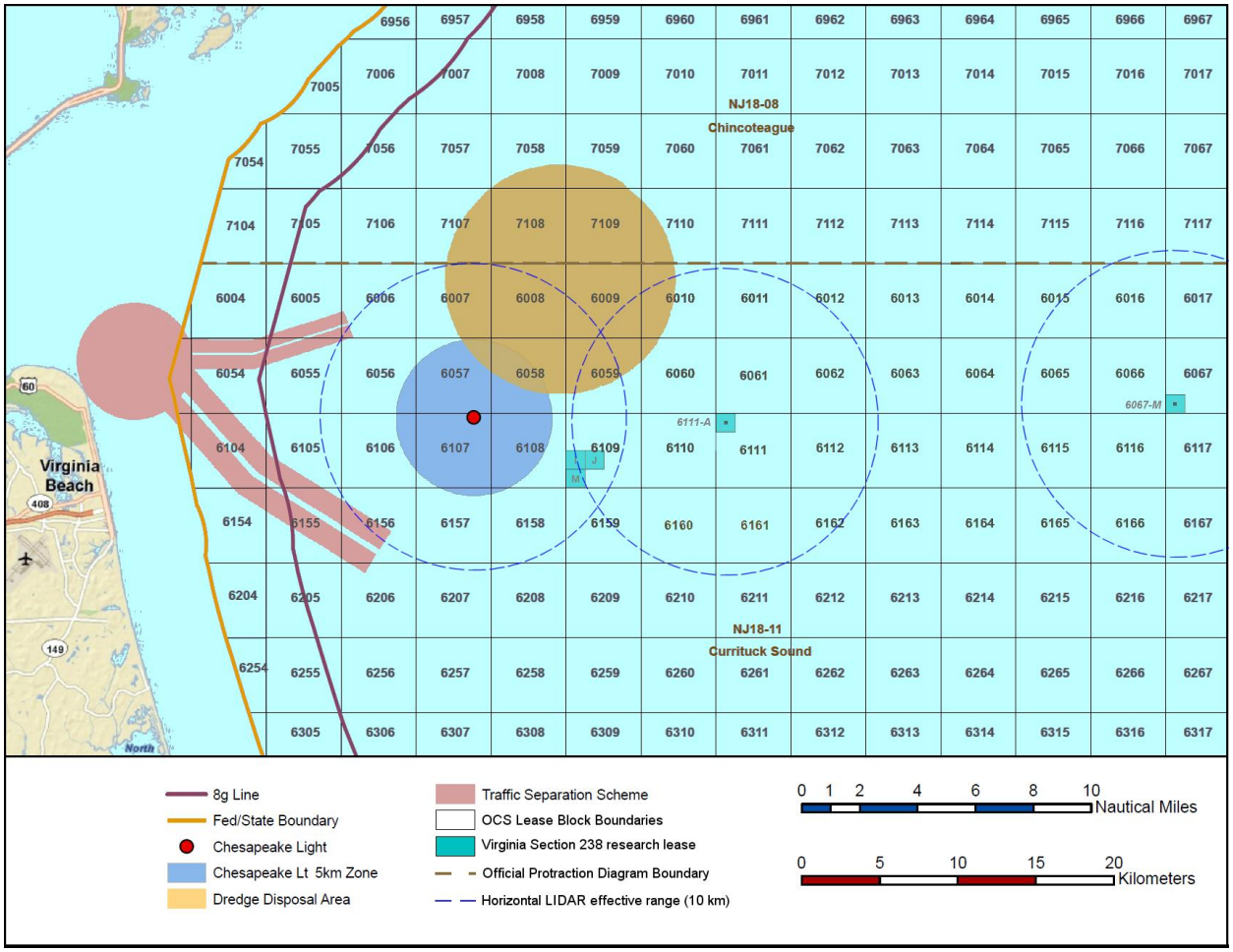

Figure 13. Virginia offshore wind RFI area, showing possible Section 238 research leases

Overall Budget Possibilities

The first two phases of the recommended program consist only of new equipment to be installed on the CLT, costing $500K for Phase I and up to $3.5 million for Phase II for a total budget of $4 million covering the first two phases.

Depending on early results from the second phase, Phase III could cost as little as $2.5 million or as much as $7 million. If Phase II is successful in demonstrating the ability of volume-scanning LIDARs to obtain bankable wind measurements at a horizontal offset distance of up to 10 km (Scenario A), then Phase III could cost up to $3.5 million. Under this scenario, Virginia could have six months of bankable offshore wind resource data over its potential first-round leasing area by December 2012, at a total cost of $5 million to $7 million, and also have an established volume-scanning LIDAR for its proposed near-shore and onshore test pads of the NOWTC.

If buoy-based vertical-profiling LIDARs prove to be inadequate for obtaining bankable accuracy (Scenario B), then Phase III must install a new met tower in Virginia's lease area, at a cost of $4 million to $7 million. This would bring the total cost of all three phases to a total ranging from $8 million to $11 million, with the first six months of bankable offshore wind data not available until December 2013.

Phase IV would cost an additional $4 million to $7 million, bringing the total program cost to a range of $9 million to $14 million.

Note that even if Phase II verifies the long-range bankable wind measuring accuracy of volume-scanning LIDARs, regulatory requirements for avian monitoring over offshore project sites may require a new fixed tower be installed to support marine radar monitoring well east of the CLT. In this case, Virginia could still have six months of bankable offshore wind resource data over its potential first-round leasing area by December 2012, at a total cost of $5 million. An additional $4 million to $7 million would still be needed for the new tower, which could serve as a useful long term re-calibration point for the volume-scanning LIDAR on the CLT. In this case, when combined with a similar tower installed for Phase IV, the total budget for the entire program could be as high as $19 million. It will be important to have the best science-based consensus to inform this decision, which will be based on whether avian monitoring is required directly within offshore project sites or whether CLT-based avian monitoring from tens of kilometers away will meet regulatory and environmental permitting requirements.

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