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Virginia Offshore Wind Studies, July 2007 to March 2010: Final Report

Virginia Coastal Energy Research Consortium

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Final Report

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The Primary Author is solely responsible for any omissions or errors contained herein.

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ACKNOWLEDGEMENTS

The work of the Virginia Coastal Energy Research Consortium (VCERC) would not have been possible without the creation of VCERC by the Virginia Energy Plan legislation introduced by state Senator Frank Wagner during the 2006 General Assembly session, and the subsequent monetary support of $1.5 million provided by the state's General Fund, as legislated in the 2007 General Assembly session through budget amendments sponsored by Senator Frank Wagner, Senator Edward Houck, Delegate Phillip Hamilton and Delegate Leo Wardrup. Despite statewide budget cuts that reduced the initial appropriation by 11%, this inaugural funding from the Commonwealth enabled us to assemble a strong offshore wind team and begin research on our three core offshore wind projects.

Governor Timothy Kaine included VCERC in his FY 2008/2009 biennium budget request for a total of $1.5 million to be divided between the two years. During its 2008 legislative session the General Assembly generously agreed to move the second year of funding up, to be combined with the 2008 request in order to maintain level funding of VCERC so that work could continue uninterrupted on the projects initiated in the previous fiscal year.

Through the state legislative and executive actions described above, the VCERC offshore wind program has received two full years of support from the General Fund, starting 01 July 2007 and ending 30 June 2009, with a no-cost time extension to 30 September 2009. For twelve months preceding that, when VCERC had been created but not funded, the core wind researchers at SAIC, VT-ARI, ODU, and JMU received varying degrees of internal support from their home institutions. During the last six months, from 01 October 2009 to 31 March 2010, the VT-ARI offshore wind team also was supported by internal funding. This generous financial support by VT-ARI Director Saifur Rahman has made it possible for the primary author to compile this 42-month body of work into a single final report that integrates our three offshore wind projects. I am grateful for his support, the financial support of the Commonwealth of Virginia, and the tremendous research contributions by all of the individuals and organizations acknowledged below, as well as the leadership of VCERC Executive Director Patrick Hatcher.

The offshore wind research results reported herein were based on a truly collaborative effort performed by VCERC members and industry partners, who worked together in a very collegial fashion. The three project focus areas were closely interrelated and constant communication and cooperation was needed to make sure the final product was a truly integrated report. Such close collaboration has enabled us to complete one of the most comprehensive assessments to date of a state's offshore wind economic feasibility and associated resource and job creation potentials.

For the Project 1 economic feasibility assessment of a hypothetical offshore wind farm design, we had considerable support from several departments and centers at Old Dominion University (ODU). Basic meteorological and oceanographic data were developed by Larry Atkinson and Jose Blanco of the Center for Coastal Physical Oceanography (CCPO). Monopile foundation design calculations were performed by David Basco and Scott Wiesner of the Department of Civil Engineering's Coastal Engineering Center. Optimization and design of the electrical system, including array cables and export cable for transmitting power to shore were performed by Shirshak Dhali and Mahidhar Nandigam of the Electrical and Computer Engineering.

Additional contributions to the Project 1 design effort include cable shore crossing evaluation by ODU student Gregory Hodges while working as an intern for Science Applications International Corporation (SAIC), and geospatial data on water depth and sediment grain size distributions within our hypothetical project footprints by Remy Luerssen of James Madison University (JMU). Matthew Unger of the Virginia Tech Advanced Research Institute (VT-ARI) integrated all of the ODU and JMU inputs as well as actual maritime industry supply chain cost estimates provided by Tim Wilkins of Paliria Energy, Inc., resulting in a realistic offshore wind cost and performance model. Matthew Unger of VT-ARI also developed a project financing model for estimating the levelized cost of energy for the VCERC offshore wind reference baseline design and for new fossil fuel generation project designs.

Sarah Karpanty of Virginia Tech's Department of Fisheries and Wildlife Sciences surveyed avian data sets relevant to potential siting of offshore wind projects along the Virginia coast. With funding support from this project, she also is engaged in an innovative field trial of satellite imagery for gathering seabird data. VCERC will issue a report on those results in June 2010.

The Project 2 mapping and geospatial analyses of offshore wind resources and potential conflicts were led by Jonathan Miles, Remy Luerssen, and James Wilson of James Madison University. Geospatial data for this project were compiled by the JMU team, with important data inputs and mapping support from Julie Herman of the Virginia Institute of Marine Sciences; Mark Swingle of the Virginia Aquarium & Marine Science Center; Jay Odell, Chris Bruce, and Gwynn Crichton of The Nature Conservancy; Nick Meade of the Virginia Coastal Zone Management Program, Wayne Johnson of the NASA Wallops Flight Facility; and Donna Heimiller and Marc Schwartz of the National Renewable Energy Laboratory (NREL). Matthew Unger of VT-ARI estimated annual energy outputs for the NREL wind class regimes. Tony Watkinson of the Virginia Marine Resource Commission provided the maps reproduced in Figures 14 and 15.

Project 2 also involved considerable individual engagement of many different stakeholders, including environmental groups, Navy commands, commercial interests in the coastal recreation and tourism industry, and local civic groups. This effort was (and continues to be) ably led by Neil Rondorf of SAIC Maritime Operations, with support from ODU student interns Gregory Hodges and Justin Turner. As a JMU adjunct faculty member, Don Giecek contributed strongly to this effort and made vital introductions. Additional outreach activities developed for K-12 and informal science education venues were planned and conducted by Remy Luerssen of JMU and Jose Blanco of ODU's CCPO. This broad spectrum of private engagement and public outreach activities has been critical to VCERC's success and a generally favorable view toward offshore wind that many stakeholder groups now hold at the state and local level.

Our Project 3 assessment of job creation and economic development potential was led by Tim Wilkins of Paliria Energy, Inc., based on an analysis concept formulated in collaboration with Macki Sissoko of Norfolk State University. In order to ensure consistency between Projects 1 and 3, supply chain labor analyses from European offshore projects were scaled to our baseline design by Matthew Unger of VT-ARI, based on man-hour tables and NAICS codes provided by Paliria Energy, Inc. We gratefully acknowledge Greg Grootendorst of the Hampton Roads Planning District Commission (HRPDC) for these labor estimates into its implementation of the Regional Economics Models, Inc. (REMI) Policy Insight model.

Before publication, this report was reviewed by several experts outside the group of research contributors named above. Outside reviewers who provided particularly helpful comments that significantly improved the quality of this report were Steve Walz, Director of the Virginia Department of Mines, Minerals and Energy; Laura McKay, Virginia Coastal Zone Management Program Manager; Ted Fasca, Manager of Generation System Planning for Dominion Virginia Power; and Harold Adams, former Project Director, Business Development, for Dominion Resources Services, now working as a consultant for Downes Associates. Inc. Thanks also to Steve Fegley of the University of North Carolina at Chapel Hill (UNC-CH) Institute of Marine Sciences for his review of the "*Environmental Effects*" section, which derived much of its information from the UNC-CH June 2009 report on North Carolina's offshore wind energy potential. The assistance of these five individuals is gratefully acknowledged, but this report does not reflect any policies, views or opinions of their respective organizations.

Kenneth Newbold, Program Manager for the VCERC Virginia Wind Energy Center at JMU, provided a fresh reading of the entire report, catching errors that survived many cycles of revision. Elizabeth Unger edited the final product for spelling and grammar.

Due to the severe economic recession in Virginia and nationally, further funding of VCERC in 2009 and 2010 was not considered by the General Assembly. Even so, the VCERC offshore wind program can be credited with recent outcomes beyond the production of this final report. Virginia's substantial offshore wind resources have been described in many public presentations throughout the past three years as its characteristics became better understood. This has led to two commercial developers of potential offshore wind projects submitting unsolicited lease applications to the Minerals Management Service, the U.S. Department of Interior agency responsible for overseeing the commercial development of this resource in federal waters.

Commercial interest also has prompted establishment of the Virginia Offshore Wind (VOW) Coalition, which brings together project developers, wind turbine manufacturers, other supply chain industries, electric utilities, and local government interests to help stand up this new industry and make Virginia an east coast leader in offshore alternative and renewable energy. The VOW Coalition already has had a positive influence during the 2010 General Assembly in their strong support of legislation creating the Virginia Offshore Wind Development Authority, as described in the "Government Policy Roadmap" section of this report.

In the short time since his new administration has been in place, Governor Robert McDonnell has shown strong willingness and leadership to encourage the development of energy-related industries that create new jobs and economic opportunities in Virginia. His meeting with Secretary of the Interior Ken Salazar and other Mid-Atlantic governors on offshore wind issues in February of 2010 indicates a solid commitment to Virginia's offshore wind energy future. The Virginia Coastal Energy Research Consortium offers this report as an information resource to further these initiatives and looks forward to working closely with the Governor, his Cabinet and staff as development of Virginia's offshore wind resources moves forward from here.

George Hagerman
Primary Author

EXECUTIVE SUMMARY

Feasibility-Level Design and Economic Assessment

For investor-owned utilities in Virginia, balance-sheet financing of new generation projects having an in-service date of 2012 and an installed capacity just under 600 MW yields the following levelized cost of energy (LCOE) estimates, in constant March 2008 dollars:

- $105-130 per megawatt-hour (MWh) for an offshore wind farm
- $85-100 per MWh for a coal-fired plant
- $80-100 per MWh for a combined-cycle gas turbine (CCGT) plant.

The above LCOE estimates do not include carbon capture and sequestration (CCS) as potential added costs for fossil fuel projects. Assuming that CCS has a levelized cost of $50 per ton of carbon dioxide (tCO_2) over the service life of a generation project commissioned in 2012, with emission rates of 1.0 tCO_2 per MWh for a coal-fired project and 0.4 tCO_2 per MWh for a CCGT project, then levelized electricity costs would increase to $135-150 per MWh for coal-fired generation and $100-120 per MWh for CCGT generation. Thus, *when CCS has a levelized cost of $50 per tCO_2 utilities can anticipate that a new offshore wind project will yield a lower energy cost than a new coal-fired project, and may be marginally competitive with a new CCGT project.*

VCERC's offshore wind cost model has been validated with data from actual large offshore wind projects in Europe for three major cost centers that account for 80-85% of the total project cost: wind turbines, submarine power cables, and monopile foundations. *This supports our estimate that offshore wind projects can be built off Virginia at a cost of $3,000 to $3,600 per kilowatt.*

A recent forecast of wholesale power prices in the PJM regional electricity market indicates that nominal-dollar on-peak and off-peak prices will more than double by 2018, and triple by 2028. Based on this forecast, our estimated LCOE for utility-generated offshore wind is unlikely to be competitive with purchased power before 2017. This is consistent with our mid-range estimate of the first year when a several-hundred-megawatt offshore wind project could become fully operational in federal waters off Virginia, based on European offshore wind experience for similarly sized projects and even the most optimistic U.S. federal permitting scenarios.

The greatest downside risk in our offshore wind energy cost estimates is the large uncertainty associated with the vertical distribution of wind speeds, which yield a standard deviation in the range of 20% to 25% in annual energy generation estimates at hub height. *This can be mitigated by an aggressive program of wind resource modeling validated by tall mast wind measurements.*

The greatest upside opportunity for reducing the cost of offshore wind energy in Virginia is to attract major elements of a Mid-Atlantic offshore wind supply chain to the state. These would include turbine assembly plants in Hampton Roads, having large component staging areas on deep-water wharves with unconstrained access to the open ocean, being fed by 1st- and 2nd-tier suppliers in Virginia and neighboring states. Virginia's existing shipbuilding capabilities also would be leveraged to fabricate large steel components. *If the turbine and tower package was manufactured in Virginia, we estimate that the capital cost of an offshore wind project would decrease by $480 per kilowatt, yielding a LCOE range of $90 to $115 per MWh.*

Preliminary Mapping of Offshore Areas

By working collaboratively with many organizations, James Madison University has compiled a large geospatial database of more than 25 different data layers. Organizations that contributed data and/or shape files to this VCERC project included the U.S. Minerals Management Service, the U.S. National Renewable Energy Laboratory, the U.S. Navy, the Virginia Institute of Marine Sciences, the Virginia Aquarium & Marine Science Center, and The Nature Conservancy.

The Chesapeake Bay and Atlantic state waters within 3 nautical miles offshore are dominated by Class 4 winds, while Atlantic federal waters on Virginia's Outer Continental Shelf (OCS) are dominated by Class 5 and Class 6 winds. The total potential wind farm capacity in Class 5 and Class 6 winds on Virginia's OCS between 3 and 50 nautical miles offshore is 47,900 MW, having a maximum potential annual energy output of 176 million megawatt-hours per year.

Avoiding conflicting uses such as shipping lanes, Navy live-ordnance training ranges, a space launch hazard area, and dredge spoil disposal sites, *VCERC has identified 25 OCS lease blocks of entirely Class 6 winds beyond 12 nautical miles offshore (the approximate visual horizon), in water depths less than 30 m (suitable for commercially available monopile foundations), which could support approximately 3,200 MW of offshore wind farm capacity. Assuming an array efficiency of 89%, these 25 lease blocks could generate 11 million megawatt-hours per year* or approximately 10% of Virginia's annual electricity consumption.

Evaluation of Economic Development Potential

VCERC has identified 25 lease blocks with 3,200 MW of potential offshore wind capacity in relatively shallow Class 6 waters beyond the visual horizon. Build-out of this potential would require a total of 125,000 job-years, including direct, indirect, and induced jobs, assuming that it can be supported by Virginia-based turbine and power cable manufacturing plants. If sustained at a build-out rate of 160 MW per year (equivalent to one 320-MW project being commissioned every two years), this would support 6,200 jobs that could last for a two-decade career. To this would be added operation and maintenance jobs, which are estimated to accrue at 1.1 to 1.7 jobs per cumulative megawatt, reaching 3,500 to 5,400 jobs after the first 3,200 MW of near-term commercial potential off Virginia has been built out over the next 20 years.

Thus, within two decades, 9,700 to 11,600 career-length jobs can be created, solely associated with developing the 3,200 MW of offshore wind potential that VCERC has identified in shallow waters beyond the visual horizon off Virginia Beach. Since offshore foundations and submarine power cables are designed for a service life of 40 to 50 years, a second generation of jobs could be created for simply repowering the first 3,200 MW. Beyond this is a vast, deeper water potential that remains to be developed farther offshore.

Any development of deeper water wind resources farther offshore must manage potential conflicts with routinely expended debris from rocket launches at the NASA Wallops Flight Facility and the Mid-Atlantic Regional Spaceport (MARS). Likewise, the Navy has several training ranges farther offshore that involve live ordnance, which also would be incompatible with offshore wind energy development. The NASA Wallops and MARS launch hazard area and Navy live ordnance training ranges are east of the 25 VCERC-identified lease blocks and so do not represent an impediment to commercial development over the next two decades.

VIRGINIA COASTAL ENERGY RESEARCH CONSORTIUM OVERVIEW AND FUNDING

VCERC Background

The Virginia Coastal Energy Research Consortium (VCERC) was created by the Virginia Energy Plan legislation SB262, introduced by state Senator Frank Wagner and passed into the Code of Virginia under Title 67, Chapter 6, by the 2006 General Assembly. VCERC serves as an interdisciplinary study, research, and information source for the state on coastal energy resources, which include offshore winds, ocean waves, tidal currents, marine biomass, and methane hydrates. VCERC activities include researching and disseminating information about coastal energy resources and the technical and economic feasibility of harnessing them, as well as developing new coastal energy technologies for commercialization. For more information about VCERC visit www.vcerc.org.

VCERC Membership

The five founding academic members named in SB262 are Old Dominion University (ODU), the Virginia Tech Advanced Research Institute (VT-ARI), James Madison University (JMU), the Virginia Institute of Marine Science (VIMS), and Norfolk State University (NSU). This bill also named two state agencies to VCERC: the Virginia Department of Mines, Minerals, and Energy, and the Virginia Marine Resources Commission. SB262 also named two industry groups to VCERC: the Virginia Manufacturers Association and the Virginia Maritime Association.

The 2007 General Assembly added three additional academic members to VCERC through legislation SB841, introduced by state Senator Jeannemarie Devolites Davis: the University of Virginia, Virginia Commonwealth University, and Hampton University. Also named in this bill were two additional industry groups: the Hampton Roads Technology Council and Virginia Clean Cities, represented by the Hampton Roads Clean Cities Coalition. The 2008 General Assembly added the Virginia Department of Environmental Quality, represented by its Coastal Zone Management Program, through legislation (SB1346) introduced by Senator Wagner. The 2010 General Assembly added George Mason University as our newest academic member and directed that the NASA Langley Research Center have non-voting representation on the VCERC Board, through legislation (SB713) introduced by state Senator Chap Petersen.

No private companies are individually represented on the VCERC Board, but the Maritime Operations Division of Science Applications International Corporation (SAIC), based in Virginia Beach, VA, was a motivator for the creation of VCERC and has served as its lead industry partner. Paliria Energy, Inc., of Chesapeake, VA, was a primary supplier of maritime industry supply chain costing and strategies, provided industry outreach, and served as the project lead on evaluating job creation and economic development potential.

VCERC State Funding and Associated Projects

During Virginia's 2006 fiscal year (01 July 2006 to 30 June 2007), ODU, VT-ARI, JMU, and SAIC laid the groundwork for the offshore wind and algal biodiesel studies reported herein, supported entirely by their own internal funding. During Virginia's 2007 and 2008 fiscal years, VCERC received a total of $2.941 million in state support from the General Fund, with better than 1:1 matching support from internal funds and non-state sponsored research contracts.

During Virginia's 2007 fiscal year, state support of $1.341 million enabled VCERC to initiate four major research projects, as follows:

> VCERC Project 1: Feasibility-Level Design and Economic Assessment for a Reference Baseline Offshore Wind Power Project (*VT-ARI responsible for overall direction and integrated report preparation*)
>
> VCERC Project 2: Preliminary Mapping of Offshore Areas Suitable for Offshore Wind Development, with Identification of Excluded Areas to Avoid Potential Conflicts, and Mapping of Offshore Benthic, Pelagic and Avian Habitats (*JMU responsible for overall direction and integrated GIS tool preparation, with support from VIMS*)
>
> VCERC Project 3: Evaluation of Economic Development impact of Commercial Offshore Wind Power Development and Associated Workforce Training and Preliminary Planning for an Ocean Test Bed (*SAIC and Paliria Energy, Inc., responsible for overall direction and integrated report preparation, with support from NSU*)
>
> VCERC Project 4: Feasibility-Level Design and Economic Assessment for an Algae-to-Biodiesel Culture and Processing System (*ODU responsible for overall direction and integrated report preparation*)

During Virginia's 2008 fiscal year, an additional state appropriation of $1.600 million was awarded to VCERC to continue these projects. Due to the late disbursement of FY2008 funds, the performing universities' contract end dates were extended to 30 September 2009. An added six months of support for the VT-ARI team, to March 2010, was provided by internal funding.

The breakdown of total state funding support by project and institution is given in Table 1.

Table 1. VCERC FY2007 and FY2008 Budget Distribution[1] from the General Fund

Offshore Wind	**VA Tech**	**ODU**	**ODU (industry[2])**	**JMU**	**NSU**	**VIMS[3]**	**Total**
Project 1	$400K	$200K	$39K	$42K		$0K	$681K
Project 2	$53K	$84K		$200K		$95K	$432K
Project 3	$20K		$150K	$42K	$117K		$329K
Wind Total	**$473K**	**$284K**	**$189K**	**$284K**	**$117K**	**$95K**	**$1,442K**
Algal Biodiesel		**ODU**	**UVA**	**VCU**	**HU**	**VIMS**	**Total**
Project 4		$1,179K	$100K	$40K	$40K	$139K	$1,498K

[1] VA Tech = Virginia Polytechnic Institute and State University
ODU = Old Dominion University
JMU = James Madison University
NSU = Norfolk State University
VIMS = Virginia Institute of Marine Science
UVA = University of Virginia
VCU = Virginia Commonwealth University
HU = Hampton University

[2] SAIC Maritime Operations and Paliria Energy are ODU industry partners

[3] VIMS supported Project 1 through its normal advisory activities.

OFFSHORE WIND RESEARCH RESULTS

Project 1: Feasibility-Level Design and Economic Assessment

For investor-owned utilities in Virginia, balance-sheet financing of new generation projects having an in-service date of 2012 and an installed capacity just under 600 MW yields the following levelized cost of energy (LCOE) estimates, in constant March 2008 dollars: $105-130 per megawatt-hour (MWh) for an offshore wind farm using 3 MW turbines with 90m diameter rotors, $85-100 per MWh for a coal-fired plant, and $80-100 per MWh for a combined-cycle gas turbine (CCGT) plant (Figures 1 and 2). Project details are given in Appendix A.

The above LCOE estimates for coal-fired and CCGT generation assume the following fuel price scenarios, based on utility forecasts and market futures pricing: coal costing $65 to $70 per short ton in 2012, with a real annual escalation rate of 0% to 2%, and natural gas costing $7.00 to $7.50 per million BTU in 2012, with a real annual escalation rate of 2% to 4%.

The above LCOE estimates do not account for mitigation of carbon dioxide emissions as potential future additional costs for fossil fuel projects. They also do not account for the sale of renewable energy certificates as potential future additional revenue for offshore wind projects.

Carbon capture and sequestration (CCS) is a potential added cost for new fossil fuel projects. Assuming that CCS has a levelized cost of $50 per ton of carbon dioxide (tCO_2) over the service life of a generation project commissioned in 2012, with emission rates of 1.0 tCO_2 per MWh for a coal-fired project and 0.4 tCO_2 per MWh for a CCGT project, then levelized electricity costs would increase to $135-150 per MWh for coal-fired generation and $100-120 per MWh for CCGT generation. Thus, *when CCS has a levelized cost of $50 per tCO_2, utilities can anticipate that a new offshore wind project will yield a lower energy cost than a new coal-fired project, and may be marginally competitive with a new CCGT project.*

A recent paper by the Energy Technology Innovation Policy group of the Belfer Center for Science and International Affairs at Harvard Kennedy School of Business (Reference 1) has estimated the likely representative range of life-cycle costs for carbon capture technologies (excluding transport and storage) as $100-150 per tCO_2 for first-of-a-kind utility-scale plants and plausibly $30-50 per tCO_2 for nth-of-a-kind, production plants (Figure 3).

Although a federally mandated "cap and trade" system may not be passed in the current economic and political climate, a recent report by SAIC for the American Council for Capital Formation and the National Association of Manufacturers (Reference 2) forecasts that under the system outlined in the Waxman-Markey bill, atmospheric carbon emission allowance costs would rise from $20-25 per tCO_2 in 2012, to $50-60 per tCO_2 by 2020 and over $120 per tCO_2 by 2030 (Figure 4).

The sale of renewable energy certificates (RECs) could provide an additional revenue stream for offshore wind projects. In northeastern states with long-standing, binding renewable portfolio standards, recent REC values for 2010 forward bids have been in the range of $6-8 (in NJ) to $25-35 (in CT and MA) per MWh. In DC and MD, however, recent REC values have been well under $5 per MWh (Reference 3).

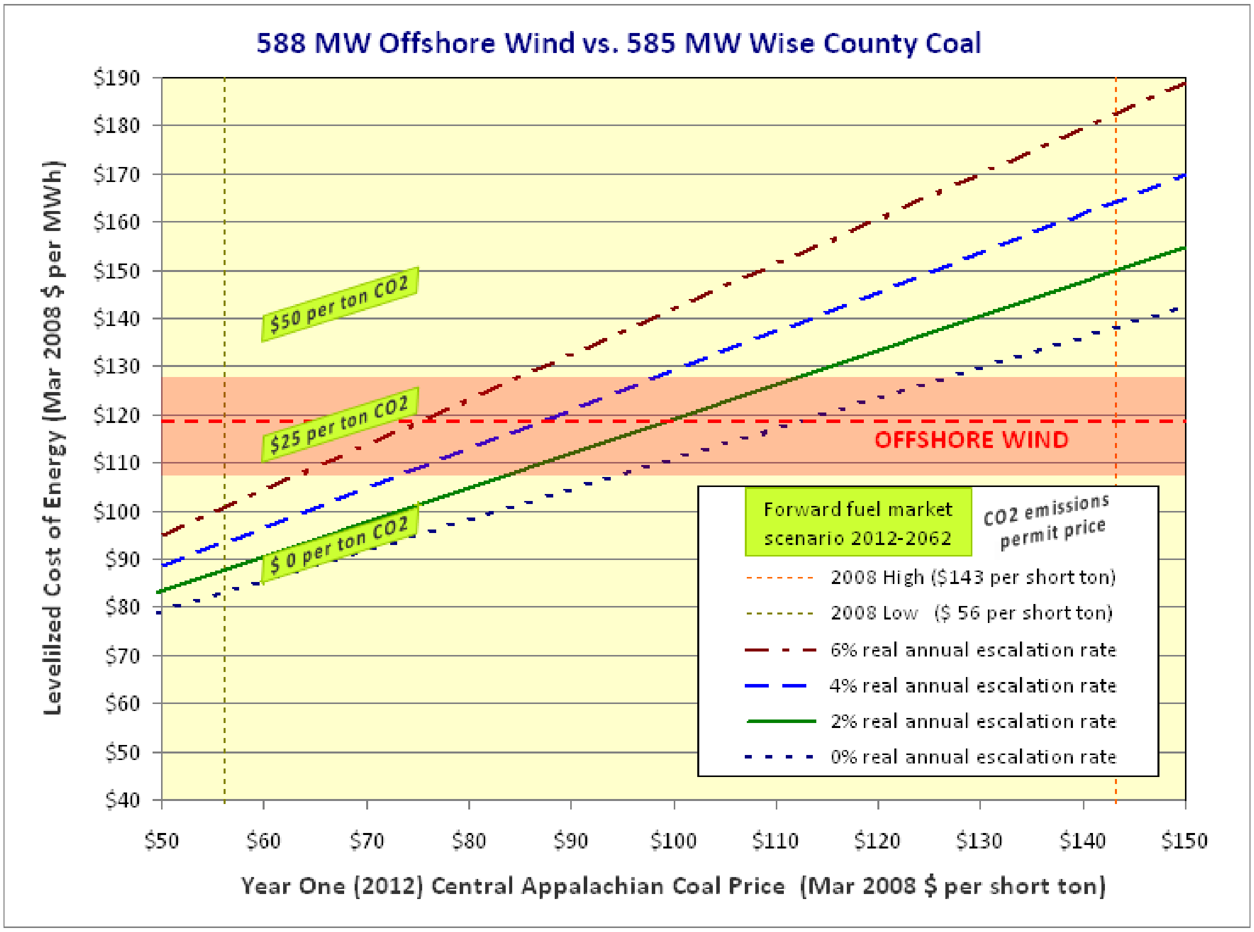


Figure 1. Levelized cost of energy from VCERC hypothetical design of a large offshore wind farm compared with a similarly sized coal-fired generation plant based on Dominion Virginia Power's capital and operating characteristics for a similarly sized project in Wise County, VA.

Our forward fuel market scenarios (lime green parallelograms) assume a coal price of $65 to $70 per short ton in the first year of plant operation (2012), with a real annual escalation rate of 0% to 2%. Three permutations of this market scenario are indicated for carbon emissions permit pricing of $0, $25, and $50 per t$CO_2$, which can be compared with future emissions allowance costs projected in Figure 4. If these are equated to carbon capture and sequestration (CCS) costs, they also can be compared with future carbon capture costs projected in Figure 3.

Vertical dotted lines indicate that in 2008 the cost of coal ranged from $56 to $143 per short ton, showing how fossil fuel price volatility is affected by the global economy.

The horizontal dashed red line represents the annual energy generated at a hub height of 80 m above sea level, for a Vestas V-90 3MW turbine using wind speed data at Chesapeake Light tower (CHLV2), where the wind speed at CHLV2 anemometer height of 43 m above sea level is extrapolated to hub height using a 1/7 power law. The shaded band above and below the red dashed line represents the mid-point spread of other wind shear profile formulations.

See Appendix A for project cost and performance data, as well as project financing parameters.

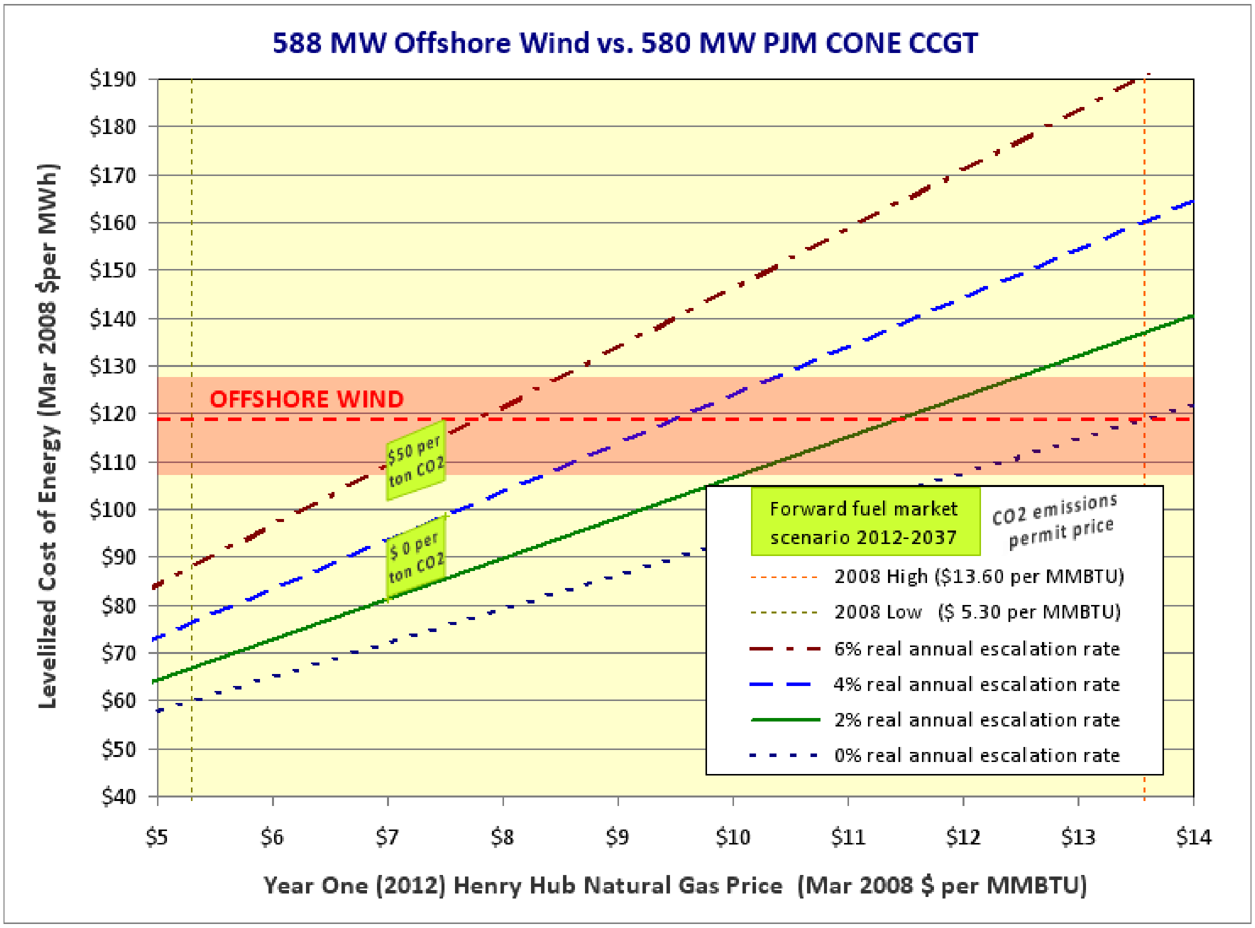


Figure 2. Levelized cost of energy from VCERC hypothetical design of a large offshore wind farm compared with a similarly sized CCGT generation plant based on "Cost of New Entry (CONE) capital and operating characteristics for a similarly sized new project in PJM region.

Our forward fuel market scenarios (lime green parallelograms) assume a natural gas price of $7.00 to $7.50 per million BTU in 2012, with a real annual escalation rate of 2% to 4%. Two permutations of this scenario are indicated for carbon emissions permit pricing of $0 and $50 per tCO_2, which can be compared with future emissions allowance costs projected in Figure 4. If these are equated to CCS costs, they also can be compared with future carbon capture costs projected in Figure 3.

Vertical dotted lines indicate that in 2008 the cost of natural gas ranged from $5.30 to $13.60 per million BTU, showing how fossil fuel price volatility is affected by the global economy.

The horizontal dashed red line represents the annual energy generated at a hub height of 80 m above sea level, for a Vestas V-90 3MW turbine using wind speed data at Chesapeake Light tower (CHLV2), where the wind speed at CHLV2 anemometer height of 43 m above sea level is extrapolated to hub height using a 1/7 power law. The shaded band above and below the red dashed line represents the mid-point spread of other wind shear profile formulations.

See Appendix A for project cost and performance data, as well as project financing parameters.

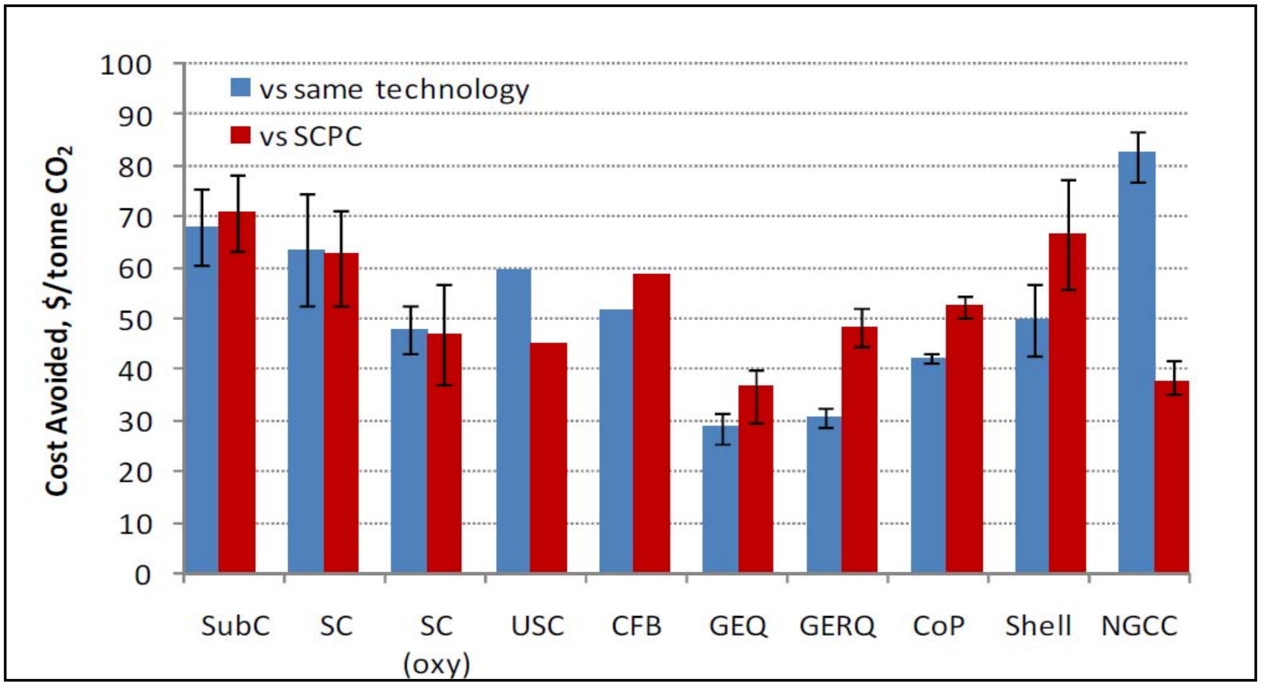


Figure 3. Levelized cost per metric ton of avoided CO_2 for nth-of-a-kind production plants for different types of carbon capture technologies, not including the cost of sequestration. Source: Reference 1, which should be consulted for carbon capture technology abbreviations.

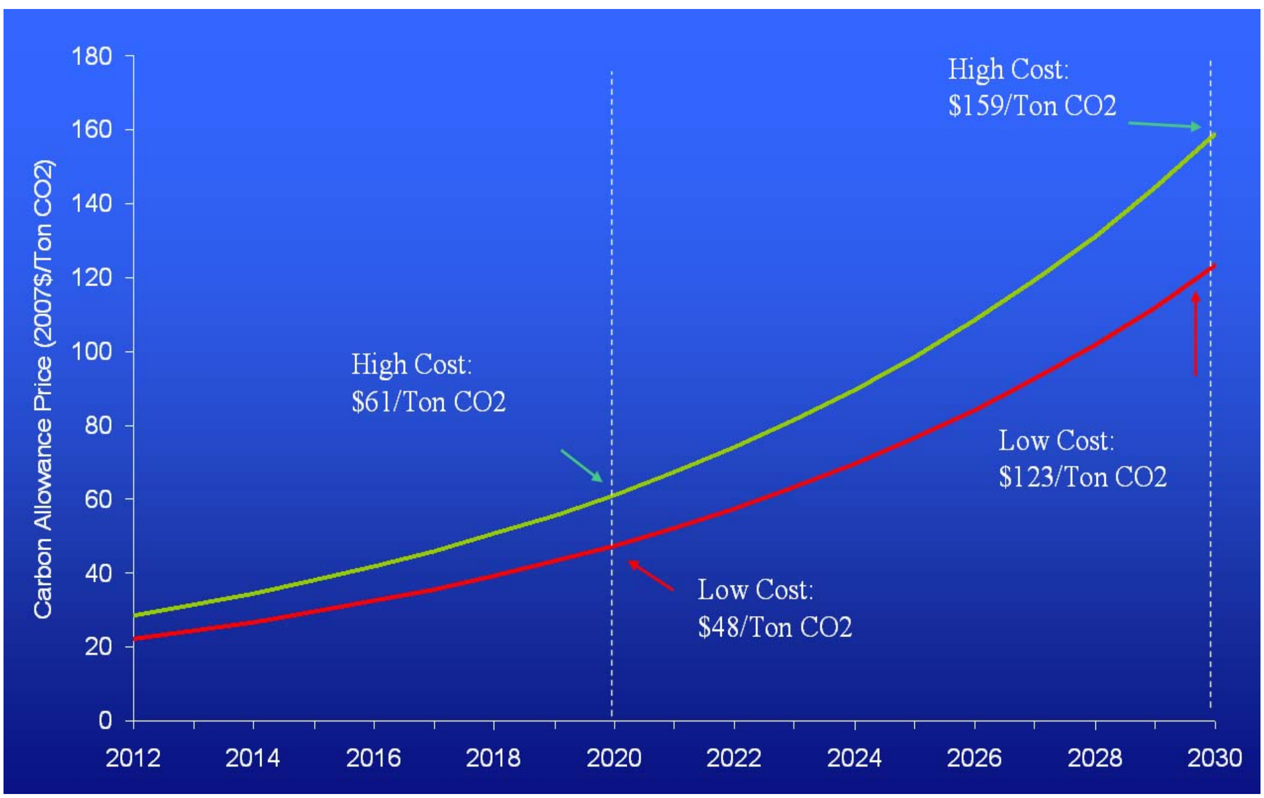


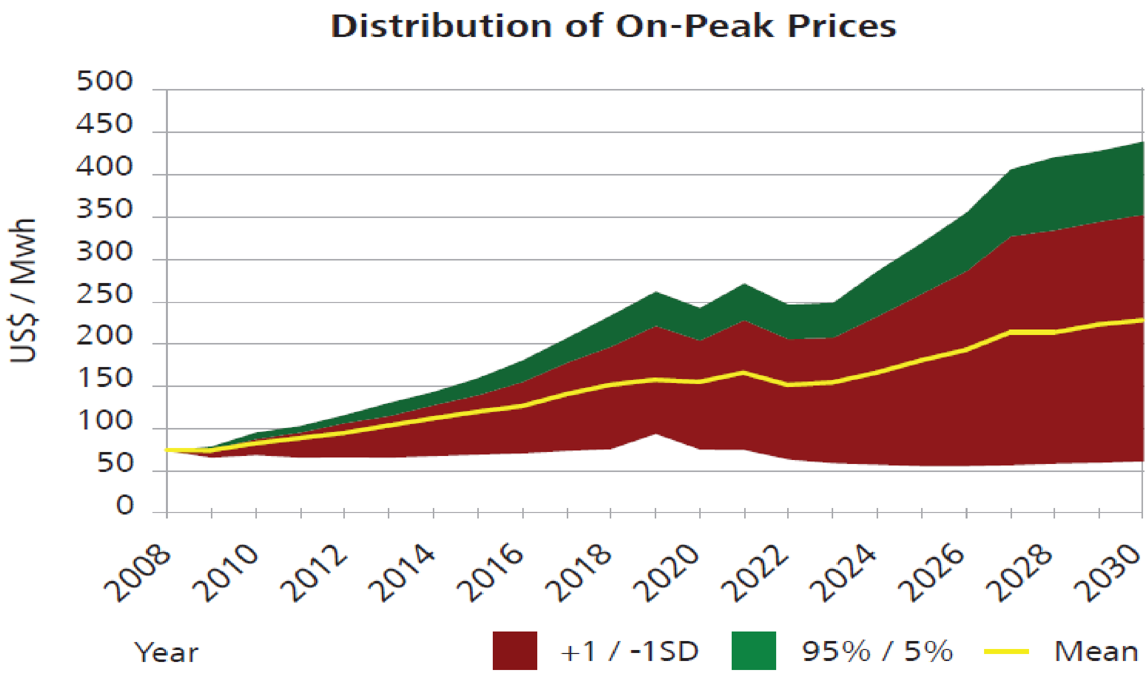
Figure 4. Forecast range of "cap and trade" carbon dioxide (CO2) atmospheric emissions allowance pricing under pending federal legislation. Source: Reference 2.

A recent forecast of wholesale power prices in the PJM regional electricity market indicates that nominal-dollar on-peak and off-peak prices will more than double by 2018, and triple by 2028 (Reference 4). This forecast was published by NERA Economic Consulting, whose case study incorporated multiple uncertainties related to fossil fuel prices, RPS standards, greenhouse gas regulations, load growth and power plant replacement costs. In the case study, each of the key variables had three associated forecasts. This created 729 potential permutations.

The resulting forecast statistical distributions of on- and off-peak prices are shown in Figure 5, derived from 5,000 Monte Carlo simulations where prices in each successive year are dependent on the prices in the prior year (the Markov Chain process). As expected, uncertainty related to the distribution of PJM power pricing increases over time. While there are relatively symmetric distributions at plus and minus one standard deviation, there is an asymmetric distribution in the 5th and 95th percentiles, weighted toward higher wholesale prices driven by upward pressures on the costs of capital, fuel, and carbon emissions, all of which are more likely to increase than decrease over the coming years and decades.

Based on this forecast, our estimated LCOE for utility-generated offshore wind is unlikely to be competitive with purchased power before 2017. This is consistent with our mid-range estimate of the first year when a several-hundred-megawatt offshore wind project could become fully operational in federal waters off Virginia, based on European offshore wind experience for similarly sized projects and even the most optimistic U.S. federal permitting scenarios.

In 2009, Dominion Virginia Power generated 33% its energy from coal, 32% from nuclear, 9% from natural gas, and 1% from oil, meeting the remaining 25% of its customer demand from purchased wholesale power (Reference 5). Given the prevalence of coal and purchased power in Dominion Virginia Power's supply portfolio, carbon-heavy fossil fuel generation in the PJM regional power market, and the likelihood of carbon dioxide emissions regulations in coming years, *there is substantial risk of future energy price increases to eastern Virginia's electricity customers*. Utility investment in offshore wind generation would provide a hedge against such future energy price increases and maintain Virginia as an attractive place for energy-intensive businesses, notably Internet data centers and high-tech manufacturing.



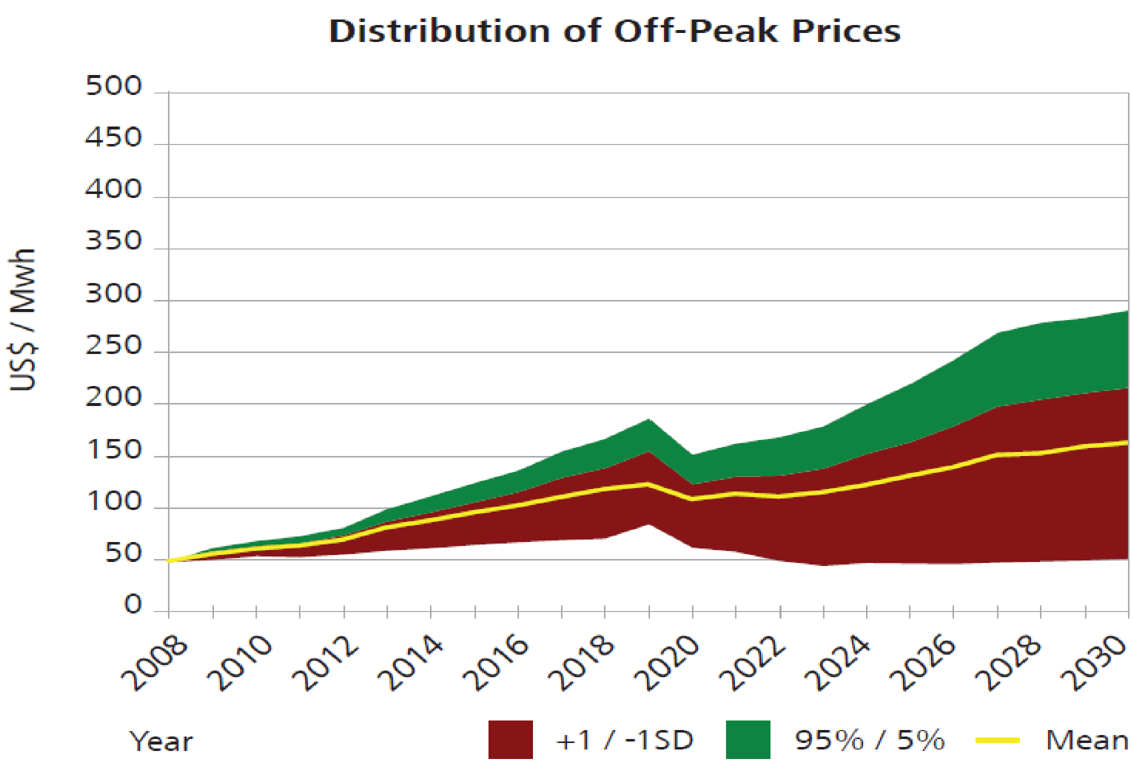


Figure 5. Forecast statistical distribution of on-peak (upper graph) and off-peak (lower graph) wholesale power pricing in PJM market, in nominal dollars, assuming a 2.5% inflation rate. Source: Reference 4.

Validation of VCERC Offshore Wind Cost Model. The three largest cost centers for an offshore wind project are the supply of the turbine-and-tower package, foundations, and submarine export cables, which together account for 85% of the total project capital cost for turbines manufactured in Europe, and just under 80% of the total project cost for turbines manufactured domestically. The following paragraphs compare our model estimates for these three most important cost centers with actual data from large offshore wind projects now being built in Europe.

<u>European Turbine Supply</u>: The VCERC cost model estimates that offshore wind turbines similar to the Vestas V90 3 MW design would cost $2,160 per kW for the turbine-and-tower package if manufactured in Denmark or Germany and ordered in a quantity sufficient to build our reference design. As a validation point, VCERC's modeled estimate is compared with the value reported by for the 630 MW turbine supply contract for Phase I of the London Array (Reference6), which was awarded in the amount of €1 billion to Siemens in May 2009 for 175 turbines having a rated capacity of 3.6 MW, a rotor diameter of 107 m, and a hub height of 87 m. As documented in Appendix B, the currency exchange rate at the time of the London Array turbine contract was $1.36 per €, yielding a turbine order value of $1.36 billion, which amounts to $2,160 per kW, *virtually identical to VCERC's modeled estimate*.

The Siemens rotor swept area is larger than that of the Vestas V90, with consequently larger thrust loads on a somewhat taller tower (our reference design has a hub height of only 80 m), which should have yielded a more costly turbine-and-tower-package. This suggests that our March 2008 turbine cost estimate is conservative, reflecting higher steel prices and the turbine seller's market that existed at that time, rather than the more balanced turbine supply and demand that existed in May 2009, after many turbine orders had been canceled due to the recession.

<u>Foundation Supply</u>: VCERC estimated the dimensions and weight of monopiles and transition pieces appropriate to survive the highest wind speeds and largest waves measured in our study area, and then furnished these to two local marine fabricators in the Hampton Roads region to quote a budgetary supply cost. These averaged $410 per kilowatt for our hypothetical project.

Since foundations would be manufactured locally, European supply contract values would not be appropriate for validation, particularly considering the much higher wages paid in European fabrication yards than in U.S. yards. Instead, we obtained data on foundation material weights and production labor hours for the 300 MW Thanet offshore wind project (Reference 7).

Like our hypothetical design, the Thanet project uses Vestas V90 3MW turbines, with project water depths ranging from 19.5 m to 29.5 m, quite similar to our 20–30 m depth range, but the hub height is only 70 m, resulting in a somewhat lower overturning moment compared with our hypothetical design, but similar base shear.

Thanet's 100 monopiles range in weight from 246 to 515 metric tons, with an average weight of 362 metric tons. The 100 transition pieces have an average weight of 110 metric tons. The total weight of primary steel (welded cans) for the monopiles and transition pieces is 47,391 metric tons. The total weight of secondary steel (access ladders, boat landings, platforms, railings and stanchions, J-tubes, mountings for sacrificial anodes) is 5,000 metric tons. The total weight of all structural steel used in the Thanet foundations is 52,391 metric tons, or 51,564 long tons.

Using a March 2008 steel plate price of $715 per short ton, equivalent to $800 per long ton, and assuming an overhead multiplier of 1.4 and 10% profit, the structural materials contract for the Thanet foundations, if fabricated in Hampton Roads, would be $64.5 million. The cost of marine paint and sacrificial anodes would bring the total materials contract value to $71.1 million.

The estimated labor requirement is 10 hours per long ton of primary steel (highly automated) and 100 hours per long ton of secondary steel (70% for prefabrication and painting of the different secondary steel components, and 30% for the welding of these components to the primary steel structures, blasting and painting of the primary steel structures, and final assembly). This yields a total of 970,400 hours for fabrication. At a yard charge-out rate of $60 per hour, customary for Hampton Roads waterfront facilities, the total labor contract value would be $58.2 million.

If the 300 MW Thanet project foundations were fabricated in Hampton Roads, the total contract value for materials and labor would be $129.3 million, or $431 per kW. *This is 5% greater than the VCERC modeled cost for our hypothetical foundation design, which is reasonably close*.

<u>Submarine Export Cable Supply</u>: There are no high-voltage, armored submarine power cable manufacturing facilities in North America. For Mid-Atlantic projects such cables probably would be sourced from Europe where factories exist in Italy (Prysmian), Germany (NKT), Norway (Nexans), and Sweden (ABB). Note that our cable supply cost center does not include installation but assumes that this would involve contractors from the local maritime economy rather than overseas installers from Europe. Our model embeds cable installation within the total installation cost sector that also includes foundation and turbine installation.

The most complete submarine export cable data available for validating our modeled cost are from the 630 MW Phase I London Array project. In December 2009, Nexans announced that it had received a €100 million contract to design, manufacture and supply four 150 kV XLPE submarine power cables, each 53 to 54 km in length, to be laid in parallel over a 50 km export cable route to the shore substation. Each cable core will consist of three copper conductors with a cross-section of 630 mm^2 for the main length and 800 mm^2 at each cable end. Two cables will be delivered in 2011 and two in 2012 (Reference 8). The installation contract for these cables has been awarded separately, enabling a consistent comparison with our modeled cost.

Applying the currency exchange rate at the time of the December 2009 announcement, this cable supply contract has a value of $143 million. This amounts to $2.67 million per kilometer of export cable route distance. When normalized against project rated capacity this amounts to $4.54 per km per kW. Copper prices in December 2009 were lower than in March 2008, and adjusting for this yields a distance-capacity-normalized cost of $5.48 per km per kW.

Although the VCERC hypothetical project capacity of 588 MW is similar to the 630 MW capacity of the London Array Phase I project, the Nexans export cable is rated for a higher voltage than the VCERC hypothetical design (150 kV vs. 132 kV) and therefore can use a smaller conductor cross-section (630 mm^2 for the main length vs. 800 mm^2 in our design). The VCERC modeled cost for the export cable cost center is $93.1 million, with the same level of redundancy (four cables) over an offshore route distance of 28.6 km. This works out to a distance-capacity-normalized cost of $5.54 per km per kW. *This is only 1% higher than the Nexans value, giving good confidence in the VCERC cost model.*

Domestic Turbine Supply: Because European turbine supply accounts for two-thirds of the VCERC modeled offshore project cost, we also estimated the cost impact of having the turbines manufactured in Virginia, to see what the potential savings might be. This estimate was based on the Lawrence Berkeley National Laboratory (LBNL) annual survey of wind turbine purchase transactions and project costs in the United States during the previous calendar year. Our source report is the “2008 Wind Technologies Market Report” published in July 2009 (Reference 3). The trend in turbine costs over time is plotted in Figure 6, below.

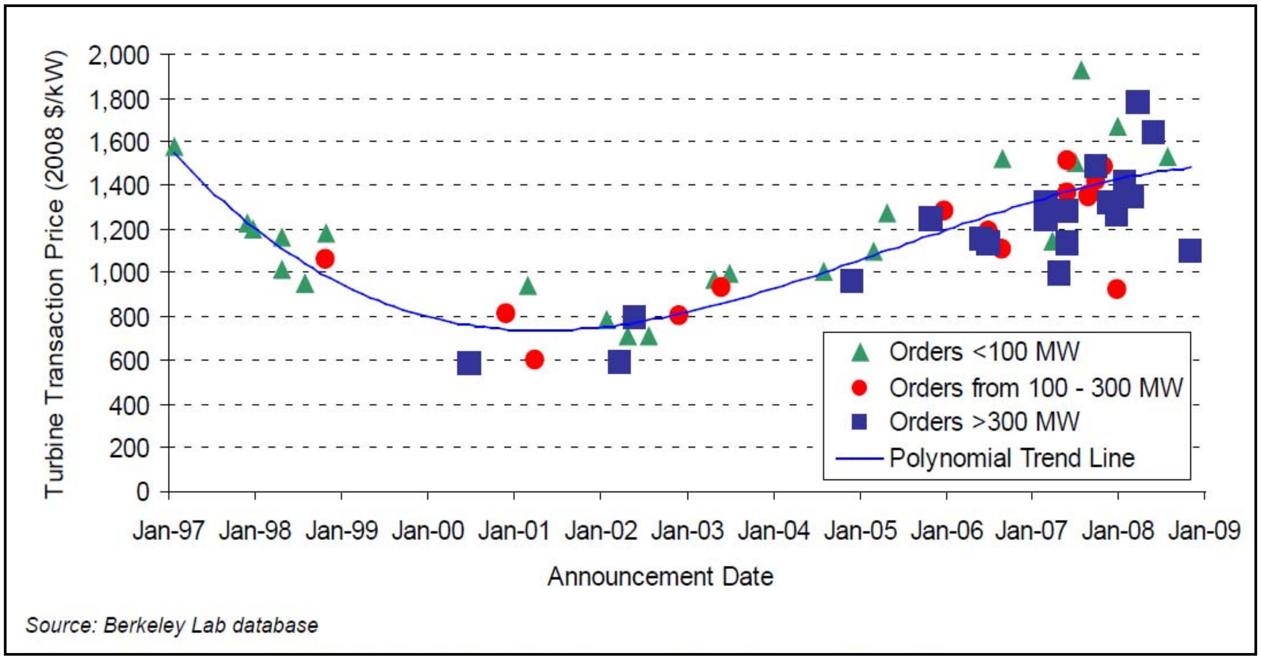


Figure 6. The value of wind turbine supply contracts over time in constant 2008 dollars. This plot is derived from data on 59 U.S. wind turbine transactions totaling 21,100 MW, including ten transactions summing to 4,500 MW in 2008 alone. These data suggest that larger turbine orders have yielded generally lower pricing than smaller orders at any given point in time, as most of the larger turbine orders are below the polynomial trend line, while most of the smaller orders are above that line. Source: Reference 3.

Most transaction price data were derived from press releases and news reports. Wind turbine transactions differ in the services offered (e.g., whether or not towers and erection are included, the length of the service agreement, etc.) and on the timing of future turbine delivery. Most of the transactions included in the LBNL database include turbines, towers, erection, and limited warranty and service agreements.

Between 2007 and 2008, the capacity-weighted average turbine price increased by roughly $90/kW (7%), from $1,270/kW in 2007 to $1,360/kW in 2008. Increases in turbine prices over this period have been caused by several factors, including the declining value of the U.S. dollar relative to the euro, increased materials and energy input prices, a general move by wind turbine manufacturers to improve their profitability, shortages in certain turbine components, up-scaling of turbine size (and hub height), and improved sophistication of turbine designs.

Recalling that all U.S. projects to date are land-based, the LBNL's average turbine supply price of $1,360/kW in 2008 must be adjusted upward to account for marinization and offshore wind design requirements. Vestas adds 10%, while the National Renewable Energy Laboratory (NREL) adds 13.5%. We use the more conservative NREL factor and also make an exchange rate adjustment for valid comparison with our modeled European turbine supply cost. This yields an estimate of $1,680/kW for a domestically produced offshore wind turbine.

<u>Influence of Steel Pricing</u>: Escalation of fossil fuel prices in the first half of 2008, and their subsequent decline with the global recession in the second half of 2008, yielded a 2.5- to 2.6-fold variation in natural gas prices and coal prices during the course of that calendar year (see Figures 1 and 2). This led to a similar rise and fall of commodity prices, particularly of steel, which is by far the largest material component of an offshore wind project. VCERC's cost model is indexed to a variety of different Producer Price Indices published by the U.S. Bureau of Labor Statistics. Our sensitivity analysis suggests that turbine, tower, and foundation contracts placed with North American suppliers any time between mid-2007 and mid-2009 for our hypothetical in-service date of 2012 would yield an offshore wind project cost range of approximately $3,000 to $3,600 per installed kilowatt, based solely on the historical variation of real steel prices (Figure 7).

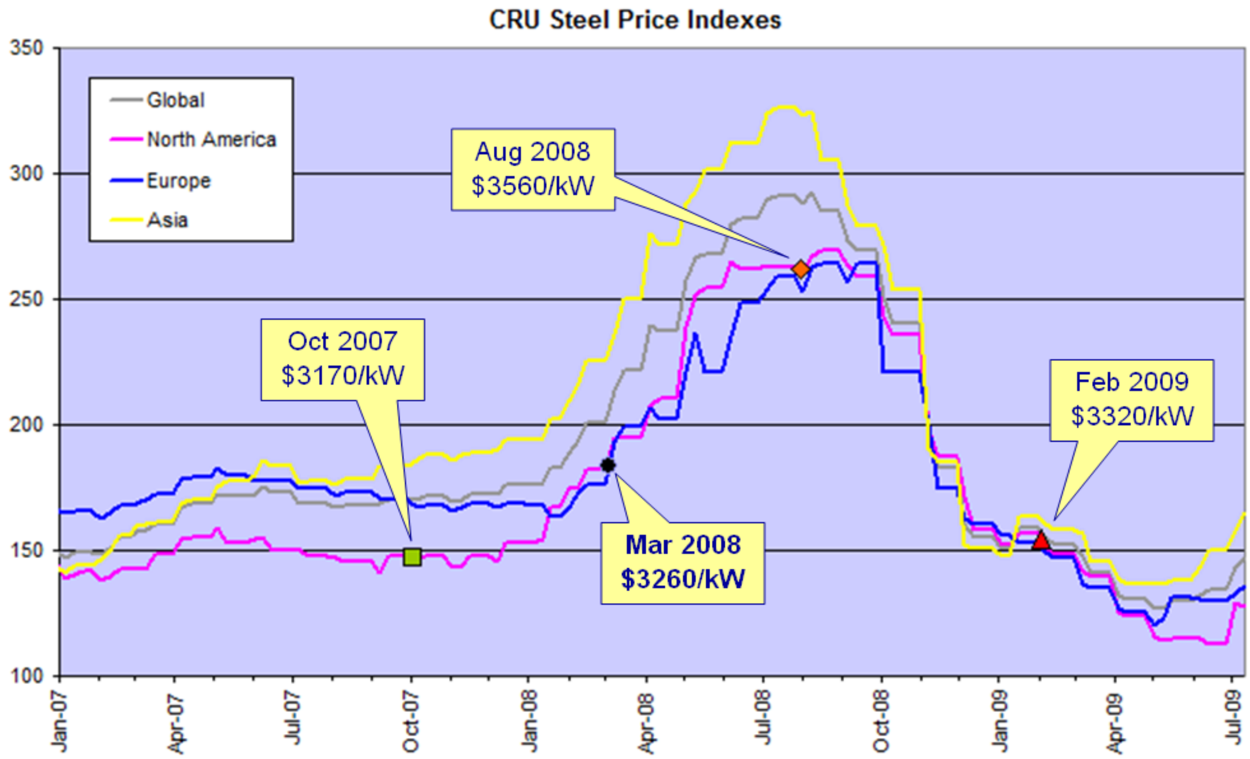


Figure 7. VCERC modeled capital cost variation (in March 2008 dollars) sensitivity to historical variation of steel prices alone, based on the CRU Steel Price Index. Source: Reference 9.

Ratio-Based Approaches to Derive Offshore Wind Capital Cost: As an independent check using a completely different method with no relationship to the VCERC cost model, we applied the European ratio of offshore to land-based project costs to the average cost of land-based projects in the U.S. to see how this compared with VCERC's modeled capital cost estimate.

A March 2009 report by the European Wind Energy Association (EWEA) indicates that in 2006 euros, offshore wind project costs average €2.1 million per MW, while land-based project costs average €1.2 million per MW, which yields a ratio of 1.75 (see Reference 10 for details). The dollar has depreciated quite a bit relative to the euro, so rather than converting these estimates to dollars, we simply apply this European ratio as a multiplier to the most recent average of U.S. land-based project cost estimates.

In the LBNL report cited earlier, the capacity-weighted cost for U.S. land-based projects coming on line in 2008 was $1,915/kW. Multiplying this U.S. land-based project cost by the European offshore-to-land-based cost ratio of 1.75 yields a U.S. offshore project cost of $3,350/kW, which is only 3% greater than the $3,260/kW estimate produced by the VCERC model.

Another ratio-based assessment is given in the June 2009 North Carolina offshore wind report (Reference 11), which assumed a land-based project cost of $2,000 per kW in 2009 dollars. This report multiplies the land-based project cost by 1.4 to estimate the cost of a project in shallow sounds, and then again by 1.2 to estimate an ocean project cost of $3,360 per kW. Although derived independently, this result is nearly identical to ours derived from LBNL and EWEA data.

Between validating 80-85% of VCERC's offshore wind cost model with data from actual large offshore projects in Europe, as described earlier, and two independently derived ratio-based results, as described above, we are confident that *a suitably designed offshore wind project of 500 to 600 MW can be built in federal waters off Virginia at a cost of $3,000 to $3,600 per kilowatt*. Nevertheless, this represents a tremendous capital investment, in the range of 1.5 to 2.2 billion dollars for such a large project, and it is important that our offshore wind cost model be more completely validated, as recommended in the "*Applied Research Roadmap*" section of this report.

<u>Uses of Currency Exchange Rates</u>: Simply applying a prevailing currency exchange rate to total project cost can be misleading. For example the total cost of the 630 MW Phase I London Array project was reported to be "almost €2bn" when the remainder of its major supply contracts were announced in December 2009 (Siemens' turbine supply contract was announced in May 2009; see Reference 6 for information about the remaining six supply contracts). At the prevailing currency exchange rate when the December 2009 announcement was made, € 2 billion was equivalent to $2.9 billion, which yields a unit capital cost of $5,100 per kilowatt. This simplified assessment suggests that offshore wind capital costs have more than tripled since the Horns Rev I 160 MW project was built in 2002 at a cost of only $1,600 per kilowatt.

A different story is evident when viewing the history of offshore wind capital costs in euros, as shown in Figure 8 (next page). Reviewing reported costs for three sample projects (as indicated in the call-out boxes in Figure 8), unit capital costs increased from € 1.7 M per MW for Horns Rev I (on-line 2002; Reference 10) to € 3.2 M per MW for Thanet (on-line 2010; Reference 12) to € 3.5 M per MW for London Array Phase I (on-line 2012; Reference 6). Thus unit capital costs for European offshore wind projects, in nominal euros, will have approximately doubled rather than tripled when London Array Phase I comes on line in 2012. At the prevailing exchange rate in 2002, Horns Rev I cost $1,600 per kW, and in constant 2002 dollars, the London Array would cost ~$3,200 per kW, which better reflects the real escalation of offshore wind capital costs.

As documented in Appendix B, the euro appreciated ~60% relative to the dollar from the time of the Horns Rev I construction phase in 2001-2002 to December 2009, when the remaining London Array supply contracts were announced. Multiplying our 2002-constant-dollar cost estimate for the London Array of $3,200 per kW by a currency appreciation multiplier of 1.6 yields a unit capital cost of ~$5,100 per kW, which is consistent with the initial simplified assessment, but this additional increase reflects the changing relative valuation of the two currencies rather than any further real escalation of offshore wind capital costs.

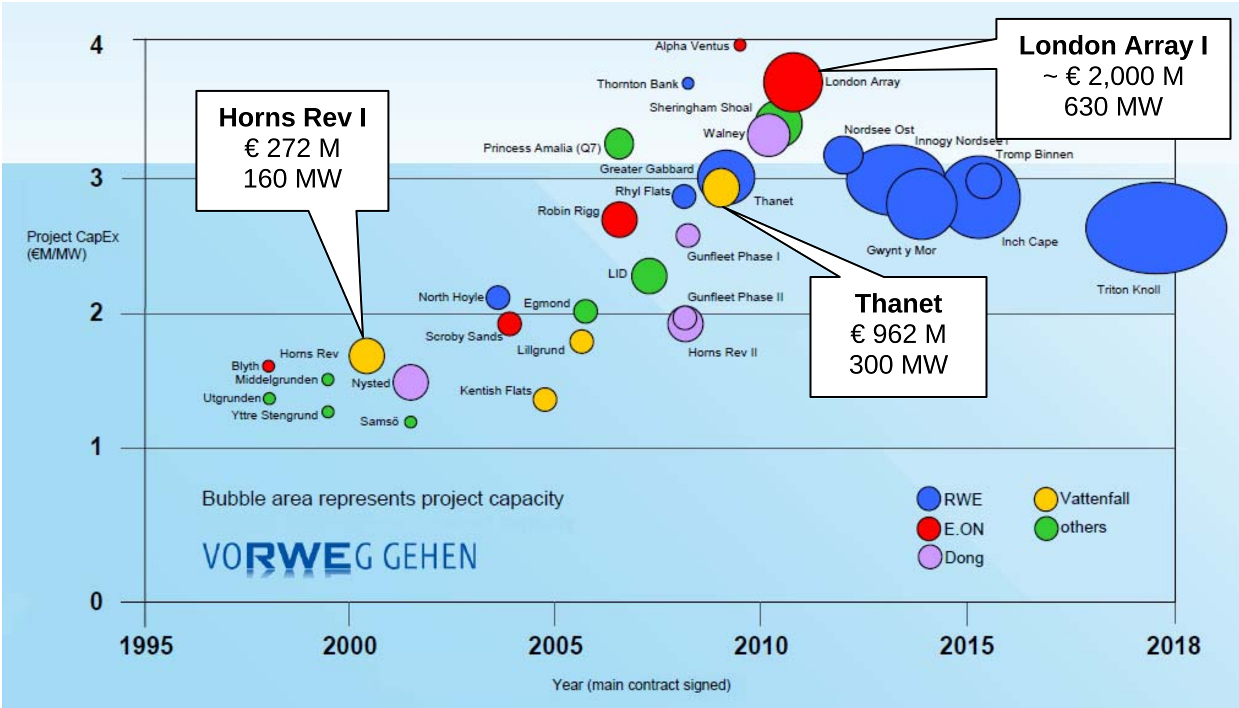


Figure 8. European offshore wind capital cost history, in nominal million euros per megawatt. Source: Reference 13. Project capital costs in the call-out boxes came from different sources (References 6, 10, and 12) and so do not entirely agree with the graph from Reference 13. All projects to 2010 have used turbines of 2 MW to 3.6 MW rated capacity, except Thornton Bank and Alpha Ventus, which used 5 MW turbines, and Utgrunden, which used 1.5 MW turbines.

While it is misleading to apply currency exchange rates to total project costs, it is necessary to apply them to those items that are manufactured only overseas. These include the high-cost centers of the turbine-and-tower package and high-voltage submarine cables. The strength of the euro against the dollar is one reason to attract manufacturing of these high-cost items to Virginia. Another reason is the much higher wages paid to production workers in countries where offshore wind turbines are manufactured. In 2007, which is the most recent year surveyed, such wages were 72% higher in Denmark and 53% higher in Germany (Reference 14).

Offshore Wind Downside Potential Risks. There are several wind resource-related concerns associated with our LCOE estimated range of $105 to $130 per MWh. These concerns are with the location of measured wind data relative to our hypothetical project site, uncertainty in our extrapolation of wind speeds from wind measurement height to turbine height, and turbine wake effects within the project. Each of these is addressed separately, below.

The location of measured wind data closest to our hypothetical project area is the Chesapeake Light Tower, a Coastal-Marine Automated Network (C-MAN) station designated CHLV2, where wind speed and direction have been measured at 43.3 m above mean sea level and archived by the National Data Buoy Center since 1984. CHLV2 is located in a Class 5 wind zone as mapped by NREL, while our hypothetical project footprint is located farther offshore, in a Class 6 wind zone that is more representative of Virginia's most promising MMS lease blocks (see Figure 9).

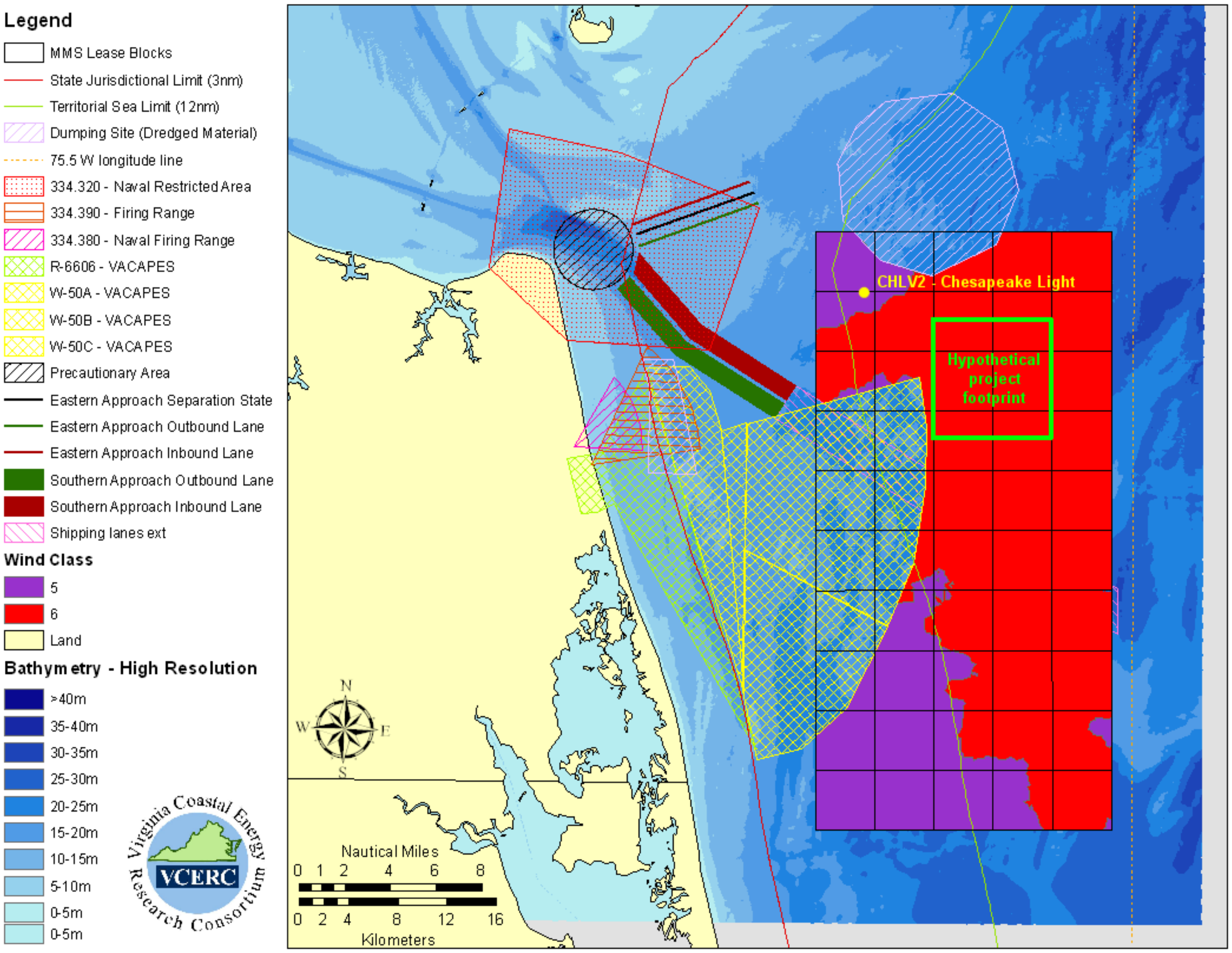


Figure 9. Location of C-MAN station CHLV2 and VCERC's hypothetical wind project footprint relative to NREL mapped offshore wind Class 5 (purple) and Class 6 (red) regions off Virginia.

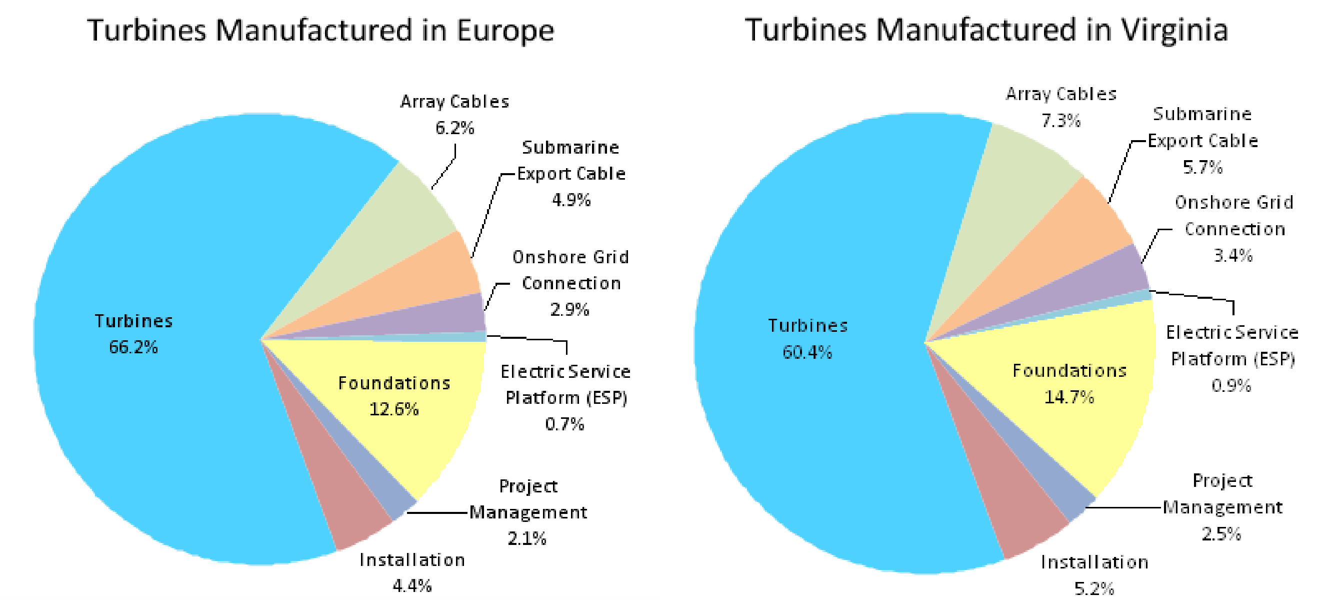
Our analysis suggests that turbines similar to the Vestas V90-3MW would generate 12.6% more energy in our hypothetical project footprint than at CHLV2. This is based on the performance curve (power vs. wind speed) for a single, isolated turbine, assuming a Rayleigh probability distribution of wind speeds in each of the Class 5 and Class 6 zones mapped in Figure 9.

The turbine output reductions caused by wake effects within the wind project is another uncertainty embedded in our offshore wind LCOE estimates. Measurements made within the Horns Rev project off Denmark, which has a turbine spacing of 7 rotor diameters, indicate that when compared with a single, isolated turbine, total project-level annual output is reduced by 11%. Our hypothetical project off Virginia has a turbine spacing of 7.6 rotor diameters, and so project-level energy losses due to wake effects would be similar to or less than at Horns Rev.

The greatest risk in our offshore wind energy production estimates is the large uncertainty associated with the vertical distribution of wind speeds, which yield a standard deviation in the range of 20% to 25% in annual energy generation estimates at hub height. *This can be mitigated by an aggressive program of wind resource modeling validated by tall mast wind measurements*, as described under the "Offshore Wind Recommendations" section of this report.

Offshore Wind Upside Potential Opportunities. *<u>The first and greatest opportunity</u> for reducing the cost of offshore wind energy in Virginia is to attract offshore wind turbine manufacturing to the state.* This would include turbine assembly plants in Hampton Roads, where large, open staging areas on deep-water wharves have unconstrained access to the open ocean. This would involve a chain of first- and second-tier suppliers to be qualified throughout the state and also leverage Virginia's existing shipbuilding industry capabilities to fabricate large steel components that go into the turbine such as yaw bearings, gears, shafts, and nacelle base plates.

Figure 10 compares the capital cost breakdown of an offshore wind project with turbines and tower sections purchased from Europe, and the capital cost breakdown of an offshore wind project assembled from turbines and tower sections manufactured in Virginia. In both cases, turbine supply accounts for more than half the total project cost and *proper turbine selection is critical to the economic viability of any offshore wind project off Virginia*, particularly with regard to the ratio of rotor swept area to generator rated capacity. Our economic modeling suggests that turbines developed for faster North Sea winds are not optimally cost-effective for the slower winds of the Mid-Atlantic offshore region (see Appendix C).



	Turbines Manufactured in Europe	Turbines Manufactured in Virginia
Plant cost at offshore ESP busbar:	$ 1,763 million	$ 1,483 million
Submarine export cable to shore:	$ 96 million	$ 96 million
Onshore transmission upgrade:	$ 57 million	$ 57 million
Total plant overnight cost:	**$ 1,916 million**	**$ 1,636 million**
	$ 3,260 per kW	**$ 2,780 per kW**

Figure 10. VCERC modeled capital cost breakdown (in March 2008 dollars) for a hypothetical 588 MW offshore wind project, derived from units similar to the Vestas V90 3 MW offshore turbine. The left-hand pie chart is based on purchase of turbines manufactured in Europe, and the right-hand pie chart is based on the purchase of turbines manufactured in Virginia. These estimates do not include interest paid on funds used during construction or contingency funds.

Our modeled European offshore wind turbine supply cost is $2,160 per kW for turbines manufactured in Denmark or Germany. When compared with a domestic turbine supply cost of $1,680 per kW, this amounts to a project cost difference of $280 million for our hypothetical 588 MW project design ($1.916 billion total project cost if turbines manufactured in Europe vs. $1.636 billion total project cost if turbines manufactured in Virginia). The savings over two such projects would more than pay for the estimated investment cost of ~$500 million to establish a turbine manufacturing complex on a "greenfield" site.

The benefit of having in-state wind turbine manufacturing is substantial. If the turbine and tower sections were manufactured in Virginia, we estimate the project capital cost would decrease by $480 per kilowatt and the mid-range cost of energy would decrease by about $15 per MWh, yielding a LCOE range of $90 to $115 per MWh. Domestic turbine manufacturing reduces costs associated with dollar devaluation relative to the euro, and minimizes shipping costs and delays.

Despite the doubling of project costs over a decade, European offshore wind projects continue to be built because legally binding requirements for renewable energy supply portfolios and/or carbon emission reduction obligations have enabled national governments to provide generous financial incentives. This enables European offshore projects to be commercially viable, even though they use erection techniques derived from their land-based predecessors, by assembling three-bladed upwind turbines on bolted together tower sections, in sequential crane lifts.

European-style financial incentives are unlikely in the U.S., which challenges us (and provides a second opportunity for capital cost reduction) to use turbine designs, support structures, and erection methods specifically developed for the ocean environment, and to create a supply chain solely dedicated to offshore wind, which does not rely on or compete for assets used by other industries such as port construction or offshore oil and gas. Relying on European offshore wind supply chain goods and services is not only more costly (due to currency exchange and shipping costs), but with the ongoing acceleration of offshore wind deployment in Europe, bottlenecks already are forecast for just meeting the needs of European projects, particularly in installation vessels for offshore wind turbines and submarine power cables.

A third opportunity is the development of ocean-classed turbines with greater rotor swept area per unit generator capacity, optimized for Mid-Atlantic wind speeds, which range from 8 to 8.5 m/sec as compared with 9 to 9.5 m/sec in most of the North Sea (see Appendix C). Larger rotors are more costly and impart greater thrust loads on the drive train, as well as greater base shear and overturning moment on the tower and foundation, but we anticipate that these cost increases will be more than offset by increased output, particularly during the summer peak hours when electricity is most valuable in the PJM region.

To date, only two manufacturers produce ocean-classed turbines with rotor swept areas more appropriate for Virginia's offshore wind climate, both announced in September 2009 at the European Offshore Wind Conference & Exhibition in Stockholm, Sweden. Vestas announced the commercial availability of the V112, which has a 3 MW generator, and a rotor diameter of 112 m (Reference 15). This yields a rotor swept area of 3,284 m^2 per MW of generator capacity, which is 55% larger than the V90, enabling it to capture more energy from lower wind speeds. VCERC estimates that depending on wind shear profile assumptions, *the V112 would yield 23% to 29% more energy than the V90 on Virginia's OCS*.

Also in September 2009, Siemens announced a larger-rotor version of its proven 3.6 MW offshore turbine, with a rotor diameter of 120 m (Reference 16). This new model has a rotor swept area that is ~75% larger than the Vestas V90, but for a somewhat higher generator rated capacity, giving it a capacity-specific swept area of 3,142 m^2 per MW.

Other newer offshore wind turbine products with large rotor swept areas are Suzlon Energy's REpower 5M (Reference 17), which has a rotor diameter of 126m, the AREVA Multibrid 5000, which has a rotor diameter of 116 m (Reference 18), and the General Electric direct-drive model based on its recently acquired ScanWind technology, which has a rotor diameter of 110 m (Reference 19). These turbines have higher generator ratings, however, giving them lower capacity-specific rotor swept areas: 2,494 m^2 per MW for the 5 MW REPower turbine, 2,114 m^2 per MW for the 5 MW AREVA Multibrid turbine, and 2,376 m^2 per MW for the GE 4 MW direct-drive machine. Off Virginia, these units are likely to have annual average capacity factors in the range of 35-40%, similar to the Vestas V90, which has a capacity-specific rotor swept area of 2,121 m^2 per MW. By comparison, the Vestas 3 MW V112 and the Siemens SWT-3.6-120 have capacity-specific rotor swept areas of 3,284 m^2 and 3,142 m^2 per MW, respectively, which would give them 45-50% capacity factors off Virginia (see Appendix C for details).

An analysis of land-based wind project performance in the PJM region during 2009 indicates that the region-wide annual average capacity factor is 29.1% (Reference20). If offshore projects are able to achieve a capacity factor of only 40%, then they can cost no more than 1.37 times their land-based counterparts and still be commercially viable in the PJM region under present energy market conditions. Using larger rotor swept areas to achieve a capacity factor of 50% would enable offshore projects to be as much as 1.72 more costly than their land-based counterparts, which is much closer to the offshore-to-land-based capital cost ratio of 1.75 experienced in Europe (as previously described on page 13; see Reference 10 for details).

Larger rotor diameters would entail proportionally greater spacing distances between the turbines in order to reduce inter-turbine wake losses, and this would lead to higher costs for array cables, as well as a larger project footprint area requiring additional leased blocks for a given project capacity. An economic model that evaluates both cost and performance at the full project level (as opposed to the individual turbine level) is required to determine the most cost-effective turbine spacing for each capacity-specific rotor swept area among the different turbine makes and models that might be considered for an offshore wind project.

Environmental Effects. Another aspect of VCERC Project 1 was to evaluate the environmental effects associated with an offshore wind project footprint of this size. Avian populations are of particular concern, and Virginia Tech's Department of Fisheries and Wildlife Sciences (VT-FiW) reviewed data availability for shorebirds and sea birds that inhabit or transit Virginia's coastal ocean. *Virginia-specific data on over-water movements of birds and bats proved to be sparse, particularly for the open Atlantic Ocean*. Appendix D catalogues six avian data sets having some information that could be useful in offshore wind project development off Virginia, but these only represent a starting point to inform the work that remains to be done. Field data must be gathered on the seasonal and diurnal flight migratory pathways and associated flight elevations of birds and bats, their offshore foraging behaviors, and their population demographics. These data must then be merged to develop species-specific risk profiles for turbine collision and habitat loss or shift.

VT-FiW researchers also are engaged in an innovative field trial to assess the utility of very high resolution satellite visual imagery for monitoring the effects of offshore wind development on avian populations in coastal Virginia, particularly the loss or shift of habitats. This involves the collection of satellite images concurrent with "ground truth" visual observations to verify images for target populations of sea ducks in coastal Virginia waters. Based on the life histories and migration patterns of these target species, this research is being undertaken in the winter and spring of 2010. VCERC will issue a separate report on the results of this study in June 2010.

Appendix E provides a bibliography of selected publications that are relevant to understanding the potential environmental effects of offshore wind development off Virginia. Based on a review of these publications, here are some key environmental issues to be considered. This is by no means a complete list but is intended to draw attention to some important concerns.

- Extensive surveys off the coast of New Jersey and anecdotal reports off North Carolina suggest that resident seabird activity over the Atlantic Ocean generally decreases with distance from shore and may be significantly reduced beyond 12 nautical miles. Activity picks up again approaching the Gulf Stream, beyond the edge of the continental shelf.
- North-south migration of various bird species groups occurs during most months of the year and little is known about their flight paths over the open ocean. Even less is known about bats offshore. Migration pathways over the open ocean are completely unmapped for some federally-listed threatened and endangered species of shorebirds, including the Roseate Tern, Piping Plover, and Red Knot. Tracking studies show that some shorebirds (e.g. whimbrels; see Reference 21) fly directly from the Delmarva Peninsula to the West Indies and South America, possibly over potential offshore wind project sites off Virginia.
- The height at which birds fly offshore – above, below, or within the potential blade impact zone of a wind turbine rotor – varies from species to species, and also can vary with time of day, weather conditions, and season, as well as age class and gender. Birds often fly at different heights when foraging for food than when migrating, and the height of daily movements may differ from the height of seasonal migrations.
- The ability of birds to fly around turbines or to avoid projects depends on the species and weather conditions. Birds that glide along air currents, such as petrels and shearwaters, may be less able to avoid collisions, particularly during high winds and storms.
- Artificial reef effects around the bases of turbines may benefit underwater life but could be detrimental to bird species attracted by the increased food supply and thus at greater risk of collision. These could include cormorants, gannets, gulls, and pelicans. Within this group, cormorants in particular may be at greater risk, as they must land frequently to dry out their wings and may use walkways and other emergent foundation structures for this purpose.
- Populations of sea ducks and gannets often congregate over the same shoal areas that represent lower-cost foundation sites for offshore wind turbines, due to shallower water. These species may be more likely to experience habitat loss or shift away from offshore wind projects, and this is one motivation for the satellite imagery study described above.
- Radar for avian monitoring has important limitations. Used alone, it cannot distinguish different species of birds from one another, it cannot distinguish birds from bats, and it cannot distinguish individual small birds from distant flocks. Visual confirmation by

human observers is required for interpretation of radar tracks using today's commercially available technologies. Future developments in both traditional marine and harmonic radar may allow scientists to identify more specific targets, but these developments are expected to take 5-10 years before they are available for implementation.

- To meet FAA requirements for aviation hazard marking of turbines and met towers, steady-burning lights should be avoided, and strobes or flashing lights should be either red-only or dual red-and-white (Reference 22). Only a portion of the turbines within a project should be lighted, and all strobes or flashing lights should fire synchronously.
- Best-practice guidelines for land-based wind projects and anecdotal observations of seabird behavior suggest that use of steady-burning area lighting should be minimized. When needed for safe access to towers and servicing of turbines or platforms by offshore personnel, such lights should be switched off during routine, unmanned operation. Area lighting should be hooded downward to minimize horizontal and skyward illumination.
- Structural appurtenances at the base of towers should be designed to minimize their attractiveness to birds as roosting or nesting sites. Contrasting colors on the blades also have been suggested as a means of reducing bird collision risk.
- Interstate cooperation is needed to coordinate offshore wind project construction schedules up and down the coast are thoughtfully timed to minimize cumulative impact on seasonal migrations of the North Atlantic Right Whale. Off Virginia, southbound whales appear in October through December and northbound whales appear in February through April.
- Underwater noise from the high-energy hammers used to drive large-diameter monopiles is a major concern for marine mammals during construction. Acoustic pingers have been used to "warn" seals away from a construction area as they learn to associate the pinger signals with the onset of pile-driving. Response to pingers varies from species to species, however; for example, Harbor Porpoises are more likely to be deterred than Bottlenose Dolphins, and frequencies used for marine mammals are too high for sea turtles to hear.
- All five species of Atlantic Ocean sea turtles are federally listed as threatened or endangered. At least two of these species probably will forage around offshore turbine bases to feed on crabs and mussels that will be abundant on foundation structures and scour protection rubble. This would put them at higher mortality risk if trawling is permitted between turbines.
- Some shellfish and other sediment-living invertebrates will be killed and their populations dislocated where foundations are installed and surrounded by anti-scour rubble protection. Where submarine power cables are buried, their numbers should recover within months.
- In preparing its recent Environmental Impact Statement for the Virginia Capes Operating Area, which extends from Cape Henlopen, Delaware to Cape Hatteras, North Carolina, the U.S. Navy has systematically collected data on the distribution, abundance and behavior of many marine and avian species. Navy reports and data resources are listed in Appendix E.
- Atmospheric emissions are a concern and will require permits from the Environmental Protection Agency for the operation of any diesel or gasoline generators used to power wind-sensing LIDARs and radars used for avian surveys or vessel traffic monitoring.
- All pre-construction environmental risk assessment studies should be rigorously designed and explicitly linked to plans for post-construction monitoring and mitigation.

Maintaining safety is a serious issue for offshore wildlife studies, including aerial surveys and the installation and occupation of any temporary platforms to provide “ground truth” visual observations in support of satellite or radar studies. There have been fatal accidents associated with such activities off the coasts of Delaware and New Jersey (Reference 23). Virginia should ensure that all plans for such environmental monitoring activities are subject to third-party safety review and are well coordinated with other ocean users who might be engaged in potentially hazardous operations at the same time, particularly military training and testing in the Virginia Capes Operating Area and space launches from Wallops Island.

Environmental studies must address potential negative effects that offshore wind development might have on the marine environment, but consideration also should be given to ways in which the marine environment might benefit from offshore wind development. One potential benefit is reduction of atmospheric emissions of carbon dioxide (CO_2) by fossil fuel generation that would be displaced by offshore wind generation, which would help mitigate ocean acidification.

PJM recently issued a report on the market-wide impact of various alternative measures to curb atmospheric CO_2 emissions in the PJM region (Reference 24). In order to understand the effects of wind penetration, PJM modeled the addition of 15,000 MW of wind capacity, mostly in the western part of their service region, but also assuming that much of the offshore wind capacity planned off New Jersey and Delaware would be in place.

PJM’s model results indicated that 15,000 MW of wind capacity operating at an annual average capacity factor of 33% would displace 26,300 gigawatt-hours (GWh) of coal-fired generation and 13,000 GWh of gas-fired CCGT generation, yielding CO_2 emissions reductions of 34 million to 37 million short tons per year. This was without any “cap and trade” or other carbon pricing scheme, but simply due to fossil fuel plants backing down when wind power comes on line.

Wind-generated CO_2 emissions reductions also would reduce electricity costs. The fossil fuel prices modeled by this scenario were $6.44 per MMBTU for natural gas and $2.43 per MMBTU for coal in the southeastern region of PJM. Under these market conditions, 15,000 MW of installed wind capacity would yield electricity price reductions of $4.50 to $6.00 per MWh. Based on a forecast PJM-wide annual demand of nearly 789,000 GWh in 2013, this would yield total customer savings of $3.55 billion to $4.74 billion per year.

While installation of offshore wind farms can have negative effects on shellfish, they also can have positive effects by reducing the rate of ocean acidification that is a growing concern for commercially harvested shellfish in the Mid-Atlantic region, particularly in the Chesapeake Bay. For example, a laboratory study of shell formation by larvae of the Eastern oyster (*Crassostrea virginica*) found significant decreases in shell growth and calcification when subjected to a range of elevated atmospheric concentrations of CO_2 as projected for the latter half of the 21st century (Reference 25). A more recent laboratory study by a different research group found even more pronounced effects on the larvae of hard clams (*Mercenaria mercenaria*) and bay scallops (*Argopecten irradians*) (Reference 26). Under a recent legal settlement, the Environmental Protection Agency is now considering how to regulate ocean acidification under the Clean Water Act using a provision of the Act that requires states to identify threatened or impaired waters and to set limits on the input of pollutants into such waters (Reference 27).

Project 2: Preliminary Mapping of Offshore Areas

By working collaboratively with many organizations, James Madison University has compiled a large geospatial database of more than 25 different data layers. Organizations that contributed data and/or shape files to this VCERC project include the U.S. Minerals Management Service, the U.S. National Renewable Energy Laboratory (NREL), the U.S. Navy, the Virginia Institute of Marine Science, the Virginia Aquarium Foundation, and The Nature Conservancy.

Because Virginia's state waters are heavily used by many groups, VCERC's focus has been on federal waters of the outer continental shelf (OCS) in the open Atlantic Ocean. On Virginia's OCS beyond the state boundary 3 nautical miles offshore, the wind resource is predominantly Class 5 or higher, increasing with distance from shore (see map in Figure 9).

Avoiding conflicting uses such as shipping lanes, Navy live-ordnance training ranges, a space launch hazard area, and dredge spoil disposal sites,, *VCERC has identified 25 OCS lease blocks of entirely Class 6 winds in depths less than 30 m, and thus suitable for commercially available monopile foundations*. Accounting for shipping traffic, *these 25 lease blocks could support approximately 3,200 MW of offshore wind capacity, which – assuming an array efficiency of 89% as at Horns Rev – could generate 11 million megawatt-hours per year*, or approximately 10% of Virginia's annual electricity consumption..

The area breakdown by wind power density class, for Virginia's state and federal waters is given in Table 2. The Chesapeake Bay and Atlantic state waters are dominated by Class 4 winds, while Atlantic federal OCS waters are dominated by Class 5 and Class 6 winds.

Table 2. Virginia Offshore Wind Resource Areas (km^2) by Power Density Class

	Class 3	Class 4	Class 5	Class 6
Inland Waterway	50	46	0	0
Chesapeake Bay	923	3,018	181	0
Atlantic (to 3 n.mi. offshore)	277	823	566	0
Atlantic (3 n.mi. - 12 n.mi.)	0	83	2,632	256
Atlantic (12 n.mi. - 50 n.mi.)	0	0	623	3,972

The wind power density classes in the above table are based on the mapped range of annual average wind speeds at a 50 m hub height (and associated wind power density range) as follows:

Class 3: 6.4 to 7.0 m/s mean wind speed (300-400 W/m^2 mean power density)

Class 4: 7.0 to 7.5 m/s mean wind speed (400-500 W/m^2 mean power density)

Class 5: 7.5 to 8.0 m/s mean wind speed (500-600 W/m^2 mean power density)

Class 6: 8.0 to 8.8 m/s mean wind speed (600-800 W/m^2 mean power density)

The wind power density class areas of Table 2 were converted to total annual energy output as follows. Using a turbine similar to the Vestas V90 3 MW model, we assumed a wind turbine installation density of 6.4 MW of rated capacity per km^2. This yields a turbine spacing of 7.6 rotor diameters between towers.

Assuming a Rayleigh probability distribution of wind speeds in a given class and a 1/7 power law for the wind speed profile, VCERC estimated the annual capacity factor at 80 m hub height for a turbine similar to the V90 3 MW model as follows: Class 6 – 44%, Class 5 – 39%, Class 4 – 35%, and Class 3 – 30%. The resulting estimates of total annual energy generation potential are shown in Table 3, below.

Table 3. Virginia Offshore Annual Wind Energy Generation Potential (GWh/yr)

	Class 3	Class 4	Class 5	Class 6	**Total**
Inland Waterway	735	901	0	0	**1,736**
Chesapeake Bay	15,410	59,134	3,978	0	**78,523**
Atlantic (to 3 n.mi. offshore)	4,625	16,126	12,441	0	**33,191**
Atlantic (3 n.mi. - 12 n.mi.)	0	1,623	57,858	6,320	**65,801**
Atlantic (12 n.mi. - 50 n.mi.)	0	0	13,690	98,214	**111,904**

Note that the above annual energy estimates are based on the performance curve for a single, isolated turbine. Individual turbine wake losses within a project and overall wake losses between projects could reduce this potential by up to 10 to 15%, depending on several factors, including spacing of turbines within a project and the spacing of projects. Using a turbine similar to the Vestas V90 3 MW model and assuming an installation density of 6.4 MW of turbine capacity per square kilometer, Horns Rev data would predict an inter-turbine array efficiency (project output divided by single, isolated turbine output) of 89% or better (Reference 28).

Project wake effects affecting adjacent projects have yet to be modeled on the Mid-Atlantic continental shelf. Measurements at Horns Rev show for that project, the lee-side wind speed recovers to approximately 90% of its free-stream value within 5 km after leaving the last turbine. Further wind speed recovery is more gradual, extending for an additional 15-20 km downwind (Reference 29).

Neglecting project wake effects and inter-turbine wake effects within projects, the upper bound of total potential energy output of Class 5 and Class 6 wind resource areas in federal waters between 3 and 50 nautical miles offshore is 176 terawatt-hours per year (TWh/yr). As noted previously, *the 25 OCS lease blocks identified by VCERC in Class 6 areas beyond the visual horizon 12 nautical miles offshore and mapped in Figure 9* could yield 11 TWh/yr and thus *represent 6.25 % of Virginia's maximum offshore wind generation potential in federal waters*.

In collaboration with VCERC, The Nature Conservancy has mapped the offshore wind resources of the Mid-Atlantic Bight, which is the region between Cape Hatteras, NC, and Cape Cod, MA. As shown in Figure 11 Virginia has far more Class 6 wind area inside the 30 m depth contour on its federal OCS than any other Mid-Atlantic state. Off northern New Jersey and New York City, there are only small pockets of Class 6 wind that are not covered by shipping lanes or underwater telecommunications cables or not subject to dredge and bottom trawl fishing. Farther north, the 30-meter depth contour lies largely inside the 12-nautical-mile visual horizon, except around Nantucket Shoals. *Development of an offshore submarine high-voltage, north-south "backbone" (with offshore interconnection capability) would enable Virginia's large offshore wind resource area to supply Maryland, Delaware, New Jersey, and Pennsylvania.*

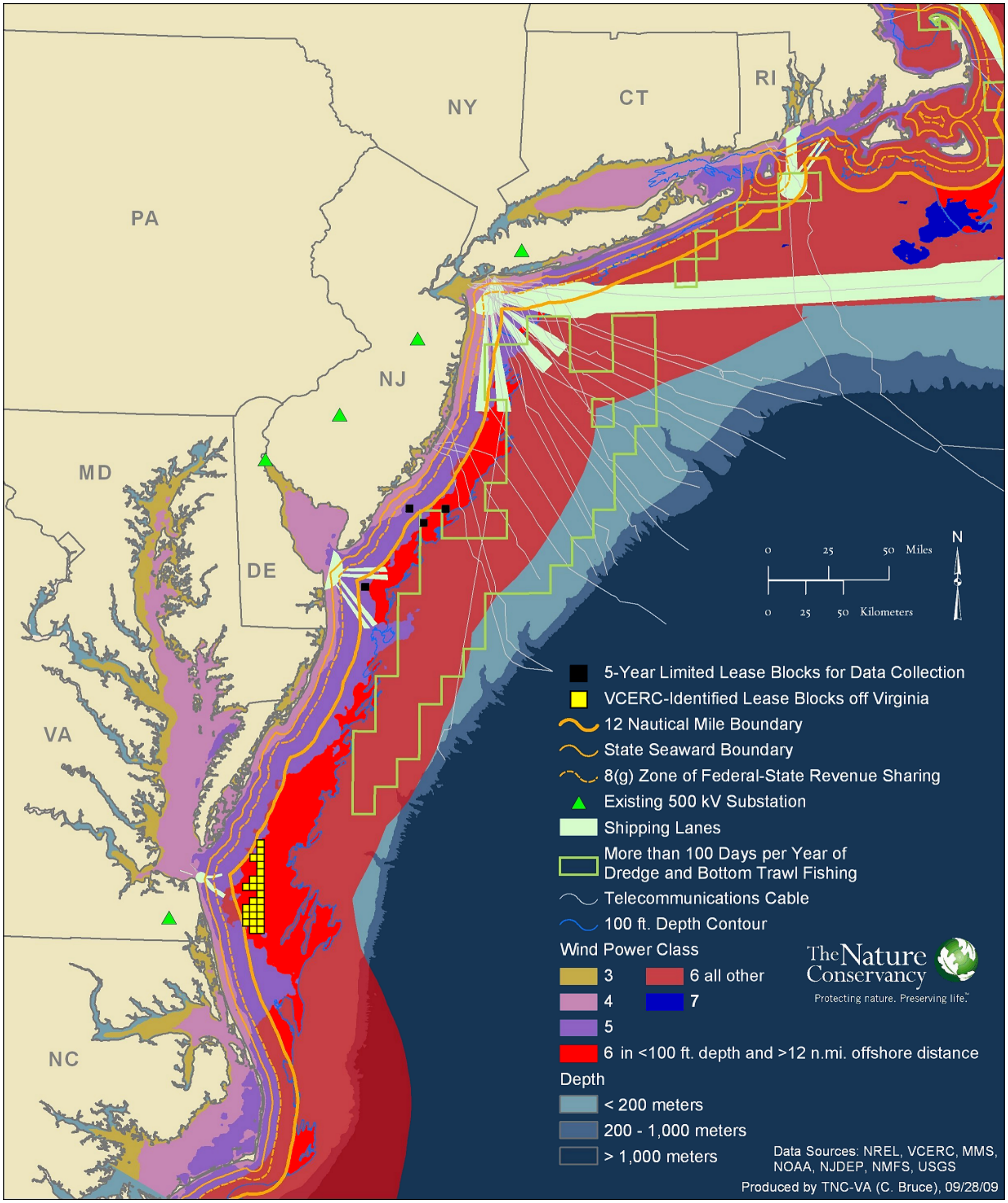


Figure 11. Map produced by The Nature Conservancy, in close collaboration with VCERC researchers, showing the location of offshore wind power density class areas and other ocean uses and features of the Mid-Atlantic Bight from Cape Hatteras, NC, to Cape Cod, MA. The 25 lease blocks that VCERC has identified just beyond the 12-nautical-mile territorial sea limit off Virginia have the potential to meet nearly 10% of the state's annual electricity demand.

An important commercial fishery in Virginia's Class 6 wind areas beyond 12 nautical miles offshore and within the 30 m depth contour is conch and whelk trapping. Commercial wind farm developers should work closely with this fishery to avoid productive trap sites when siting individual turbines within a project and also to avoid damaging traps when laying array cables between the turbines and offshore substation. Insurance arrangements should be negotiated to cover mutual liabilities for accidental damage to traps and boats by offshore wind activity and accidental damage to turbine towers or submarine cables by fishery activity. Some fishery practices and gear types are likely not to be permitted within certain areas of an offshore wind project, and these fisheries should be consulted early in the project site selection process.

VCERC focused its initial offshore wind mapping efforts on a rectangular area of lease blocks directly offshore Virginia Beach (Figure 9). Late in the study period, however, we received a vessel traffic density map produced by the Virginia Aquarium Foundation, which caused us to modify our original assessment (Reference 30). The VCERC-identified lease blocks shown in Figure 11 form a more irregular pattern, based on areas shown by the new data to be relatively free of shipping traffic. These 25 blocks are all located beyond the Territorial Sea limit of 12 nautical miles, which is a good proxy for the offshore visual horizon, are all in water depths of 30 m or less, and with one exception, all blocks are located entirely within NREL's mapped Class 6 wind zone. These 25 blocks are thus identified as having the greatest potential for commercial offshore development, with the understanding that developers would consult with all potentially affected stakeholders in proposed lease areas and identify project specific effects on marine and avian ecology as part of their environmental permitting process under the MMS rule. More details on the identification of these 25 blocks are given in Appendix F.

Under Project 2, VCERC also engaged in the following activities to engage the U.S. Minerals Management Service (MMS) in that agency's regulatory activities for both renewable and fossil energy development in federal offshore waters on Virginia's Outer Continental Shelf (OCS):

- Informed and advised federal and state decision-makers during development of the MMS comprehensive rule for the development of alternative energy sources in federal waters of the U.S. OCS, as well as the interim-policy rule for research projects and met towers.
- After the MMS final comprehensive rule was published on 29 June 2009, a group of VCERC researchers, the Governor's Senior Advisor for Energy Policy, and representatives from the Department of the Navy and the City of Virginia Beach met with MMS program officials in Herndon, Virginia, on 13 July 2009 to discuss proactive and reactive scenarios by which MMS would establish a federal-state-local government task force. Under subpart A, § 285.102(e) of the new rule, task force members can make recommendations and contribute to the MMS planning process. MMS indicated that they would consider input from such a task force in determining appropriate siting of offshore wind energy projects and leasing priorities. Such input notwithstanding, however, MMS has final discretion in making the determination of whether or not to offer areas for leasing.
- Following the 13 July meeting, VCERC provided input to the Governor's office on the relative merits of reactive and proactive scenarios and recommended that the Governor ask MMS to establish a federal-state-local task force as described above. The Governor made such a request on 15 September 2009. MMS agreed to establish a Virginia task force, and its inaugural meeting was held on 08 December 2009 (see page 28).

- Informed and advised state decision-makers during the development of the current MMS Five-Year Program for U.S. offshore oil and gas leasing in 2007-2012, which includes a planned lease sale off the coast of Virginia (Sale 220). VCERC was well represented at the MMS "Workshop on Environmental Research Needs in Support of Potential Virginia Offshore Oil and Gas Activities" hosted by the Virginia Institute of Marine Science in Williamsburg on 03-04 December 2008.

To brief federal program managers on our project results, VCERC researchers made informal presentations at the U.S. Department of Energy and the National Renewable Energy Laboratory in December 2009 and at the U.S. Department of Interior in January 2010. We also briefed the newly formed Virginia Offshore Wind Coalition during these months.

Project 2 activities included focused individual engagement by privately meeting with many other stakeholders as well, including environmental groups (including the Virginia chapter of the Sierra Club, The Nature Conservancy, the Chesapeake Climate Action Network, and the Chesapeake Bay Foundation), local Navy commands, the Hampton Roads Military and Federal Facilities Alliance, commercial interests in the coastal recreation and tourism industry, the City of Virginia Beach, and neighborhood civic groups. Public outreach activities were developed and conducted for K-12 teachers and at informal science education venues (including Nauticus and the Virginia Aquarium). This broad spectrum of private engagement and public outreach activities has contributed to the generally favorable view toward offshore wind that many stakeholder groups now hold at the state and local level.

A final task under this project has been to plan the development of field test facilities. To this end, VCERC researchers have been exploring use of the Chesapeake Light Tower as a platform for hosting a variety of different instruments, including meteorological instrumentation sufficient to characterize the marine atmospheric boundary layer and wind shear profile up to 150 m above sea level, avian detection and tracking radar, and vessel traffic monitoring radar. We also have met with Navy and local officials to identify potential sites in Hampton Roads for a coastal wind turbine to be used as a test bed for measuring sensor and control system reliability in corrosive salt air, turbine response to tropical storm and hurricane winds, and military radar interactions. These two planning efforts – use of the Chesapeake Light Tower and development of a coastal wind turbine project – are ongoing and will continue after publication of this report.

Project 3: Evaluation of Economic Development Potential

Regardless of where the turbines are manufactured, *our hypothetical 588 MW offshore wind project would attract $403 million investment in the local economy ($685 per installed kilowatt),* associated with the following activities, in addition to on-site project management:

- Fabrication of turbine foundations (monopiles and transition pieces), involving a primary steel fabricator for the welded cylindrical sections, and a secondary steel fabricator for transition piece appurtenances, such as flanges, hatches, ladders, access platforms, and array cable J-tubes, as well as painting and sacrificial anodes for corrosion protection.
- Fabrication and outfitting of the electric service platform (ESP) where the 33 kV array cables interconnect and are stepped up to higher-voltage for transmission to shore.
- Offshore installation of foundations, towers, wind turbines, and the ESP would involve a variety of chartered vessels, as well as leasing of large waterfront areas, cranes, and other handling equipment for component staging and load-out operations. Lay barges for the array and export cables also would be chartered and outfitted locally with cable reels, lifts, and subsea work systems provided by second-tier suppliers in the state or region.
- Onshore transmission installation (underground cabling to Pendleton high-voltage substation from an underground vault where the submarine export cable makes landfall), installation of substation interconnection transformers and switchgear at Pendleton, and reinforcement of high-voltage overhead transmission lines from Pendleton to the Fentress 500 kV substation. Pendleton is only a 115 kV substation at this time and not capable of absorbing a large amount of interconnected generation. Land-based transmission upgrades are likely to need more than simple reinforcement of lines from Pendleton to Fentress, especially if the total interconnected offshore wind capacity is more than 600 MW. Transmission and substation upgrades could be needed at many different facilities located miles to tens of miles away from the coast, as would be determined by load flow analysis.

To develop the 3,200 MW of offshore wind capacity in the 25 OCS lease blocks identified by VCERC, at a notional build-out rate of 160 MW per year, the annual value of goods and services contracted to the local economy for the above activities would be about $110 million per year, totaling $2.2 billion after two decades. This is for the locally contracted items listed above and does not include potential one-time investments in new fabrication or manufacturing facilities.

As shown in Figure 10, locally contracted activities – fabrication of foundations, fabrication and outfitting of the ESP, offshore installation of all components and cables, onshore transmission installation and upgrades, and project management – combine to account for a quarter of the total project value (23% to 27%, depending on source of turbine supply). Submarine power cable fabrication accounts for nearly an eighth (11% to 13%, depending on source of turbine supply).

The vast majority of offshore wind project value (60% to 66%) is associated with the turbine supply contract. The one-time investment to build a turbine manufacturing plant (including a foundry for large castings, and separate facilities for blade fabrication, tower fabrication, and nacelle assembly) is estimated to be at least $500 million. Review of trade publications and conversations with turbine manufacturers suggest that a demand of 100 to 150 turbines per year (or 500 to 800 MW per year) for a minimum of 5 years is required to justify such an investment.

In terms of job creation, the National Renewable Energy Laboratory (NREL) estimates that offshore wind construction employment would total 39 job-years per installed megawatt (Reference 31). Economic modeling by Paliria Energy, Inc. and the Hampton Roads Planning District Commission estimates that nearly 12% of this total, or 4.6 job-years per megawatt, would be created in the local economy for the contracted activities listed above. Operations and maintenance requirements create an additional 1.1 to 1.7 local jobs per cumulative installed megawatt (Reference 31), sustained for the 20- to 30-year service life of the project.

The above estimates include direct, indirect, and induced jobs, categorized as follows:

- Direct jobs are the on-dock or at-sea installation jobs and in-plant jobs that directly produce purchased equipment or components (e.g. turbines, tower sections, foundations).
- Indirect jobs are in upstream sectors that supply materials (steel plate, turbine parts) and services (rail and truck delivery of materials and parts to the turbine assembly plant).
- Induced jobs are created by the spending of direct and indirect job-holders when their personal income from these jobs is spent in the local economy.

To translate these NREL job creation estimates to Virginia, VCERC has identified 25 OCS lease blocks with 3,200 MW of potential offshore wind capacity in relatively shallow Class 6 waters beyond the visual horizon. Build-out of this potential would require a total of 125,000 job-years, including direct, indirect, and induced jobs, assuming that it can be supported by Virginia-based turbine and power cable manufacturing plants. If sustained at a build-out rate of 160 MW per year (equivalent to one 320-MW project being commissioned every two years), this would support 6,200 jobs that could last for a two-decade career.

As noted above, these estimates assume that manufacturing of turbines and submarine power cables occurs in state. If these are sourced from outside the state, then a total of 780 jobs for locally contracted activities listed on the previous page could be sustained for 20 years.

Of the two types of manufacturing, wind turbine production would create many more jobs than submarine cable fabrication, due to the wide variety of materials and parts that must be produced to make components, which are then assembled in the nacelle. Because turbine supply also accounts for more than 60% of the total offshore project value, developing a domestic source of supply substantially reduces the cost of energy, as described in the first section of this report.

Once an offshore wind project is completed, new operation and maintenance jobs are created. Regardless of where the turbines or power cables are manufactured, these are estimated to accrue at 1.1 to 1.7 jobs per cumulative megawatt , reaching 3,500 to 5,400 jobs after the first 3,200 MW of near-term commercial potential off Virginia has been built out over the next 20 years.

Thus, within two decades, 9,700 to 11,600 career-length jobs can be created, solely associated with developing the 3,200 megawatts of offshore wind potential that VCERC has identified in shallow waters beyond the visual horizon off Virginia Beach. Since offshore foundations and submarine power cables are designed for a service life of 40 to 50 years, a second generation of jobs could be created for simply repowering the first 3,200 MW. Beyond this is a vast, deeper water potential that remains to be developed farther offshore.

OFFSHORE WIND RECOMMENDATIONS

This section is intended to serve as a comprehensive offshore wind "roadmap" for future commercial development, applied research, and government policy making activities.

Commercial Development Roadmap

The Minerals Management Service (MMS) Final Rule governing alternative energy development on the Outer Continental Shelf (OCS) was published on 29 April 2009 and became effective 60 days later (Reference 32). This rule implements the authority for leasing OCS submerged lands for development of offshore wind and other marine renewable energy resources, which was granted to the Secretary of the Interior by Section 388 of the Energy Policy Act of 2005.

Under this rule, MMS may invite any affected state governor or local government executive to join MMS in establishing a task force or other joint planning or coordination agreement. Task force members will be able to make recommendations and contribute to the MMS planning process and may be requested to conduct or oversee research, studies, or reports. MMS will consider input from the task force in determining appropriate siting of offshore wind energy projects and OCS leasing priorities.

On 15 September 2009, Governor Kaine sent a letter to MMS Director Elizabeth Birnbaum, formally requesting the formation of a federal-state-local task force to guide and facilitate the leasing process. A 22 September press release by the Governor's office announced this request and indicated that "Following a multi-year study by the Virginia Coastal Energy Research Consortium, a number of offshore wind developers have contacted the Commonwealth to share their plans to lease federal waters off Virginia to develop wind power."

The Minerals Management Service Virginia OCS Renewable Energy Task Force (or more simply, the "MMS Virginia Task Force") held its first meeting on 08 December 2009 in Virginia Beach. Total attendance was 58, including: 9 representatives from MMS; 41 representatives from State, Local, Tribal, and other Federal entities; and 8 members of the public who observed the proceedings. Information presented at this inaugural meeting is posted under the Virginia link at www.mms.gov/offshore/RenewableEnergy/stateactivities.htm, where the following presentations can be downloaded:

- Task Force Introduction
- Introduction to the MMS Leasing Process
- Introduction to the MMS Environmental Review Process
- Introduction to the Request for Interest (RFI)
- Offshore Wind Development Potential and Possible Timetables

The MMS Virginia Task Force is an intergovernmental group. Task Force members include Federal officials and elected state, local, and tribal officials, or designees. Meetings are open to the general public, including private industry and non-governmental organizations, who may attend as observers, but only Task Force members can participate in the proceedings.

Two Virginia companies have submitted unsolicited lease applications to MMS, each specifying OCS lease blocks on which they propose to develop offshore wind projects. These developers are Charlottesville-based Apex Wind Energy, Inc., and Richmond-based Seawind Renewable Energy Corp. (see References 33 and 34 for more information about these projects).

The MMS non-competitive lease process is estimated to take between 10 and 21 months, while the competitive lease process could require 21 to 36 months. Thus, commercial offshore wind projects in federal waters on Virginia's Outer Continental Shelf might need 1-2 years to obtain a non-competitive lease, or 2-3 years to obtain a lease if competitive auction is required.

Once a commercial lease has been awarded, we estimate 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). Preparation of the many individual permit applications required by federal and state agencies should start early during this phase, particularly for U.S. Army Corps of Engineers permits required under Section 10 of the Rivers and Harbors Act of 1899 (which regulates structures and work affecting navigable waterways) and Section 404 of the Clean Water Act (which regulates placement of fill materials).

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 begin and key permits should be in place before such large binding orders are made. Following a 3- to 5-year development phase, we estimate an additional 2 years will be required for installation and full commissioning of any project of several hundred megawatts. This is based on development and installation timetables for three large European offshore wind projects (see Appendix G).

Assuming that MMS decides to issue its Virginia Request for Interest (RFI) in the first half 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 overlapping geographic interests or any inter-tract competition due to onshore grid constraints. Under a non-competitive leasing scenario with the most optimistic development and installation timetable, a large project could be fully commissioned as early as 2016-2017. Under a competitive leasing scenario with the most pessimistic development and installation schedule, a large project might not be fully commissioned until 2019-2020. Taking the median point between these scenarios, we believe that *2018 is a reasonable target date for full commissioning of a large offshore wind project on Virginia's OCS*.

Backing up from a project commissioning date of year-end 2018, long-lead items such as wind turbines and submarine power cables must 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 under Project 1 results, having turbines supplied from an assembly plant in Hampton Roads rather than from Europe would 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 manufacturer's decision to invest in such a plant and qualify its supply chain must 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, must be known by year-end 2011*.

Wind turbines designed for the Danish, German, Dutch and Belgian sectors of the North Sea, where the hub-height mean annual wind speed is in the range of 9 to 9.5 m/sec, have rotor swept areas that are too small to be cost-effective in Virginia's offshore wind climate, where the mean annual wind speed ranges from 8 to 8.5 m/sec at a hub height of 80 m (see Appendix C). Design of a more suitable rotor swept area requires that we improve our understanding of the wind speed vertical profile offshore and reduce the uncertainty in our hub height wind speed estimates. We also need to better understand the location and horizontal extent of divergent, weak wind zones associated with sea breeze circulation cells that develop along the Mid-Atlantic coast during warm afternoons, particularly during summer months of peak power demand.

If a turbine manufacturer is to develop a new turbine rotor design that is optimally cost-effective for Virginia's offshore wind climate, then a much more accurate understanding of the offshore wind resource is needed. To accomplish this requires two parallel and coordinated development activities: (1) application of existing time-domain numerical simulation models of coastal and offshore winds to map this resource for at least two full calendar years with sufficiently high resolution in time (hourly) and space (200 m horizontally and 10 m vertically); and (2) physical validation of numerical model results based on existing offshore measurements (such as the fixed anemometer at NOAA C-MAN station CHLV2) and newly installed tall meteorological towers specifically designed for offshore wind power applications. Such offshore met towers typically are funded by commercial project developers at prospective project sites to which they anticipate exclusive access through an MMS-awarded lease, and the data are considered proprietary.

It is recommended that VCERC lead in developing a collaborative proposal involving Virginia, North Carolina, Maryland, Delaware, and New Jersey to undertake a multi-university, multi-state met-ocean modeling and measurement program. A combined order for offshore met towers, to possibly include private developers who have "interim policy" leases for met towers off NJ and DE, as well as research towers off MD, VA, and NC would enable economies of mass production in a single design-build-and-install contract for four or five offshore met towers. Private developers who provide funding toward such a combined order would not be asked to publish their measured project-specific data, but only to release their data internally for physical validation of numerical models. As described below, in "*Regional Policy Recommendations*" under the "Government Policy Roadmap" section, we recommend the Mid-Atlantic Coastal Ocean Observing Regional Association as a well-qualified and experienced organization to undertake this project and manage data collection and protection of proprietary data.

Because *accurate wind speed estimates are required by year-end 2011 to be timely for turbine supply chain investment, we recommend that MD, VA, and NC (who were not included in the "interim policy" leasing program) apply for Section 238 "research leases" as described in § 285.238 of the new rule*. Clause (c) of this section indicates that MMS may issue leases for research activities managed by a Federal agency or a State only in areas for which no commercial interest exists. To avoid this potential conflict, the states should require in their RFIs that commercial lease applications from developers must allow use of the 1/16-block (1.2 km x 1.2 km) areas on which any Section 238 met towers are sited. Such a requirement would fall under the category of "Any other information requested by MMS in the Federal Register notice." per § 285.213 (f) of the new rule, which describes what information developers must submit in response to the RFI.

Applied Research Roadmap

The highest priority research item is the met-ocean modeling, mapping, and measurement effort described above. While the other research activities, described below, could be accomplished entirely within Virginia, *the above-described met-ocean research program should be undertaken collaboratively with universities in other states*.

As described above, we predict a 7- to 8-year window between now and the full commissioning of a commercially viable, large offshore wind project in federal waters off Virginia. This gives the Commonwealth an opportunity to design and develop a dedicated offshore wind supply chain that is specifically adapted to the Mid-Atlantic ocean environment and which can commercialize innovations in (1) wind turbine design, (2) offshore installation, and (3) offshore electrical interconnection and transmission. Each of these three research areas is described below.

Wind Turbine Design. As mentioned previously, Vestas recently announced the availability of a new offshore turbine model, the V112 (Reference 15), which features a 3 MW drive train and generator with an increased rotor diameter of 112 m rather than 90 m. A new cost-of-energy estimate should be performed as soon as pricing is available for the V112. This recommendation holds true for other new turbine makes and models, particularly those developed exclusively for the offshore wind environment (e.g., see References 16, 17, 18, and 19).

Appendix C suggests that a turbine optimally designed for Virginia's offshore Class 5 and Class 6 wind regimes should have a rotor swept area per unit generator capacity in the range of 3,200 to 3,500 m^2 per MW. Moreover, the tower-top mass per unit rotor swept area should be as low as possible in order to minimize the natural frequency of the turbine-tower-foundation structure, which is the governing driver of monopile mass and cost (see Reference 35 for details).

A widely accepted strategic roadmap for U.S. wind power development is the U.S. Department of Energy's "20% Wind Energy by 2030" report dated July 2008 (Reference 36). Section 2 of that report evaluates advances in wind turbine technology, assuming that capital costs would be reduced by 10% over the next two decades, while capacity factors would be increased by about 15%, corresponding to a 15% increase in wind turbine annual energy generation. This increased annual output would be obtained by capturing more energy with a larger rotor swept area or through better turbine reliability, or a combination of both. The challenge is achieving greater rotor swept area while maintaining or improving reliability and reducing capital costs.

Turbines with a larger-diameter rotor will be more costly unless blade weight can be maintained or reduced, and unless the rotor-nacelle assembly experiences the same or reduced thrust loads. While this might be done by using an active control system to sense upwind turbulence and reactively alter blade pitch, this adds to turbine complexity and wear and tear on blade pitching mechanisms, thereby reducing turbine reliability. *A more reliable approach might be to develop a downwind rotor with lighter, more flexible blades that deflect at high wind speeds to reduce thrust loads by enabling the rotor to "cup" downwind so it presents a smaller projected area*. The challenge will be to avoid blade "snap back" and tower strike under certain fault conditions. While some turbine manufacturers are exploring downwind concepts (see next page), such a new design will require type certification, as well as the installation of a full-scale prototype for several years before its reliability can be assured for offshore commercial use in large numbers.

Today's upwind rotors must be stiff enough to maintain clearance from the tower under extreme loading conditions. Despite blade and weight and cost penalties associated with this requirement, manufacturers moved away from downwind rotors due to fatigue effects and noise caused by blades passing through the tower shadow. Noise is not as great a concern for offshore turbines located beyond the visual horizon, and modern composite design tools and materials can produce acceptable downwind rotor designs to accommodate fatigue effects. Two successful examples of commercially available downwind turbines for land-based applications are the Vergnet 1 MW two-bladed turbine (Reference 37) and a 2 MW three-bladed turbine jointly developed by Fuji Heavy Industries (manufacturer of Subaru vehicles) and Hitachi (References 38 and 39).

As a further design improvement, moving from a three-bladed rotor to a two-bladed rotor that would spin at a higher rotational speed can achieve the same wind energy absorption efficiency for a blade length increase of less than 2%. The *elimination of one blade with such a small increase in length of the remaining two blades should yield a substantial net savings in rotor fabrication cost*. This has been recognized by the Dutch company 2-B Energy, who plans to demonstrate a 6 MW offshore two-bladed downwind turbine in 2012 (Reference 40). Existing land-based two-bladed turbines include the Vergnet 1 MW downwind turbine mentioned above, and the Nordic 1 MW upwind turbine that has recently begun commercial serial production in Idaho (Reference 41). For offshore applications, the net savings in 2-bladed rotor fabrication cost must be weighed against higher rotational and blade passing frequencies, which would require stiffer tower sections to avoid sympathetic vibration at these resonant frequencies.

Coastal Turbine Demonstration Project. Installation of an ocean-class turbine that would be readily accessible on or near shore is needed to demonstrate the performance of a larger rotor (possibly downwind, possibly two-bladed), as well as address two additional research needs:

- European experience has indicated that "marinization" of land-based turbines does not ensure they can withstand the aggressive salt-air environments that occur offshore. A coastal turbine demonstration just seaward of the shoreline is needed to *verify reliable corrosion protection of equipment and components within the turbine nacelle*, as well as providing an easily accessible platform for measurements to *verify the reliability of remote systems for turbine supervision, control, and data acquisition (SCADA)*.
- The Navy, NASA, Coast Guard, and Federal Aviation Administration have significant concerns about radar interactions. Although *mitigation measures have been proposed that involve the use of signal processing techniques, these must be tested with full-scale turbines in an operational multi-radar environment*. Full-scale Doppler measurements also are required to accurately represent turbine radar signatures in numerical models that would simulate radar interactions for hundreds of turbines in a large offshore wind project or multiple projects. This is important for navigation radars on moving ships and aircraft, as well as shore-based air traffic control and surface search radars, which are stationary.

While serving as an experimental facility to measure large-rotor dynamics, drive train reliability, SCADA performance, and radar signature, a coastal turbine also could be used to qualify first- and second-tier suppliers of components and materials to be used in turbine manufacturing. Therefore, selection of a suitable make and model for the coastal turbine demonstration should be directly connected with selection of a turbine manufacturer interested in and willing to invest in a manufacturing complex for that same model in the Hampton Roads region.

Offshore Installation. The installation of monopile-based offshore wind turbines can involve up to seven different offshore crane lifts required to (1) lift a monopile into place for driving into the seafloor; (2) lift and grout a transition piece to the monopile; (3, 4, 5) lift and bolt together three conic sections to erect the tower; (6) lift the nacelle with two pre-attached blades ("rabbit ears") onto the tower top where it is bolted into place, and (7) lift the third rotor blade into place and bolt it to the rotor hub. European practice is to have one equipment spread for lifts (1) and (2), and a different spread for lifts (3) through (7), after the transition piece grout has fully cured. *The required weather window must have a significant wave height less than 1.5 m (for jacking up and down operations) and a wind speed less than 11 m/sec (for positioning tower-top items), and this combination occurs off Virginia Beach only ~120 days per year*.

Crane-lift operations require either a jack-up rig or specialized installation vessel. Due to the high demand for such installation vessels in Europe and Jones Act concerns, U.S. offshore wind developers cannot rely on having these vessels mobilized from Europe. While jack-up rigs can be mobilized from the Gulf of Mexico, there is risk that these vessels may not be available due to demands of the offshore oil & gas industry, as well as risk of loss or damage during transport (as happened with a jack-up lost in transit from the Gulf of Mexico to Liverpool Bay, delaying completion of the UK Rhyl Flats offshore wind project by six months). Moreover, as fossil fuel prices escalate in the future, lease rates for Gulf of Mexico jack-ups may become prohibitively costly to the point where it would be less expensive for project developers to own and operate installation vessels dedicated to their projects, thereby mitigating all of the above risks.

Assuming that design and fabrication of domestic, purpose-built installation vessels is the most cost-effective solution for commercial offshore wind development in the Mid-Atlantic, then rather than simply duplicating the multiple-crane-lift vessel systems used in Europe, VCERC recommends evaluating a "float and flip" method that avoids crane lifts altogether. This would derive from the "Merlin" concept developed in the UK in 2004 (Reference 42), whereby a fully commissioned turbine and tower assembly is lowered into a lifting cradle on a barge, and the barge is towed to the offshore installation site. The lifting cradle then angles the turbine back up to vertical and lowers the tower into the center well of a previously installed seafloor foundation.

In addition to eliminating all offshore crane lifts and bolting together of crane-held components, the Merlin installation system uses a foundation that does not terminate in an above-water flange (as in monopile transition pieces). The Merlin foundation terminates in a center well just above the seafloor, into which the bottom section of the tower and turbine assembly is stabbed and then grouted into place. Dynamic heave compensators on the lifting cradle are used to minimize relative vertical motion between the barge and foundation, such that tower stab-in and "landing" decelerations are acceptable to wind turbine manufacturers. *Merlin's tow-out and installation can be accomplished in conditions up to Sea State 4 (significant wave heights less than 2.5 m), nearly tripling the total installation weather window off Virginia Beach to ~350 days per year*.

Before committing to build a supply chain around such a novel concept, VCERC should perform a Virginia-specific cost-benefit analysis of a "float and flip" installation system derived from the Merlin concept. At the time of the 2004 UK report, the new-build cost of a towed Merlin barge was estimated to be half that of a towed jack-up rig and five times less than the new-build cost of a self-propelled turbine installation vessel (see Reference 42 for details).

Rather than using a driven large-diameter monopile, with its attendant loud noise that may be unacceptable when marine mammals are present, the Merlin foundation design lends itself to a variety of minimal-foundation types. Alternative seafloor mating structures for the upended tower include a steel trusswork template with small-diameter skirt piles (which can be driven with lower-energy, quieter hammers), a gravity base (as developed by grout manufacturer, Densit ApS), or a suction-caisson monobucket (as developed by Danish utility, Dong Energy). In addition to estimating the life-cycle cost of a "float and flip" turbine installation system, *VCERC also should investigate these alternative minimal-foundation concepts and their applicability to the sediment types found within the 30 m depth contour off Virginia.*

Electrical Interconnection and Transmission. At present, Fentress substation in Chesapeake, Virginia is the only 500 kV substation in the PJM regional transmission system that is within 20 km of the shoreline. In order to resolve looming reliability criteria violations and market congestion issues, PJM has already planned six major backbone upgrades to their Extra High Voltage (EHV) system. These include four coastal upgrades, mapped in Figure 12.

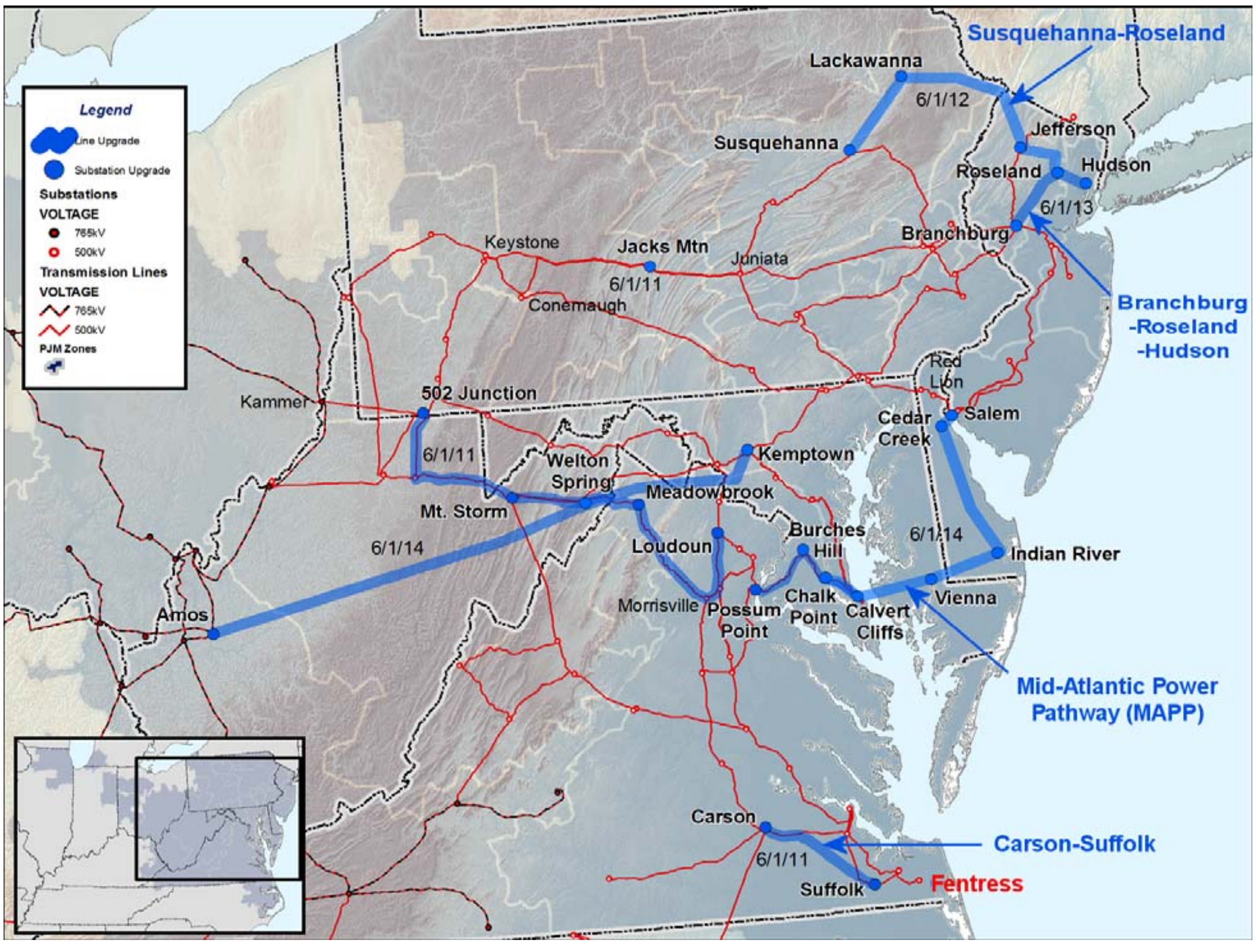
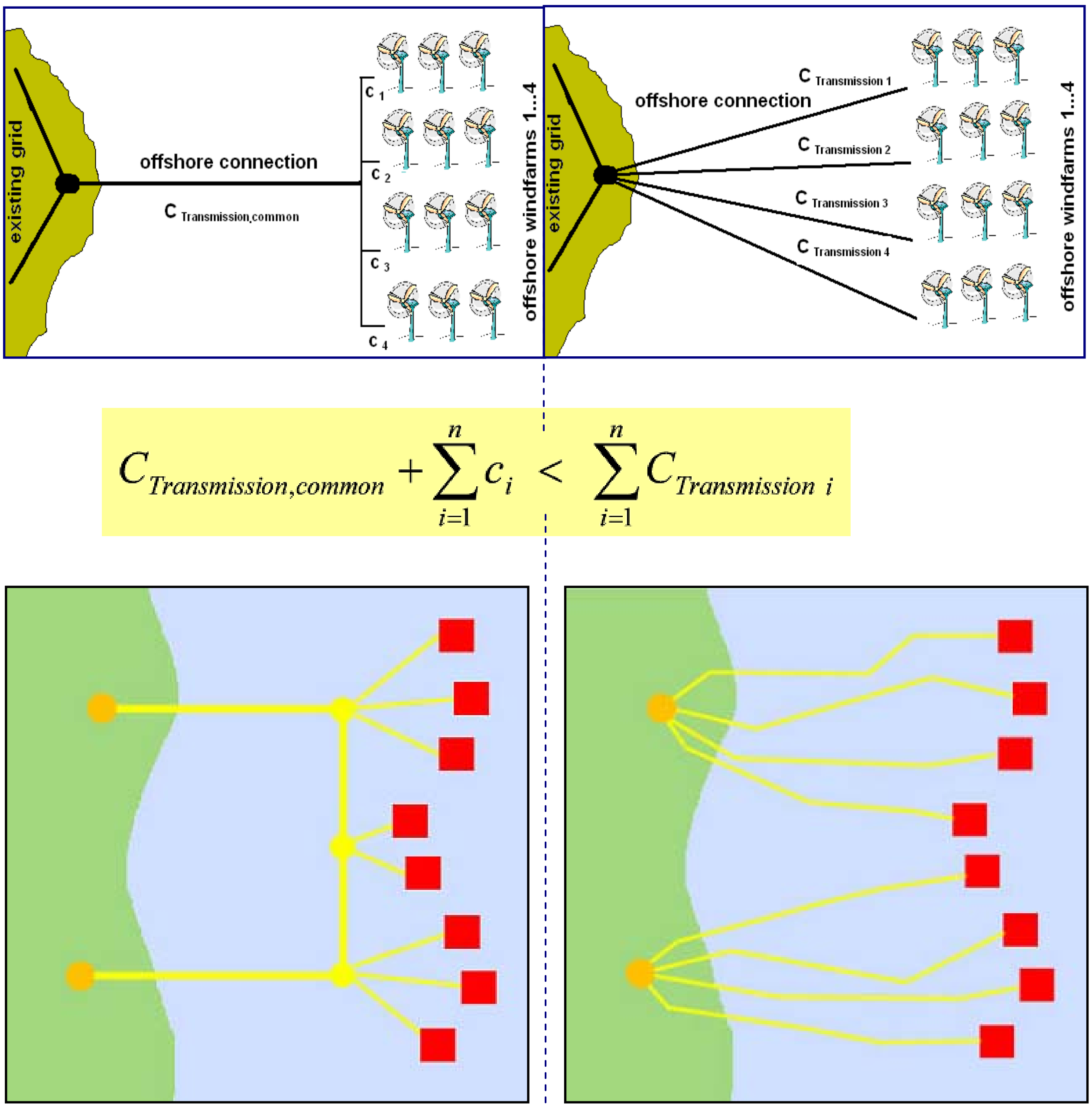


Figure 12. PJM-published map of EHV backbone upgrades, with planned in-service dates noted in m/d/yy format. By 2014 there will be two additional 500 kV substations that are as close to the coast as Fentress: one at Hudson, New Jersey, and one at Indian River, Delaware. Source: www.pjm.com/planning/rtep-upgrades-status/backbone-status.aspx.

Commercial offshore wind projects also are now being proposed off New Jersey, Delaware, and Maryland. By having a limited number of sea-to-shore export links, the total capital investment and cumulative environmental effects of having each project connected to the onshore grid by its own export cable would be higher than if the projects were connected to a common offshore "backbone" that made landfall at only a few designated shore crossing points, as conceptually illustrated below. The challenge is to make a business case for investing in a common export cable that is suitably large for multiple large projects connecting to it over years to decades.



$$C_{Transmission,common} + \sum_{i=1}^{n} c_i < \sum_{i=1}^{n} C_{Transmission\ i}$$

Figure 13. Conceptual diagram illustrating how a common offshore transmission "backbone" can reduce overall economic and environmental cost functions for interconnecting multiple offshore wind projects to the onshore transmission grid. Source: Reference 43.

Comparison of Figures 12 and 13 suggests that such a backbone might be suitable for offshore wind projects connecting into the PJM regional utility grid. Such a backbone also would enable commercial projects in Virginia's large offshore wind resource area to supply PJM customers in Maryland, Delaware, New Jersey, and Pennsylvania (see Figure 11). Selling offshore wind power to customers in these states may be commercially viable sooner than selling into Virginia, due to (1) generally higher electricity prices, (2) longer history of renewable portfolio standards, with higher-value renewable energy certificates, and (3) better seasonal load match between offshore wind output and the winter peak in energy prices in these more northern states. Subject to the arrangement of transmission service and addition of suitable grid upgrades, however, *the existing PJM onshore transmission system is capable of carrying Virginia's offshore wind to customers in these northern states without requiring an offshore backbone.*

Different merchant transmission companies are now evaluating the economic feasibility of developing a high-voltage offshore transmission network that would provide a common link for interconnecting multiple offshore wind projects, as well as providing the capacity to move bulk power north-south among four different regional transmission systems, namely the Southern Electric Reliability Council, PJM, the New York ISO, and ISO New England. Note, however, that *using an offshore backbone that directly connects Virginia with New York and New England could have the unintended consequence of raising energy prices in Virginia*. Offshore merchant transmission would extract value from electricity markets by shipping power from low-price regions to high-price regions, which would tend to raise prices on the sending end over time. This might have a damaging economic development impact that could more than offset benefits of developing a Virginia offshore wind supply chain.

Load flow modeling of various offshore interconnection scenarios, and their impact on regional congestion and local power prices should be simulated at different levels of offshore wind development along the offshore backbone, building on the findings and methodology of the Eastern Wind Integration and Transmission Study that was recently completed by NREL. A key objective should be to evaluate the difference between moving power within PJM and moving power from PJM to neighboring regional transmission systems in New York and New England. *Such modeling requires a high-fidelity time-domain simulation of the regional wind resource*, as recommended earlier, which preserves the hour-by-hour variability of wind speeds and how well they are correlated (or not) at different offshore wind project locations along the east coast from Cape Hatteras, NC to Cape Cod, MA, as well as how well they are correlated (or not) with onshore electrical loads. Most importantly, all modeled transmission – new construction or upgrade, on-shore or offshore, merchant or regulated – must be developed in a manner that is fully compliant with mandatory nation-wide standards established by the National Electric Reliability Corporation (see www.nerc.com/page.php?cid=2%7C20 for listing and download).

Various offshore network transmission topologies also should be investigated, evaluating both gas-insulated alternating current (GAC) and high-voltage direct current (HVDC) modes for the long-distance transmission links. The design and cost of array cables interconnecting turbines within each project will be determined by the mode of long-distance transmission (GAC or HVDC), as will the design of the electric service platform, and the design and cost of the turbines themselves also will be affected, as described on the next page.

At present, all commercial wind turbines produce grid-synchronous alternating current (AC) electricity at a constant frequency of 50 or 60 Hz. Variable-speed turbines are more efficient at capturing energy from time-varying wind speeds than constant-speed turbines. Such turbines generate asynchronous, variable-frequency AC and then use high-voltage power electronics to rectify the AC to DC and then invert the DC to grid-synchronous AC. Any HVDC backbone topology that involved conversion to AC on shore would enable the offshore turbines to generate DC, resulting in cost savings by eliminating the need for inverter electronics in each turbine. Any future study evaluating an HVDC offshore grid network should consider this impact on turbine design and cost-savings associated with eliminating inverter electronics from the turbine.

Finally, any study of an offshore high-voltage transmission network should consider the supply chain necessary to build out the system, and how this would compare with the supply chain for several independent offshore wind projects, each with its own export cable to shore. Dedicated cable transport and installation vessels also must be included in this assessment. Given that there are no high-voltage submarine power cable fabrication plants on the U.S. east coast at this time, *it is important that this study be accomplished by year-end 2011 so that sufficient lead time is available to design and build a suitable offshore transmission supply chain.*

Before any substantial investment is made in modeling an offshore transmission backbone, the existing transmission system in Virginia Beach and surrounding cities and counties should be modeled to determine the maximum capacity of Atlantic offshore wind that can be connected into the local Hampton Roads grid. The existing on-shore grid may be adequate if offshore wind is interconnected at 500 kV. The need for an offshore backbone could be far into the future, given the existing on-shore grid configuration, load and generation patterns and PJM market rules.

Modeling an offshore Mid-Atlantic transmission backbone should be considered only after evaluating the existing on-shore transmission grid in eastern Virginia. <u>To recap previous points</u>, wholesale price differentials between Virginia and other states within PJM are not likely to be large enough to justify construction of an offshore grid, and RECs for generators connected anywhere in PJM already are fungible and salable to retail markets of any other state within the PJM region. Therefore, if Virginia's cost share of an offshore backbone is financed in the regulated utility rate base, it could substantially raise energy prices in Virginia. Alternatively, a business case might be made for privately financing it as merchant project, but this may be comercially feasible only if connecting PJM to higher-price energy markets in New York and New England, and this also might raise Virginia energy prices as described on the previous page.

Economic Model Validation. Although the offshore wind cost and performance model developed by VCERC has been validated for a few cost centers of large European offshore projects, more extensive validation is needed. Construction risks are very high in the offshore environment, and there are many more inter-related variables than exist for a large land-based wind project. Each of the three main research projects described above should not be conducted in isolation but should be fully informed by their incorporation into the same or a similar full project cost and performance model. Moreover, the cost and performance model itself needs to be rigorously validated with data from as many actual offshore projects as possible for which such data can be found or made available.

Government Policy Roadmap

As mentioned previously, VCERC has supported the state's engagement with the U.S. Minerals Management Service (MMS) to ensure that implementation of the new MMS rule for alternative energy uses of federal waters on the outer continental shelf, as well as any offshore oil and gas leasing off Virginia, are well-supported by data and have the best possible terms for the state. Next steps already have been described for the federal-state-local task force that will guide the MMS leasing process for commercial offshore wind development on Virginia's OCS. This section will review executive, legislative, and regulatory policy steps, which can be taken at the federal and state level, as well as recommendations for multi-state regional cooperation.

Federal Policy Recommendations: MMS draws its offshore wind regulatory authority from Section 388 of the Energy Policy Act of 2005. As specified in the MMS rule that was finalized in June 2009, the federal government would derive "fair return" for the use of Outer Continental Shelf (OCS) submerged lands by collecting various payments from the developers of commercial offshore wind projects, including area-based lease fees and energy production-based royalties.

Under existing law, federal-state revenue sharing of these payments would occur only for lease areas located between 3 and 6 nautical miles offshore, in the so-called "8(g)" zone. Off Virginia, development would be almost completely excluded from this zone by Navy and Coast Guard restrictions associated with the military and commercial shipping uses mapped in Figure 9. Moreover, the visual impacts of large offshore wind turbines would be much more severe for projects located in the 8(g) zone than for projects beyond 12 nautical miles offshore. Finally, the 8(g) zone has largely Class 4 and 5 wind speeds, which are less commercially viable to develop than the Class 6 winds which lie beyond 12 nautical miles offshore, as shown in Figure 11. Therefore, *it is recommended that a different determinant be used to qualify states for federal revenue sharing of lease and royalty payments*, which would require a new act of Congress.

Another important area of federal policy making has to do with the question of planning and providing financial and regulatory incentives for high-voltage transmission lines between renewable energy projects and the customers that they serve. The American Wind Energy Association (AWEA) and the Solar Energy Industries Association (SEIA) advocate "green power superhighways" that would connect large wind and solar power developments in the west to coastal metropolitan markets. Federal policy recommendations made by that report include having Congress direct FERC to allocate the costs of these transmission lines across all retail electricity providers, in proportion to their electricity sales, and granting FERC the same full siting authority for electrical transmission lines that it now has for interstate gas pipelines.

In response to the AWEA/SEIA report, governors of 11 east coast states, including Virginia, signed a letter written to the leaders of Congress in May 2009, opposing the allocation of such transmission costs throughout the entire interconnection region, which would amount to east coast ratepayers subsidizing the development of Midwest and Great Plains wind energy. This letter suggests that if transmission is to be addressed at all in national energy legislation, it should support regional energy solutions, which on the east coast could take the form of a high-voltage offshore wind transmission "backbone" to facilitate interconnection of offshore wind projects, technical aspects of which were described earlier, under "*Electrical Interconnection and Transmission*" in the "Applied Research Roadmap" section of this report.

The May 2009 letter also requested that Congress "encourage FERC and NERC [the North American Electric Reliability Corporation] to support and facilitate robust planning ***within*** *regional transmission organizations* that provides and promotes local renewable resources integration and preserves local oversight and review." In November 2009, governors of four east coast states (NJ, DE, MD, and VA) followed up on this point, asking that FERC direct PJM to file a revision to its Regional Transmission Expansion Plan (RTEP) by 01 June 2010, to include evaluation of an offshore transmission backbone system, even if not needed to address reliability and congestion issues (Reference 44). This was in response to FERC's request for comments on open access transmission tariff reform and transmission planning under its Order No. 890.

Virginia should continue to participate in following up the May 2009 letter and November 2009 comments to FERC. The three states (Virginia, Maryland, and Delaware), who entered into a memorandum of understanding (described under "*Regional Policy Recommendations*" later in this section) can coordinate such activities.

It is further recommended that the 11 signatory states of the May 2009 letter add Pennsylvania and three southeastern states (NC, SC, and GA) to *form a Congressional caucus of 15 states that would urge appropriate federal regulatory and legislative actions to ensure that any studies of a north-south offshore wind transmission backbone be coordinated across all four east coast transmission systems*: ISO New England, the New York Independent System Operator, PJM, and the Southern Electric Reliability Council. This caucus also should urge FERC and MMS to establish a streamlined permitting regime for such an offshore transmission backbone.

State Policy Recommendations: VCERC's contribution helping to inform Governor Kaine's decision to form a federal-state-local task force to guide the MMS leasing process has been described above, under the "Commercial Development Roadmap." That section recommends Virginia (and also Maryland and North Carolina) apply for a "Section 238" research lease for the installation of an offshore meteorological and avian data acquisition tower. This would enable acquisition of much needed baseline environmental data and wind resource data one to two years before such a tower could be installed by a commercial developer, since developers cannot be expected to finance such a tower until they have been awarded a commercial lease by MMS, and as previously mentioned, that could take as long as three years under a competitive scenario.

As recommended below, the Mid-Atlantic Coastal Ocean Observing Regional Association (MACOORA) would be a good candidate for operating any such tower installed on Section 238 research leases off Virginia, Maryland, or North Carolina, being well qualified to manage data collection, quality control, analysis, and archival. Under MMS rules, however, it is *ONLY a state or federal agency that can apply for a Section 238 research lease, and we recommend that the state (rather than a federal agency) make such application as soon as possible*.

Having identified MMS rule Section 238 as an appropriate type of lease and MACOORA as an appropriate agent to manage offshore data acquisition, the next steps are for Virginia to apply for such a research lease and to finance tower fabrication and installation. To this end, and for other purposes, the 2010 General Assembly passed SB577 sponsored by Senators Donald McEachin and Frank Wagner, and HB389 sponsored by Delegate Bill Janis, creating the Virginia Offshore Wind Development Authority (VOWDA).

SB577 and HB389 create VOWDA as a body corporate and a political subdivision of the Commonwealth and is charged with the following activities:

(1) Collect meteorological, oceanographic, avian, and marine environmental data, working with NOAA to upgrade its equipment on the Chesapeake Light tower, and/or establishing a public-private partnership to design, fabricate, and install new offshore towers.

(2) Establish public-private partnerships for the upgrade of port facilities and other logistical equipment and sites to accommodate the manufacturing and assembly of offshore wind energy project components and vessels that will support the construction and operations of offshore wind energy projects, working with relevant local, state, and federal agencies.

(3) Ensure that the commercial development of offshore wind is compatible with other ocean uses, including both possible interference with and positive effects on: naval facilities and operations, government and commercial space flight operations, shipping lanes, recreational and commercial fisheries, and avian and marine species and habitats..

VOWDA is to be composed of 11 non-legislative citizen members appointed by the Governor, who are to serve without compensation. The enabling legislation names the Director of DMME as the Director of VOWDA, and DMME staff as staff to VOWDA. The bill directs DMME to: (i) request that the incumbent, investor-owned utility adjacent to any offshore wind generation project initiate a transmission study and report the findings of that study to VOWDA; and (ii) report to VOWDA by 30 September 2010 on the appropriate placement of any new offshore towers and any necessary renovations to existing structures (such as the Chesapeake Light tower) for the collection of meteorological and oceanographic data.

On behalf of the Commonwealth, VOWDA is authorized to apply to the U.S. Department of Energy for federal loan guarantees authorized or made available by the Energy Policy Act of 2005, the American Recovery and Reinvestment Act of 2009, or any similar federal legislation. *VOWDA also is the best-suited state entity to apply for Section 238 leases in federal waters for met tower installation or other wind energy research projects beyond 3 nautical miles offshore.*

The 2010 General Assembly also passed HB1022, introduced by Delegate Tim Hugo, which provides that an investor-owned electric utility will receive triple credit toward meeting the state's voluntary Renewable Portfolio Standard goal for offshore wind, as compared with land-based wind and solar, which are worth double the standard credit for other renewable sources such as biomass and hydroelectric. This will help stimulate market pull for utility-owned projects that supply Virginia ratepayers, but "big ticket" supply chain investments such as turbine manufacturing and cable manufacturing will require more market pull than is possible in any one state, and regional or national incentives also are needed.

The above-described legislative initiatives enacted by the 2010 General Assembly were strongly supported by a new membership organization, the Virginia Offshore Wind (VOW) Coalition, which was formed in November 2009. The VOW Coalition includes localities, manufacturers, electric utilities, project developers, and maritime services who have joined together to promote development of an offshore wind industry in Virginia (see www.vowcoalition.org for details).

Offshore Wind Potential in State Waters: In its 2009 legislative session, the General Assembly passed SB1350, introduced by Senator Wagner, which enlarges on the existing authority of the Virginia Marine Resources Commission (VMRC) to lease subaqueous lands in state waters, specifically authorizing leases for the purpose of commercial production or transmission of marine renewable energy, including but not limited to offshore wind power. SB1350 has four enactment clauses, described below:

(1) The first enactment clause amends § 28.2-1208 in Chapter 766 of the Code of Virginia on granting easements in or leasing subaqueous lands in state waters, as follows:

- Adds new language for marine renewable energy generation and transmission
- Specifies lease terms not to exceed 30 years; purchase payments for easements and production-based royalties remain to be determined
- Requires all production-based royalties from generation or transmission of electrical or compressed air energy from marine renewable resources to be appropriated to VCERC

(2) The second enactment clause directs the VMRC to:

- Identify 100 acres suitable for use by VCERC as a research test bed
- Determine if sufficient subaqueous lands exist in state waters to support commercial generation and transmission of offshore wind energy
- Submit report of above findings to the General Assembly by 01 March 2010

(3) The third enactment clause states that if such land exists, the VMRC shall offer the land for development in a lease auction pursuant to requirements and provisions of subsections A and B of § 28.2-1208

(4) The fourth enactment clause states that nothing in this act requires or prohibits auctions of leases for generation or transmission of renewable energy in federal waters of the outer continental shelf (OCS)

The VMRC report directed under (2) above has been prepared and submitted to the Governor and General Assembly (Reference 45). A brief summary of its findings is given below.

Through geospatial data analysis and mapping, the VMRC found that there are no large areas in state waters that are sufficiently free of conflict with other interests to enable development of industrial-scale offshore wind projects of more than 100 MW capacity. There may be suitable areas of lesser conflict where community-scale offshore wind projects might be installed, which could consist of a single turbine or perhaps one or two rows of a few turbines.

The above finding is based on considering the level of potential conflict with other resources and uses. Four levels of such conflict were identified, as described below and mapped in Figure 14.

<u>Excluded Areas</u>: Areas for which there is a legally defined use or protection. These include navigation channels and anchorages, military security and training areas, Federal Aviation Administration restricted air space, the NASA Wallops Flight Facility Hazard Area, Baylor Grounds (public oyster grounds) and private shellfish leases.

Major Potential for Resource and Use Conflict: Areas where there are significant use or resources conflicts that would appear to preclude wind energy development. Examples of areas suggested for this category include sensitive shallow water areas with depths less than 2 meters, including the Eastern Shore lagoon system behind Virginia's barrier islands, and areas along the coast that are of continental and global importance to birds due to the large number of species and individuals that migrate through this corridor and overwinter in the area. This bird importance area includes much of the Bay mouth that overlaps or is near blue crab spawning and nursery areas and fishery, marine mammal and turtle migratory corridors as well as high commercial shipping traffic and popular recreational use areas including those near recreational beaches.

Moderate Potential for Resource and Use Conflict: Areas where there appears to be some use or resource conflict, but with further analysis might possibly be considered suitable for leasing. Examples of areas suggested for this category include areas with depths from 2 to 4 meters and areas of regional bird importance due to the concentration of breeding and overwintering species. This may also include sand resource areas, and fishing reefs, as well as certain fishery management areas as established by State Code or regulation.

Lesser Potential for Resource and Use Conflict: Areas that may be suitable for leasing, recognizing that detailed environmental and use analysis will be needed before permits and leases can be issued. This includes some portions of the designated blue crab sanctuary within the main-stem of the Bay, potential hard clam resource areas and fishery management areas, as well as potential historic resource conflict areas and areas near dredge disposal sites that are not already within areas considered to be excluded or have moderate or major resource or use conflicts.

A wind resource map of the Lesser Conflict areas is given in Figure 15. Only a small area on the Bay side of Northampton County contains Class 5 winds. The largest areas of Lesser Conflict are in Class 4 and Class 3 resources located due east of the Northern Neck and Middle Peninsula. Small areas possibly suitable for siting one or two turbines may exist in western Hampton Roads.

It might be thought that lesser-class wind resources could be commercially viable in the shallow waters of the Chesapeake Bay, because extreme storm waves break before they can build to the heights possible in deeper Atlantic waters. Depth-limited wave heights do not translate into significant foundation cost savings, however, because the sectional properties of the monopile foundation and tower are governed by the required stiffness needed to avoid sympathetic vibration at frequencies resonant with the frequency at which the turbine rotates and at which the blades pass the tower. Satisfying this condition leads to support structure designs that are more than adequate to resist 50- or 100-year wave loads characteristic of 20- to 30-meter water depths in the Atlantic Ocean (Reference 35).

As shown in Figure 16, hurricane risk simulation for the coastal United States (Reference 46) suggests that for a given return period, extreme wind speeds are at least 10 miles per hour slower over Chesapeake Bay waters than over coastal Atlantic waters off Virginia Beach. Pending the development of industry-accepted extreme wind design standards and subject to more detailed analysis, it is possible that community wind turbines in the Chesapeake Bay could safely utilize larger-diameter Class II rotors, better suited to the lesser wind classes there.

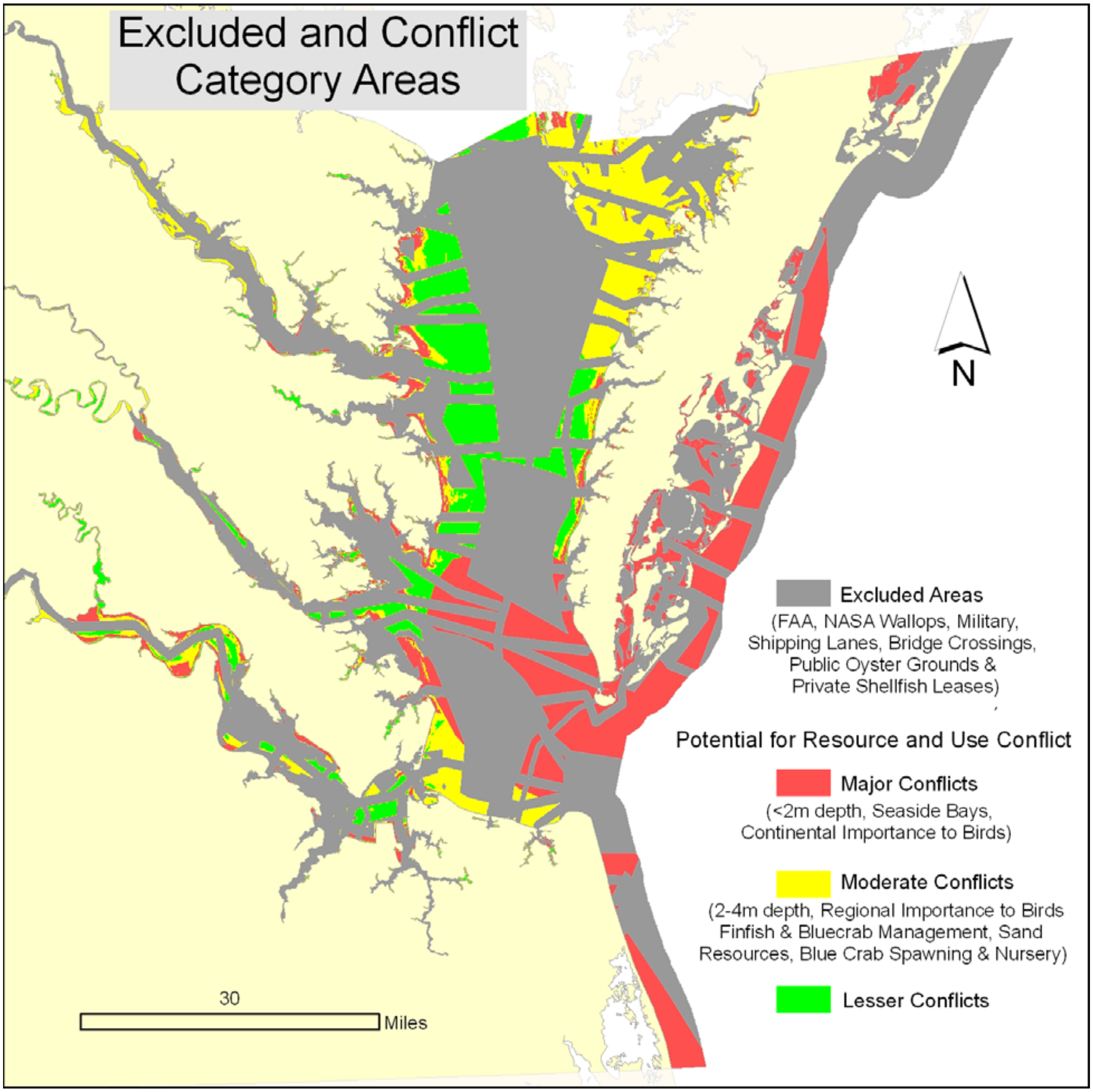


Figure 14. Map of resource and use conflict categories in Virginia state waters. Source: Reference 45.

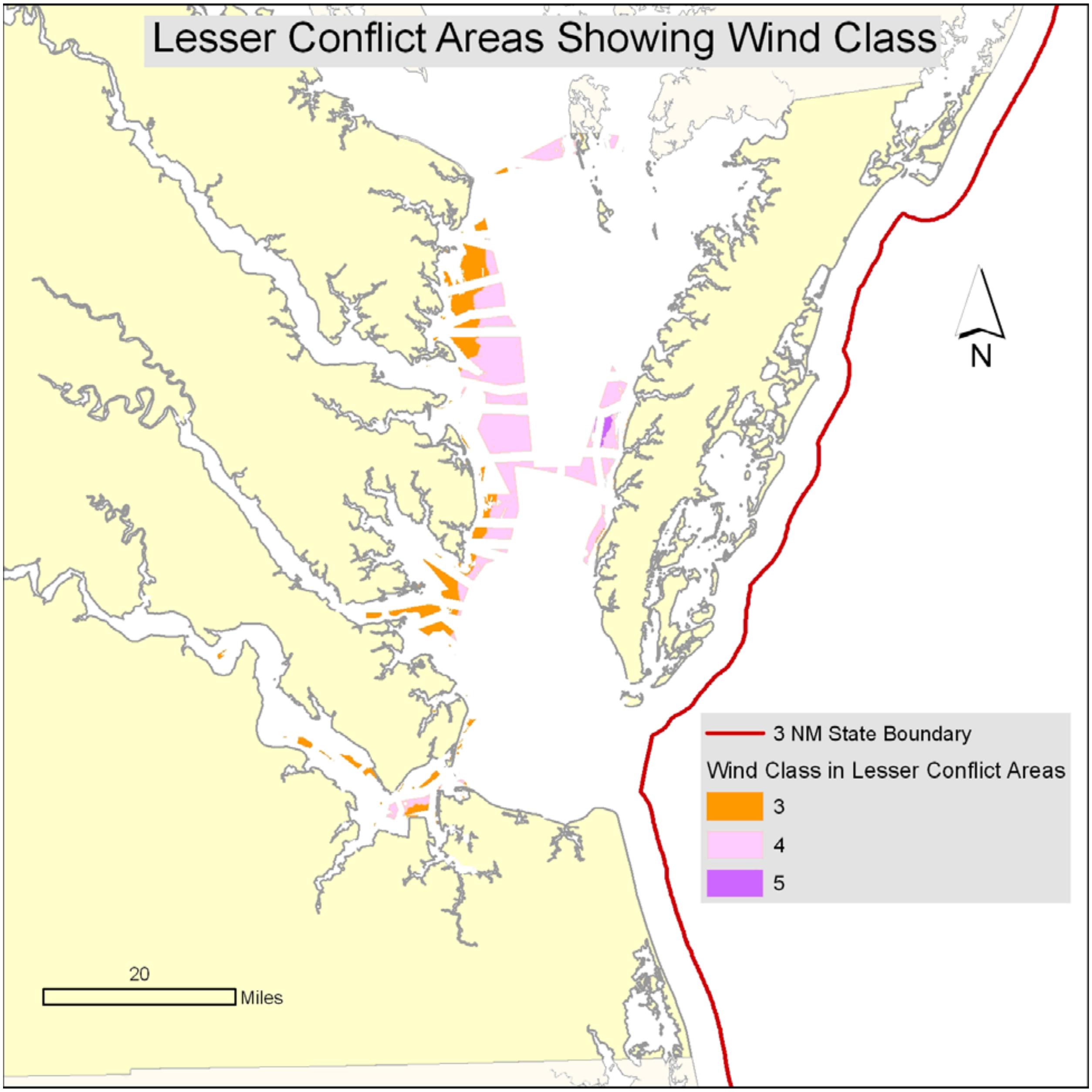


Figure 15. Map of offshore wind resource classes in Lesser Conflict areas of Virginia state waters. Source: Reference 45.

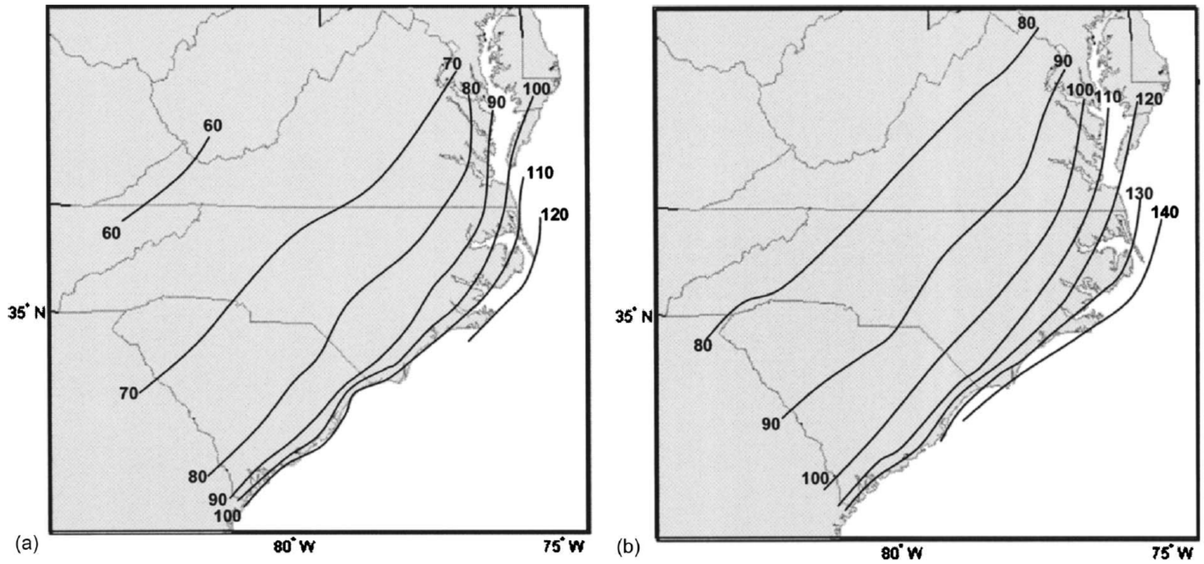


Figure 16. Hurricane 5-second gust wind speeds at 10 m above ground level over open terrain, in statute miles per hour (mph; 1 mph = 0.869 knots = 0.447 m/sec = 1.61 km/hr) in Virginia, North Carolina and South Carolina at mean storm recurrence intervals of (a) 50 and (b) 100 years (Reference 46). Contoured data have a spatial resolution of 6-digit postal zip codes. Dividing the 5-second gust speed by 1.385 yields the 10-minute mean wind speed over open water. Wind speeds at an elevation of 10 m must be extrapolated to turbine hub height using hurricane shear profile coefficients, for which industry-accepted standards have yet to be developed.

Offshore Wind and Offshore Oil and Gas: On 31 March 2010, the Obama Administration affirmed its commitment to offshore oil and gas exploration and development. MMS activities off the Virginia coast will include proceeding with seismic exploration in the Mid and South Atlantic OCS and resuming preparations for a previously planned offshore oil and gas lease sale by 2012 (Reference 47). This section provides a brief overview of MMS offshore oil and gas resource estimates in the Virginia OCS lease sale area, how the gas resource estimate compares with the natural gas equivalent of Virginia's near-term offshore wind energy resource, and environmental permitting concerns that should be addressed to ensure that these two new offshore industries can coexist with minimal interference between them.

Under the current MMS Five-Year Program for U.S. offshore oil and gas leasing in 2007-2012, the only area included off the east coast is Sale 220, on Virginia's outer shelf (Figure 17). Mean Undiscovered Technically Recoverable Resources for this lease sale area are estimated to be 1,140 billion cubic feet of gas and 130 million barrels of oil (www.mms.gov/offshore/220.htm).

These estimates are based on geophysical data 25 years old, and MMS has already taken steps to develop a revised resource assessment. MMS is now preparing a Programmatic Environmental Impact Statement (PEIS) for geophysical and geological surveys of the Atlantic OCS, and has received applications from five companies to conduct surveys, all of which include the Sale 220 area off Virginia. The geological and geophysical survey PEIS is scheduled for completion by MMS in 2010 (www.gomr.mms.gov/homepg/offshore/atlocs/gandg.html).

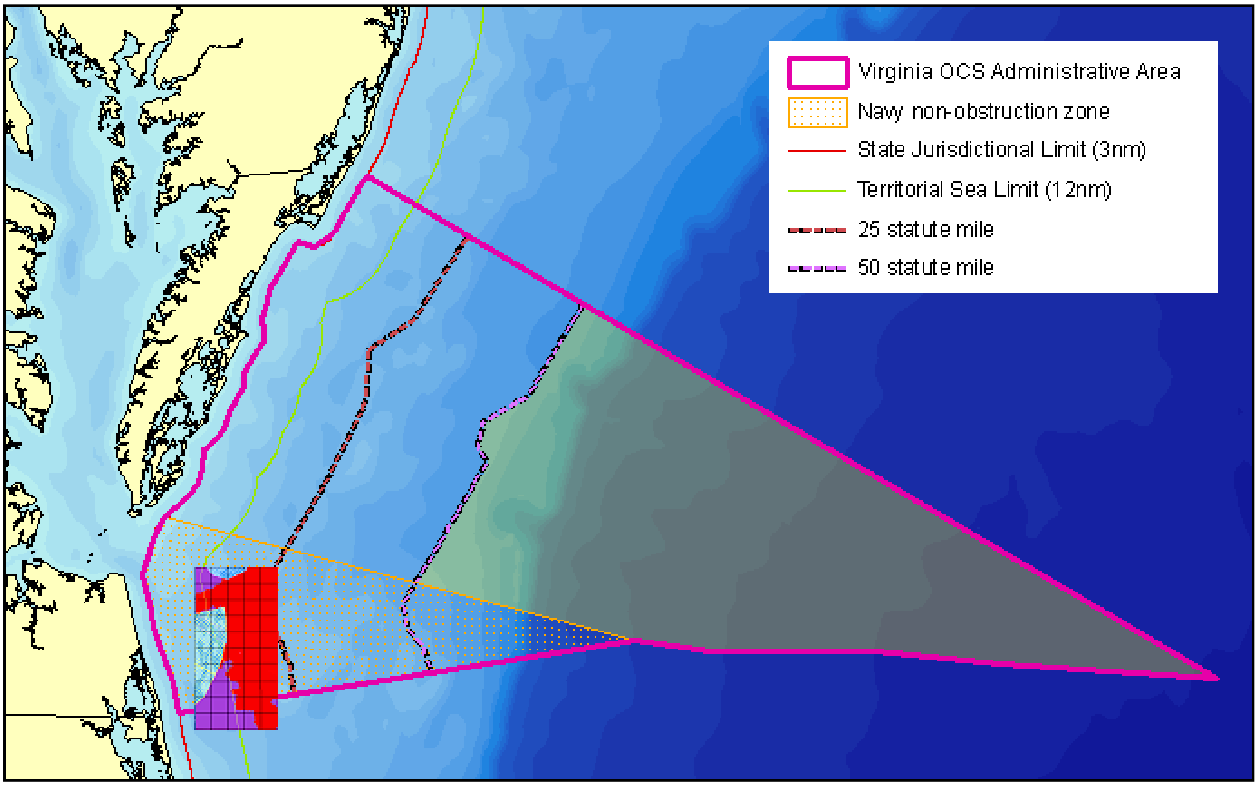


Figure 17. Virginia's offshore administrative boundaries associated with MMS planned oil and gas leasing. The Lease Sale 220 area is indicated by a yellow overlay that is semi-transparent so that underlying bathymetric contours can be seen. Most of the lease sale area lies in water depths greater than 200 m, beyond the edge of Virginia's continental shelf. The Lease Sale 220 area is circumscribed by Virginia's OCS lateral administrative boundaries as determined by MMS, truncated to the west-northwest by the 50-statute-mile line, and truncated to the south-southwest by the northern edge of the Navy's non-obstruction zone. Lease Sale 220 has a geographic area of 11,800 km^2 and is shown to scale with the rectangular VCERC offshore wind study area off Virginia Beach, which is detail-mapped in Figure 9.

As detailed elsewhere in this report, VCERC has identified 25 lease blocks of Class 6 winds just beyond the Territorial Sea limit 12 nautical miles offshore, which could support 3,200 MW of wind capacity and generate 11 million MWh per year. Because wind energy is primarily a "must run" resource, except in certain cases of transmission congestion PJM dispatchers will request other generators to reduce their output whenever wind generation increases. This will directly affect the output of so-called "marginal units" in PJM. The type of marginal fuel displaced will depend on the level of the wind turbine output, the unit's location, the load at the given time of day, and projected wind output duration.

An analysis of marginal fuel displacement by onshore wind in PJM during 2009 has been carried out by Monitoring Analytics, who compared the hourly average proportion of marginal units by fuel type to the hourly average wind generation. This analysis indicates that the approximate average breakdown of marginal fuel type displaced by onshore wind in PJM during 2009 was 70% coal, 20% natural gas, and 10% all other fuel types (see Reference 20, Figure 3-13).

Offshore wind has a higher capacity factor than onshore wind and would be injecting power into the eastern part of the region rather than in the west, where most onshore wind projects are located in PJM, so it might displace a different mixture of fuel types, and this is an important topic for future study. As a starting point, however, we assume that offshore wind would displace the same marginal fuel type mixture, then of the 11 million MWh per year annual output that would be injected from 3,200 MW of offshore wind capacity in 25 lease blocks off Virginia, 20% of this, or 2.2 million MWh, would displace gas-fired generation.

The U.S. Energy Information Administration reports state-by-state fuel consumption and electric power generation data at www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html, which we use to calculate Virginia's gas-fired generation fuel consumption rate. For the two most recent years of data, 2007 and 2008, this amounted to 8,630 and 8,530 cubic feet per MWh. Applying these rates to the displacement of 2.2 million MWh of gas-fired generation operating at the margin suggests that 3,200 MW of offshore wind capacity would save 18.8 to 19.0 billion cubic feet (BCF) per year of natural gas. During 25 years of offshore wind project service life, this displaced gas would total 469 to 475 BCF, as compared with the MMS estimate of technically recoverable reserves in Lease Sale 220 area off Virginia, which is 1,140 BCF. Thus a single generation of offshore wind development in the 25 VCERC-identified lease blocks would save the equivalent of 41-42% of Virginia's technically recoverable offshore gas resource.

As shown in Figure 14, there is no geographic overlap between the primary offshore wind study area and the MMS offshore oil and gas Lease Sale 220 area. This suggests that both industries can readily coexist, but the Commonwealth should ensure that MMS includes offshore wind energy development within the scope of the Lease Sale 220 Environmental Impact Statement (EIS) as a credible alternative scenario whereby offshore wind energy development would also occur in the federal OCS off Virginia, concurrent with offshore oil and gas exploration and development. This EIS scenario should be included in order to account for the following potential interactions between these two different offshore energy industries.

1. Potential competition (and associated need for coordinated planning) for vessels, labor, port space, fabrication and repair facilities, marine equipment and supplies, and business financing for installation services and for offshore support services.

2. Potential conflict between the routing of any offshore gas pipeline(s) and the placement of offshore wind turbine towers, the placement of offshore substation platforms, the routing of submarine power cables that connect offshore wind turbines to offshore substations, and that connect offshore substations to coastal substations.

3. Cumulative environmental effects, including
    a. Multiple physical footprints of oil and gas platforms, wind turbine towers, and other structures on the seafloor, which would have cumulative ecological impacts
    b. Combined build-up of onshore fabrication, installation, and operational support infrastructure, which would have cumulative socio-economic impacts
    c. Multiple increases in ship and helicopter traffic for offshore support services, which would have cumulative ecological and navigation impacts

Regional Policy Recommendations: On 11 November 2009, the governors of Virginia, Maryland, and Delaware announced that they had "signed a Memorandum of Understanding (MOU) creating a formal partnership that will build on the region's significant offshore wind resources to generate clean, renewable energy and a sustainable market that will bring new economic opportunities." The MOU indicates that "other Atlantic coastal states should be welcomed to join in this agreement." The addition of North Carolina is particularly important for the following reasons:

- Limited availability of high-voltage transmission lines in northeastern North Carolina means that large (hundreds of megawatts to gigawatt-scale) offshore wind projects on the OCS north of Cape Hatteras would have to connect through the 500 kV substation in Fentress, Virginia, to reach customers in the Raleigh-Durham or Charlotte areas.
- The U.S. Navy's most important training range complex, the Virginia Capes Operating Area, covers the OCS off Virginia and northeastern North Carolina, and fleet forces will want to make sure that offshore wind developments off both states are well coordinated to minimize interference with training exercises.
- Dominion Resources owns regulated electric utilities that cover both eastern Virginia and northeastern North Carolina and their integrated resource planning would benefit from coordinating offshore wind development across both service territories.
- The U.S. Army Corps of Engineers operates a research pier at Duck, NC. Naval Air Station Oceana operates four air combat training towers off Oregon Inlet, NC, which will be decommissioned in April 2010. These structures are potential locations for tall meteorological measurement towers that can be used for validating atmosphere-ocean numerical simulation models that are vitally needed to map the offshore wind resource.
- Ocean scientists and energy researchers in both the Virginia and North Carolina state university systems already have strong ties and would benefit from a more formal collaboration to seek federal and industry research funding.

The MOU identifies three actions to be of primary importance: (i) regional planning of a common transmission strategy that would reduce offshore wind energy costs; (ii) collaboration to encourage sustainable market demand by developing policies and incentives that can be used across state boundaries for the benefit of the industry as a whole; and (iii) coordinated pursuit of federal policies that would advance offshore wind in the Mid-Atlantic region, including communication of collective concerns to Congress and the Executive Branch and its agencies. Areas identified for later examination are regional coordination of supply chain development, academic research, and workforce training.

Including but not limited to the above actions described in the three-state MOU announcement, VCERC advocates a multi-state collaborative approach on the following specific items:

(1) Development of a regional, coupled atmosphere-ocean numerical simulation model of the offshore wind resource and associated waves and currents, with accurate representation of local air-sea-land heat fluxes, distinguishing the different thermal regimes of shallow sounds and bays from oceanic waters, as well as accounting for Gulf Stream effects

(2) Regionally coordinated physical validation of the above model using public data from existing coastal and offshore meteorological stations, new tall towers established by the academic research community, and private data from tall towers built by offshore wind project developers, with private data used by researchers, but protected from publication

(3) Regional operation of validated model in both hindcast mode (for design) and forecast mode (for planning offshore installation, maintenance, and repair activities, as well as providing electrical output forecasts for optimal utility grid integration)

(4) Regional research by appropriate experts on potential environmental impacts to birds, bats, marine mammals, sea turtles and finfish. While some studies exist, more could be done to ensure minimal impacts on populations of these already depleted species. The Virginia Coastal Zone Management Program has a contract in place with the College of William & Mary's Center for Conservation Biology to lay out a research protocol for determining potential avian impacts.

(5) Supply chain design for maximum economic efficiency and minimal environmental footprint, so that each state doesn't have to reproduce the entire gamut of fabrication and assembly facilities, which would lead to over-industrialization of the coastal zone. For example, existing shipyards in Newport News and Portsmouth-Norfolk, Virginia might focus on steel fabrication for support structures and large steel components in the turbine nacelle. Wilmington, Delaware might focus on composite design and fabrication for turbine blades. Baltimore, Maryland and Richmond, Virginia might focus on industrial systems integration of component suppliers with just-in-time waterborne delivery of same to turbine nacelle assembly plants at the entrances to the Chesapeake and Delaware Bays. This would enable our three-state region to utilize fuel efficient, waterborne transport between major industrial centers, reducing delay of shipments caused by winter weather or traffic congestion and minimizing supply chain environmental impacts on heavily travelled road and rail corridors.

(6) Coordinated workforce training targeted at regional supply chains, building on endemic workforce strengths (e.g. experienced welders and machinists at existing shipyards).

(7) Coordinated, phased development of multiple projects, to avoid "boom-bust" cycles and their socio-economic consequences on coastal communities

(8) Coordinated scheduling of offshore construction activities to minimize environmental effect on migratory and pelagic species (e.g., North Atlantic Right Whale)

(9) Planning of a multi-state offshore transmission backbone as described earlier, to avoid each project having its own power cable to shore, which would create a "spaghetti" of individual cable corridors through state waters and shore crossings, all of which would have a much larger cumulative environmental impact on the Mid-Atlantic region

In addition to the three-state MOU specifically focused on offshore wind energy research and development, there are two regional organizations that include offshore wind energy activities within their broader portfolios: the Mid-Atlantic Coastal Ocean Observing Regional Association (MACOORA), and the Mid-Atlantic Regional Council on the Ocean (MARCO).

The Mid-Atlantic Coastal Ocean Observing Regional Association (MACOORA) is a 501c3 member-based organization of ocean and estuarine data providers and users from federal and state agencies, private industry, non-governmental organizations, and academia, which collects, delivers, and applies observations of the coastal ocean in the Mid-Atlantic Bight, between Cape Hatteras, NC and Cape Cod, MA, encompassing nine states. Its research arm is the Mid-Atlantic Regional Coastal Ocean Observing System (MARCOOS), a research project with 30 Principal Investigators from 20 academic, governmental and private institutions, funded by the National Oceanic and Atmospheric Administration (NOAA). MARCOOS deploys and operates an integrated array of observing hardware (underwater gliders, high-frequency coastal radars, measurement buoys) and compiles these observations into databases, as well as assimilating them into numerical ocean and atmospheric models. More information may be found at www.macoora.org and www.marcoos.us.

MACOORA would be an ideal agent to undertake our recommended regional action Items (1) through (3) in the above list, possibly expanding the existing MARCOOS project to include development, physical validation, and operation of a region-wide numerical model of offshore winds, currents, and waves. As already mentioned, this is needed for proper site evaluation and design of offshore wind projects, as well as the safe and cost-effective scheduling of installation, maintenance and repair activities. Such a model is also needed to understand the project-level and multiple-project cumulative impacts of large-scale offshore wind development on physical oceanographic features such as surface currents and wave-driven sediment transport.

In June 2009, the Governors of New York, New Jersey, Delaware, Maryland, and Virginia signed the Mid-Atlantic Governors' Agreement on Ocean Conservation, bringing the five Governors together as the Mid-Atlantic Regional Council on the Ocean (MARCO), to provide a lasting forum for interstate collaboration on actions to improve the health of the region's coastal and ocean resources. MARCO's priorities for shared action are (i) coordinated protection of important habitats and sensitive/unique offshore areas; (ii) support for sustainable development of offshore renewable energy; (iii) preparing the region's coastal communities for the impacts of climate change on ocean and coastal resources; and (iv) promoting improvements in the region's coastal water quality. More information may be found at http://midatlanticocean.org.

The Governors' Agreement also called for a meeting of regional ocean stakeholders to create new partnerships in the development and implementation of these actions, which was held in New York on 09-10 December 2009. The previously described MOU among the three southern MARCO states could be considered just such a new partnership, focusing initial collaboration on priority (ii) of the Governors' Agreement at a geographic scale that is more manageable than encompassing the full MARCO region. Items (4) through (9) of our recommended regional actions listed on the previous page might well be launched by the three MARCO states that have now signed the MOU specifically dedicated to offshore wind.

OFFSHORE WIND CONCLUDING REMARKS

In the Summer 2008 issue of the *Marine Technology Society Journal*, Greg Watson, editor of that special issue devoted to offshore wind, writes in his opening article (Reference 48):

> We have come a long way since 2001 when Cape Wind Associates proposed to construct this nation's first offshore wind farm off the coast of Cape Cod, Massachusetts. At that time the concept of offshore wind energy development was still untested in the U.S., even though the first offshore wind project was installed 10 years earlier in Denmark.
>
> The physical and political climates in the United States and European Union differ markedly. These differences are reflected in their respective approaches to foster offshore wind energy development. In E.U. countries like Britain and Denmark, offshore wind is a focus of national policies designed to mitigate climate change and promote energy security. More protected shallow water sites—the marine environments where current offshore wind technology can operate reliably and economically—are more available in the E.U. than the U.S. That means that E.U. countries have more options for building offshore using existing technology.
>
> Perhaps most importantly, offshore wind developers in the E.U. have been the beneficiaries of substantial government support. This has in effect minimized if not removed much of the risks for developers to build in the costlier offshore environment. … *these projects have taught us little about the true costs and financial risks of building in marine environments*. [emphasis added]

Despite the doubling of project costs over a decade, European offshore wind projects continue to be built because legally binding requirements for renewable energy supply portfolios and/or carbon emission reduction obligations have enabled national governments to provide generous financial incentives. This enables European offshore projects to be commercially viable, even though they use erection techniques derived from their land-based predecessors, by assembling three-bladed upwind turbines on tower sections bolted together in sequential crane lifts. Since European-style financial incentives are unlikely in the U.S., we must lower capital costs by using turbine designs, support structures, and erection methods specifically developed for the ocean environment of the southern Mid-Atlantic Bight (Cape Henlopen, DE to Cape Hatteras, NC).

The southern Mid-Atlantic region must study, inform, and make investment decisions about building a dedicated offshore wind supply chain where none presently exists. In order for several hundred to a few thousand megawatts of offshore wind power to come on line in this region by 2017-2018, these studies and investment decisions must be completed by year-end 2011.

If our region simply replicates the European model, we run the risk of developing and building offshore wind projects that cannot be commercially viable without government policy incentives and financial subsidies comparable to those available in Europe. This report describes an alternative path of commercial development, applied research, and government policy-making that VCERC believes is more likely to yield offshore projects with sustainably profitable financial returns, creating an entirely new energy economy. Given the large offshore wind resource that exists in shallow waters beyond the visual horizon off Virginia and the center of shipbuilding and military-trained workforce candidates that exist in Hampton Roads, the Commonwealth has every reason to become a national leader in this development.

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