2014 WIND POWER PROGRAM PEER REVIEW

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

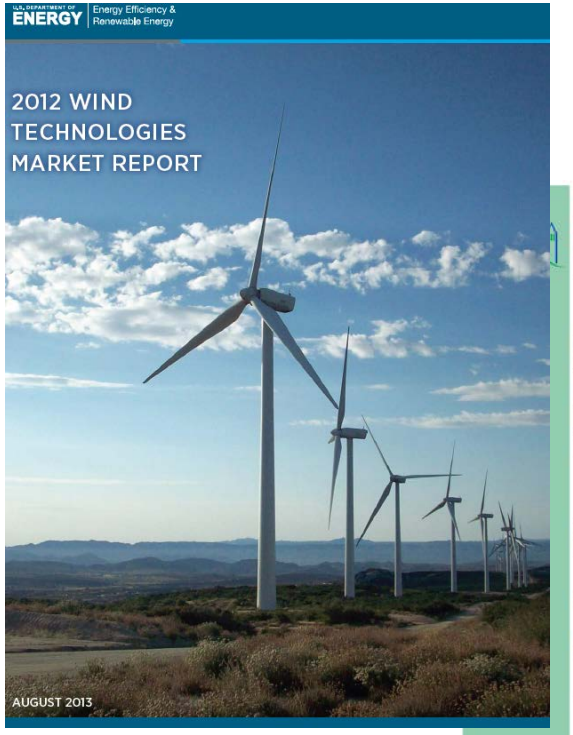
Analysis and Modeling

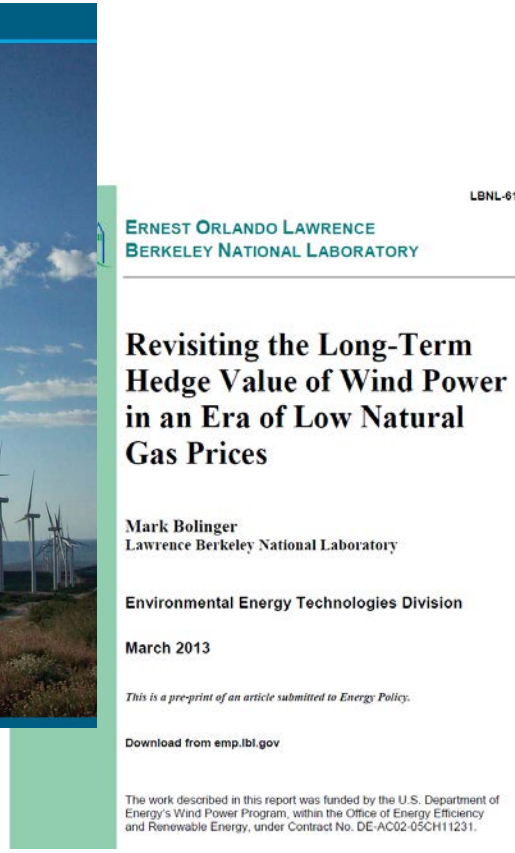
March 24-27, 2014

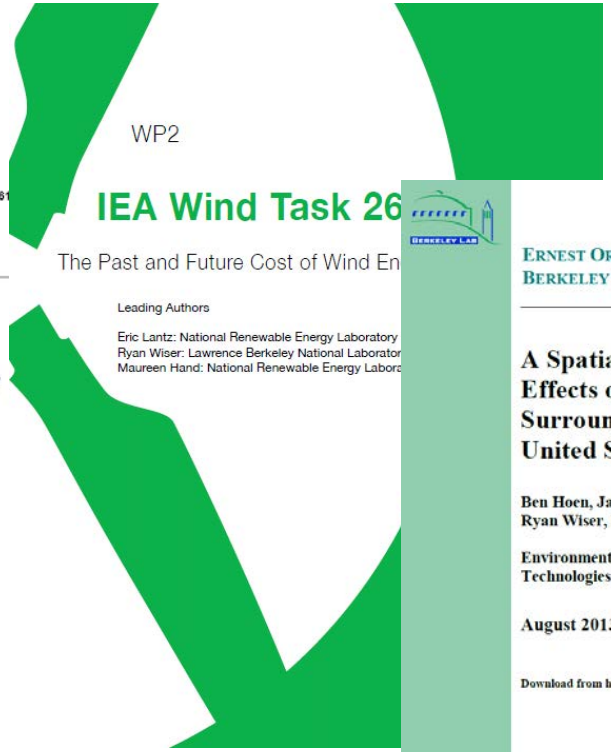
Wind Energy Technologies

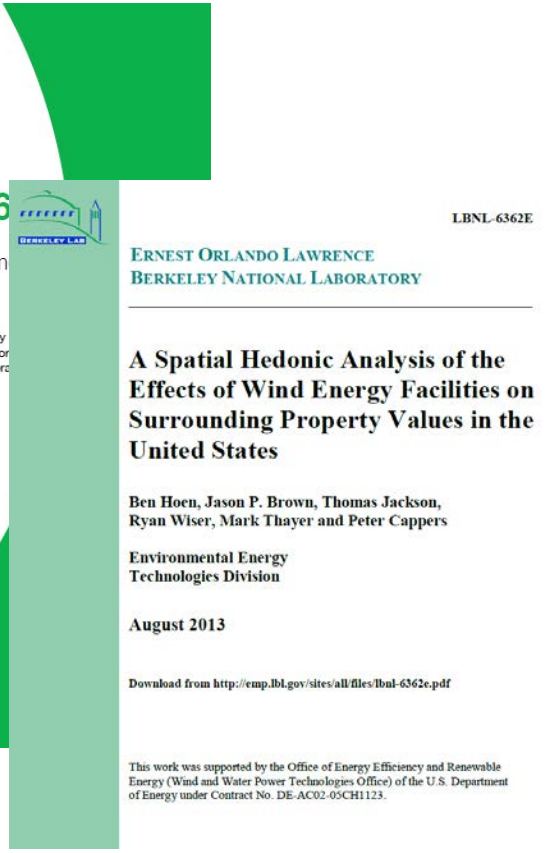
Contents

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy









Analysis & Modeling: COE & Policy Impact

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March 27, 2014

Budget, Purpose, & Objectives: Overarching Project

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Total DOE Budget[1]: $1.00M

Total Cost-Share[1]:$0.00M

Problem Statement: Rapid wind industry growth, market volatility, and politicized policy debate all complicate the creation of a clear understanding of wind's benefits, costs, and barriers at both the local and national levels

Impact of Project: LBNL provides data, analysis, and technical assistance to DOE and other key stakeholders to inform DOE R&D activities, and to provide stakeholders with unbiased data on, and objective analysis of, the potential benefits, costs, and barriers to wind power in the U.S.

Project Aligns with Following DOE Program Objectives & Priorities:

- **Modeling & Analysis:** Conduct wind techno-economic and life-cycle assessments to help program focus its technology development priorities and identify key drivers and hurdles for wind technology commercialization
- **Mitigate Market Barriers:** Reduce market barriers to preserve or expand access to quality wind resources
- **Advanced Grid Integration:** Provide access to high wind resource areas, and provide cost effective dispatch of wind energy onto the grid

[1] ***Budget/Cost-Share for Period of Performance FY2012 – FY2013***

Budget, Purpose, & Objectives – Specific Work Areas

Work falls into five general areas, each with specific objectives:

1) **Annual "Wind Technologies Market Report":** Help stakeholders stay current by publishing an annual report that provides a detailed overview of developments in the rapidly changing U.S. wind power market.

2) **Spinoff Analyses from "Wind Technologies Market Report":** More-thoroughly answer questions about the cost, performance, pricing and import of wind equipment by analyzing data collected for annual report.

3) **Other Market Analyses:** Analyze key market- and policy-related issues facing the wind sector, including issues related to the impacts, costs, and benefits of wind (informed by input from policymakers, industry, etc.).

4) **Public Acceptance:** Address critical public acceptance issues with objective analysis in order to inform stakeholders in the wind project siting and permitting process.

5) **Technical Assistance:** Provide state & federal decision-makers, as well as wind & utility stakeholders, policy- and market-related assistance on a variety of matters relating to the DOE Wind Program's mission.

Technical Approach

- The **variety of analyses performed** under this overarching "project" leads to diverse methods, including various forms of **statistical, economic, financial, and engineering analysis**
- In all cases, work is designed to **build on existing literature** to give stakeholders greater **confidence in the results**
- As much as possible, analyses are **grounded in actual data from operating wind energy projects** and in experience with wind energy deployment efforts
- Where appropriate, **experts** from other labs, academia, and elsewhere are **used as both advisors and subcontractors**
- A key goal is to **stay nimble** in order to be **responsive to emerging issues** and stakeholder needs in a timely manner
- Key objective is to ensure that work is **used and useful**

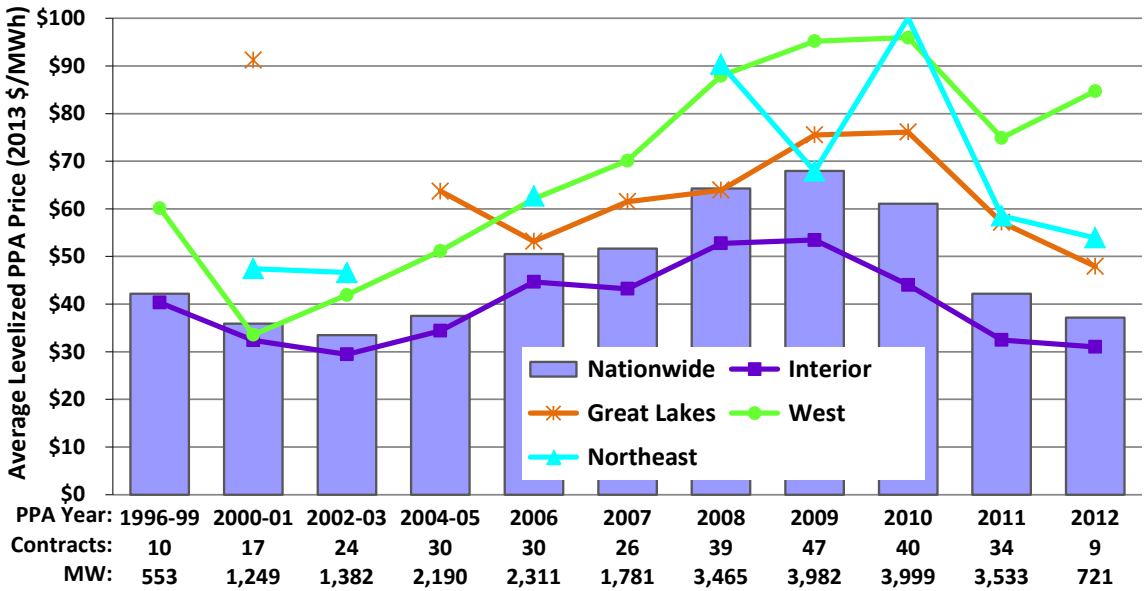
Annual Wind Technologies Market Report (WTMR)

- 2013 edition underway and will be published in mid-2014
- 2012 edition published in August 2013; 2011 edition published in August 2012
- These and previous editions available at http://eetd.lbl.gov/EA/EMP/re-pubs.html

Report Presents Data on Diverse Wind Energy Trends

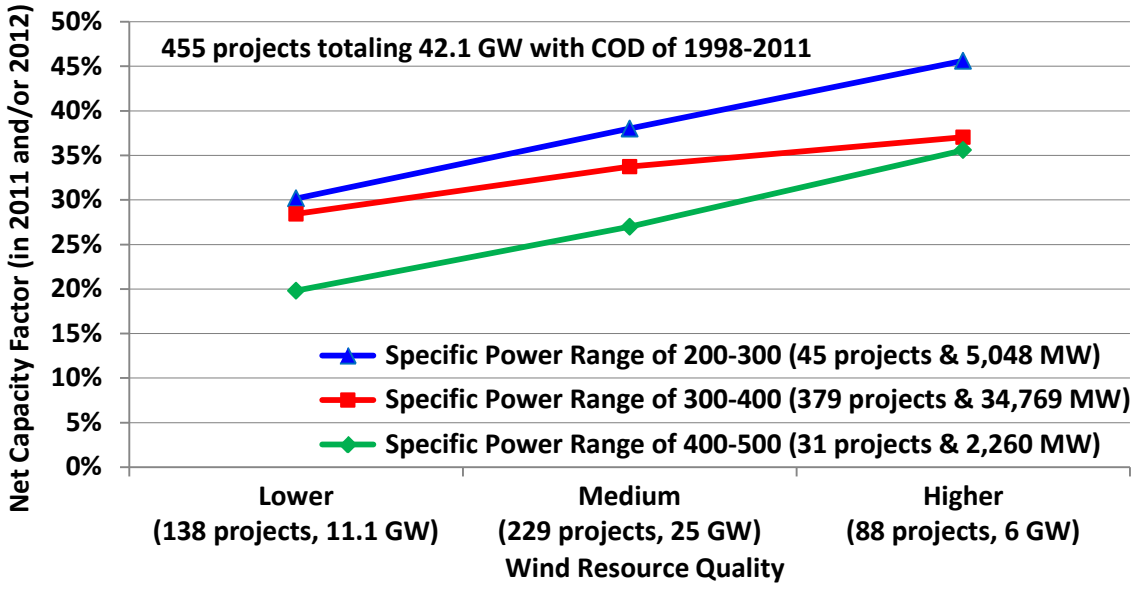
- Goal is to publish publicly available report summarizing key trends in U.S. wind market, building on other available data collection efforts
- Covers installation, industry, cost, price, performance, and policy/market driver trends, as well as future outlook
- Data sources are numerous; contributions from LBNL, NREL, DOE, AWEA, and Exeter Associates
- Has quickly become “go to” guide for wind stakeholders; helps DOE benchmark its activities; provides input to other wind energy analyses
- Most Important contribution, relative to other efforts, is collection and assimilation of wind project price, cost, and performance trends

Sample Results from Annual "Wind Technologies Market Report"



Wind power PPA prices have steeply declined since 2009

Dramatic increase in capacity factors with new technology

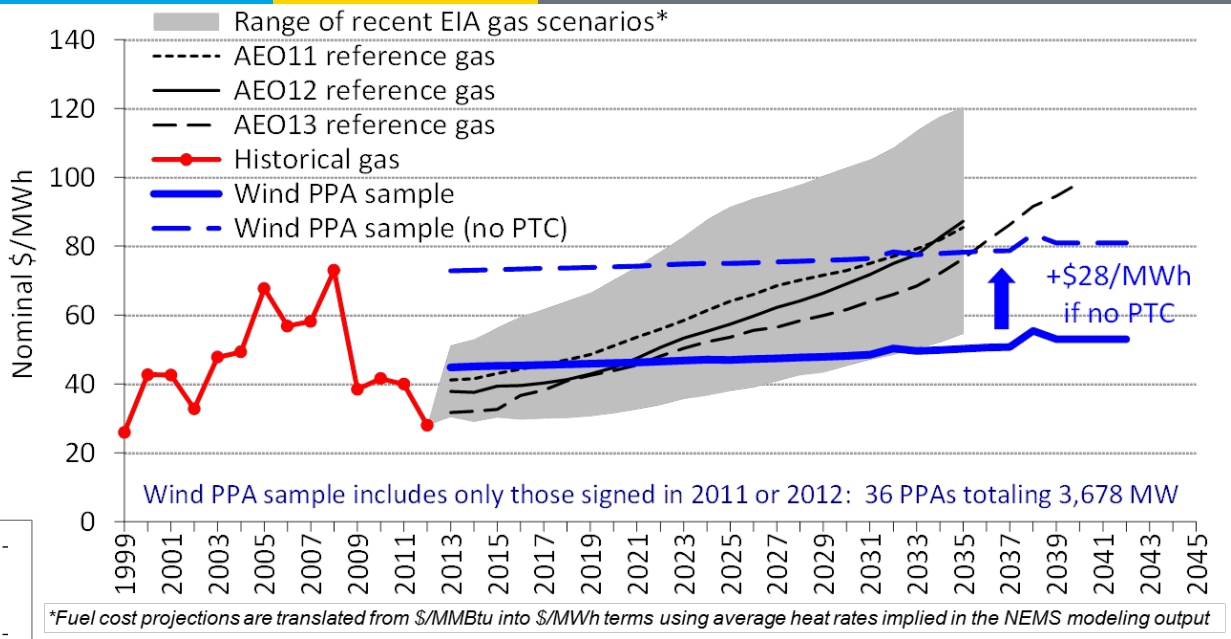


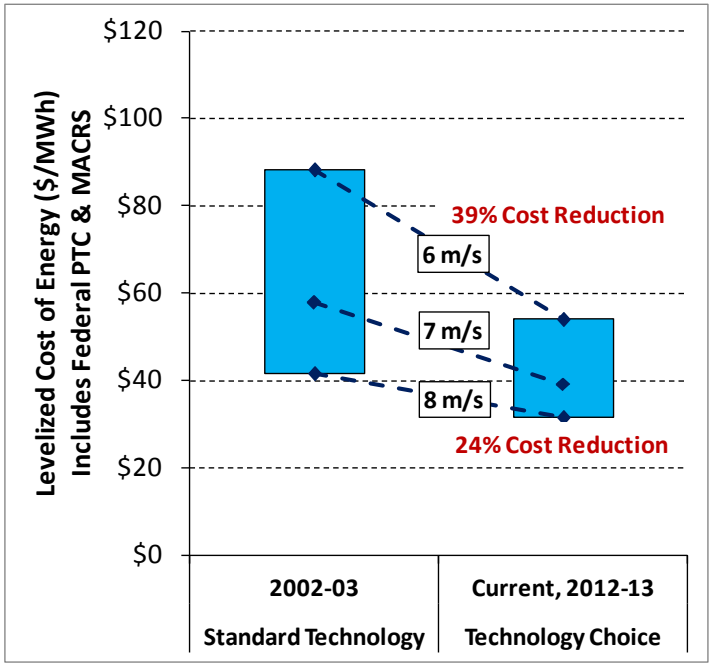
Accomplishments and Progress: Spinoff Analyses from WTMR

- **Goal:** Understand the drivers of past cost/performance/pricing/other trends to inform forecasts of future possibilities and improve DOE program planning
- **Hedge Value of Wind:** Compare wind PPA prices to natural gas price projections to illustrate the role of fixed-price wind energy in hedging natural gas price uncertainty: http://emp.lbl.gov/sites/all/files/lbnl-6103e.pdf
- **Cost of Wind Energy Update:** Analyze impact of most-recent wind cost and performance trends on LCOE, especially focused on low-wind-speed technology: http://emp.lbl.gov/sites/all/files/wind-energy-costs-2-2012_0.pdf
- **IEA Task 26:** Participate in IEA Cost of Wind Energy task, including report on recent international trends in cost, performance & pricing (report, journal and conference paper): http://emp.lbl.gov/sites/all/files/iea-wind-task-26.pdf
- **Domestic Content of Wind Equipment:** Thorough investigation of USITC wind import & shipping data, to inform domestic content estimates
- **Historical Wind Energy LCOE curve:** Created an historical curve of wind LCOE, back to the early 1980s, to show long-term trends

Sample Results from "Hedge Value" and "Cost of Wind Energy Update"

Recent wind pricing compares favorably to the projected future cost of natural gas, and offers a hedge against gas price uncertainty





New wind turbine technology, especially for low wind-speed sites, has enabled a decline in wind LCOE since 2002-03, and opened new areas of the country to potential wind development

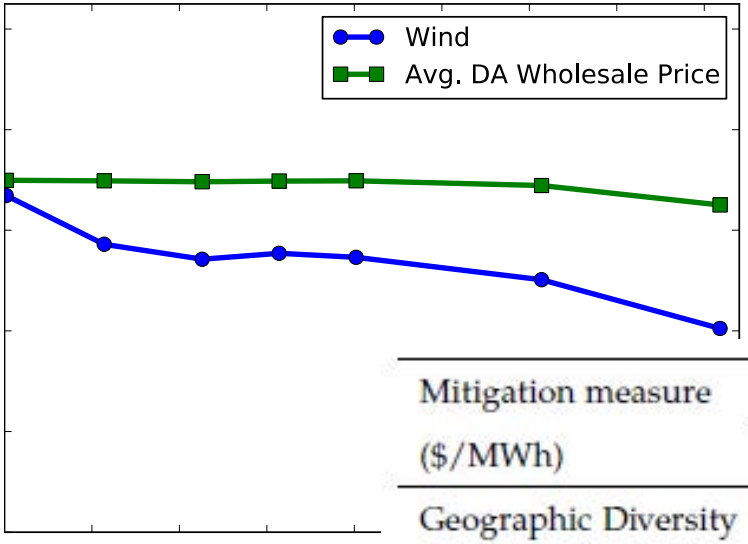
Accomplishments and Progress: Other Market Analysis

- **Goal:** Analyze market- and policy-related issues facing the wind sector, including issues related to the impacts, costs, and benefits of wind
- **Economic Development:** With USDA, assessed actual county-level economic development impacts of wind. Report, conference & journal papers, factsheet: http://emp.lbl.gov/sites/all/files/lbnl-5793e.pdf
- **Economic Value of Wind with Increasing Penetration:** Used investment and dispatch model to estimate the long-run market value of wind, and to assess the benefit of mitigation strategies to stem the decline in wind's value with increasing penetration. Report, conference and journal papers: http://emp.lbl.gov/sites/all/files/lbnl-5445e.pdf
- **Cost and Benefits of Tax Equity:** Developed methods to quantify both the costs and benefits of tax equity; using those methods to analyze a variety of policy scenarios: report in external review
- **Journal Publications on Past Work:** Wind turbine price trends, cost of transmission, etc.

Sample Results from "Other Market Analyses"

	Average Increase per MW of Wind Power Capacity	County-Level Median Increase for Counties with Wind Development
Employment	**0.5 jobs**	0.4%
Total Personal Income	**$11,000**	0.2%

Actual county-level net impacts of wind development from 2000-2008 have been positive; similar magnitude as input-output estimates



Mitigation measure ($/MWh)	Wind penetration 20%	30%	40%
Geographic Diversity	2.5	4.9	10.6
Real-time pricing	3.7	5.0	7.9
Low-cost storage	-0.1	0.4	4.4
Quick-start CCGT	0.3	0.3	-0.6
10% PV	1.1	-1.1	-5.2
10% CSP_6	-0.2	-0.6	-4.4

Marginal economic value of wind decreases with penetration, but that decline can be stemmed to a degree with various mitigation measures

Public Acceptance

- **Goal:** Better understand community concerns about wind energy; provide objective analysis of potential impacts
- **Nationwide:** Assessed the potential impacts of wind projects on nearby residential home prices, with a large nationwide sample that included many homes located within 1 mile of operating turbines: http://emp.lbl.gov/sites/all/files/lbnl-6362e.pdf
- **Massachusetts:** Assessed the potential impacts of wind projects on nearby residential home prices, with a Massachusetts-focused sample, in collaboration with Massachusetts CEC and University of Connecticut: http://emp.lbl.gov/sites/all/files/lbnl-6371e_0.pdf
- **IEA Task 24:** Participated in IEA task on the Social Acceptance of wind

Technical Assistance

- LBNL provided extensive technical assistance to numerous parties during FY12 and FY13, including federal and state policymakers, the DOE, and a variety of wind and utility stakeholders

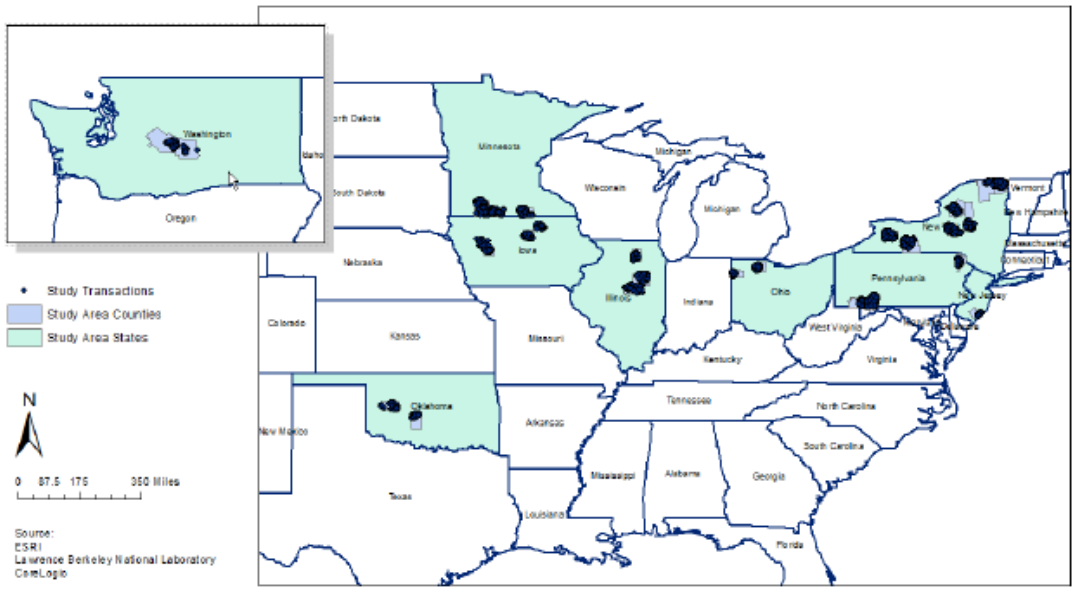
Sample Results from "Property Values" Work

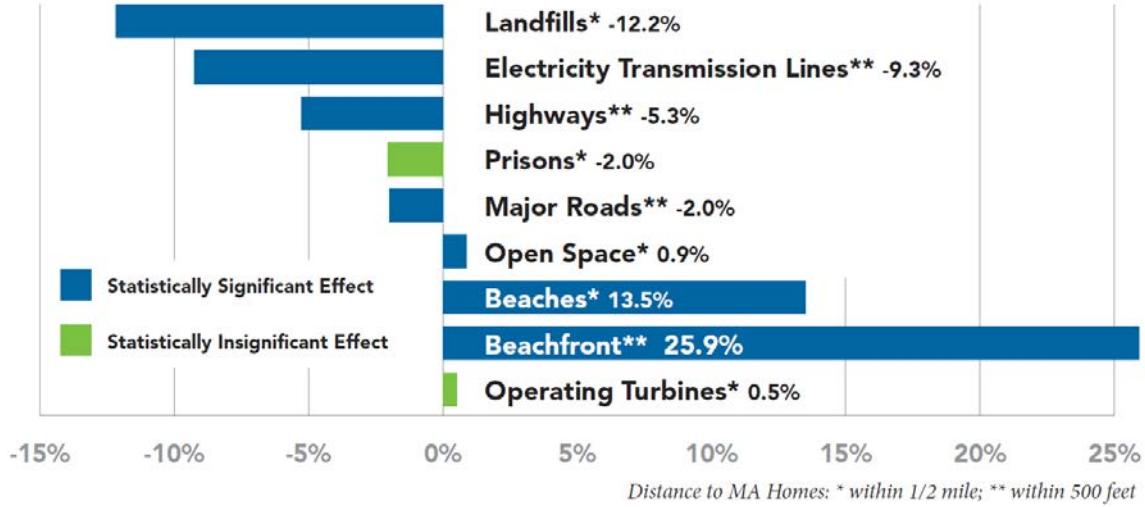
Based on nationwide sample (see map on top right) and Massachusetts sample (see results at bottom right)…

No statistical evidence that property values of homes located in proximity to turbines have been <u>systematically</u> affected by wind projects

Slight evidence that homes in close proximity may experience impacts after announcement (but, if so, those impacts fade after construction)

Figure 1: Map of Transactions, States, and Counties





Awards and Recognition

- Annual Achievement Award, Utility Variable-Generation Integration Group, 2012 (Mills, Wiser, Bolinger)
- Lead and Contributing Authors of Energy Supply chapter of IPCC 5th Assessment Report (Wiser, Mills, Hoen, Darghouth, Larsen)
- Reviewers of WINDPOWER presentation abstracts for Community Wind and Wind Integration panels
- Provided expert peer review for a large number of journal papers (e.g., Energy Policy, Journal of Environmental Policy and Planning, The Energy Journal, IEEE, etc.) and national laboratory, DOE and other reports (e.g., Canadian Social Sciences and Humanities Research Council, University of Rhode Island, Tufts, Aachen University, etc.)

Project Plan & Schedule

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Summary	
WBS Number or Agreement Number	WE 12.1.1
Project Number	21122
Agreement Number	23049

Legend

- Work completed
- Active Task
- Milestones & Deliverables (Original Plan)
- Milestones & Deliverables (Actual)

Task / Event	FY2012 Q1 (Oct-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Oct-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Oct-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)
Project Name: Analysis and Modeling: COE and Policy Impact											
Q1 Milestone: Wind LCOE analysis (PPT summary)	◆										
Q2 Milestone: Hedge value-wind PPAs and gas price projections (PPT summary)		◆									
Q3 Milestone: 2011 Wind Technologies Market Report			◆								
Q4 Milestone: Impact of wind projects on residential property values (status report)				◆							
Q1 Milestone: Hedge value-wind PPAs and gas price projections (report)					◆						
Q2 Milestone: Impact of wind projects on residential property values (report)						◆					
Q3 Milestone: 2012 Wind Technologies Market Report							◆				
Q4 Milestone: Costs and benefits of tax equity (status report)								◆			

Comments

- Milestones reflect what were included in AOPs
- Additional projects and deliverables were described earlier
- All milestones met with minimal delay

Research Integration & Collaboration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Partners, Subcontractors, and Collaborators:

- NREL (collaborator on Wind Technologies Market Report, related analyses, IEA Cost of Wind Energy task, economic development assessment)
- Exeter Associates and Ventyx (subcontractors on Wind Technologies Market Report)
- San Diego State University, Federal Reserve Bank of Kansas City, Real Property Analytics (subcontractors on national property values work)
- MA Clean Energy Center, Univ. of Connecticut (collaborators on MA wind property values work)
- USDA (collaborator on economic development analysis)

Communications and Technology Transfer:

Relevant publications are listed on earlier slides. We have also presented our research findings at a wide array of national and local venues:

1) **Wind Technologies Market Report:** WINDPOWER (2012), WPA Annual Summit (2012, 2013), DOE (2012, 2013 x2), AWEA (2012), GLWC (2013), and numerous webinars (various)
2) **Offshoot Analyses:** WPA (2012 x2), DOE (2012), AWEA (2012 x3, 2013), WINDPOWER (2012 x2), CPUC (2012), EIA (2013), TVA (2013), IEA (2013), IRENA (2013)
3) **Other Market Analyses:** CREPC (2012), CEC (2012), WINDPOWER (2013), UVIG (2013), AWEA (2013), NREL WPA (2013), DOE (2013)
4) **Public Acceptance:** NRRI (2012), AWEA (2012, 2013), IEA (2012, 2013), WPA (2013)
5) **Technical Assistance:** DOE, GAO, Treasury, Congress, Sandia, NREL, PNNL, EIA, CPUC, CEC, NGA, CESA, AWEA, Appraisal Institute, Arkansas PUC, Navigant, Deepwater, GE, Iberdrola, PG&E, many others; presentations to NGA (2013), National-State RPS (2013), Sen. Bingaman (2013)

Next Steps and Future Research

FY14/Current Research:

- **Wind Technologies Market Report:** Publication ~ August 2014*
- **Costs and Benefits of Tax Equity:** Publication ~ mid 2014*
- **Impact of Wind on Property Values:** Journal articles*, conference presentations, sales volume analysis*
- **Wind Manufacturing Domestic Content:** US ITC data analysis* and GLWN subcontract
- **IEA Task 26 Cost of Wind Energy:** Update U.S. wind cost and performance data, contribute to cross-country comparison
- **Wind Vision:** A substantial fraction of LBNL's time in FY14 is focused on Wind Vision – leading much of the impacts / benefits analysis, and contributing to most other elements of the project

* Signifies an activity that represents a FY14 AOP milestone for 12.0 agreement

Next Steps and Future Research

Berkeley Lab's future wind energy research is likely to be centered around the core areas that have defined our work in recent years:

- Wind Technologies Market Report
- Ongoing analysis of underlying data collected for the Market Report (with a focus on cost, performance, pricing)
- Targeted/nimble policy- and market-relevant analysis
- Assessment of the multi-faceted benefits, and costs, of wind
- Modeling analysis of wind energy's long-term market value at higher penetration, and approaches to maintain that value
- Analytical & survey work surrounding public acceptance of wind
- Technical assistance to federal and state policymakers as well as industry and other wind energy stakeholders

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System LCOE Analysis

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NREL

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March 27, 2014

Budget, Purpose, & Objectives

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Total DOE Budget[1]: $2.364M

Total Cost-Share[1]:$0.000M

Problem Statement: Data, models, and analysis are needed to identify market conditions, cost reduction opportunities, and deployment potential to influence the future U.S. wind industry.

Impact of Project: Inform WWPTO and external stakeholders of developing and potential future trends to improve cost competitive nature of wind technology

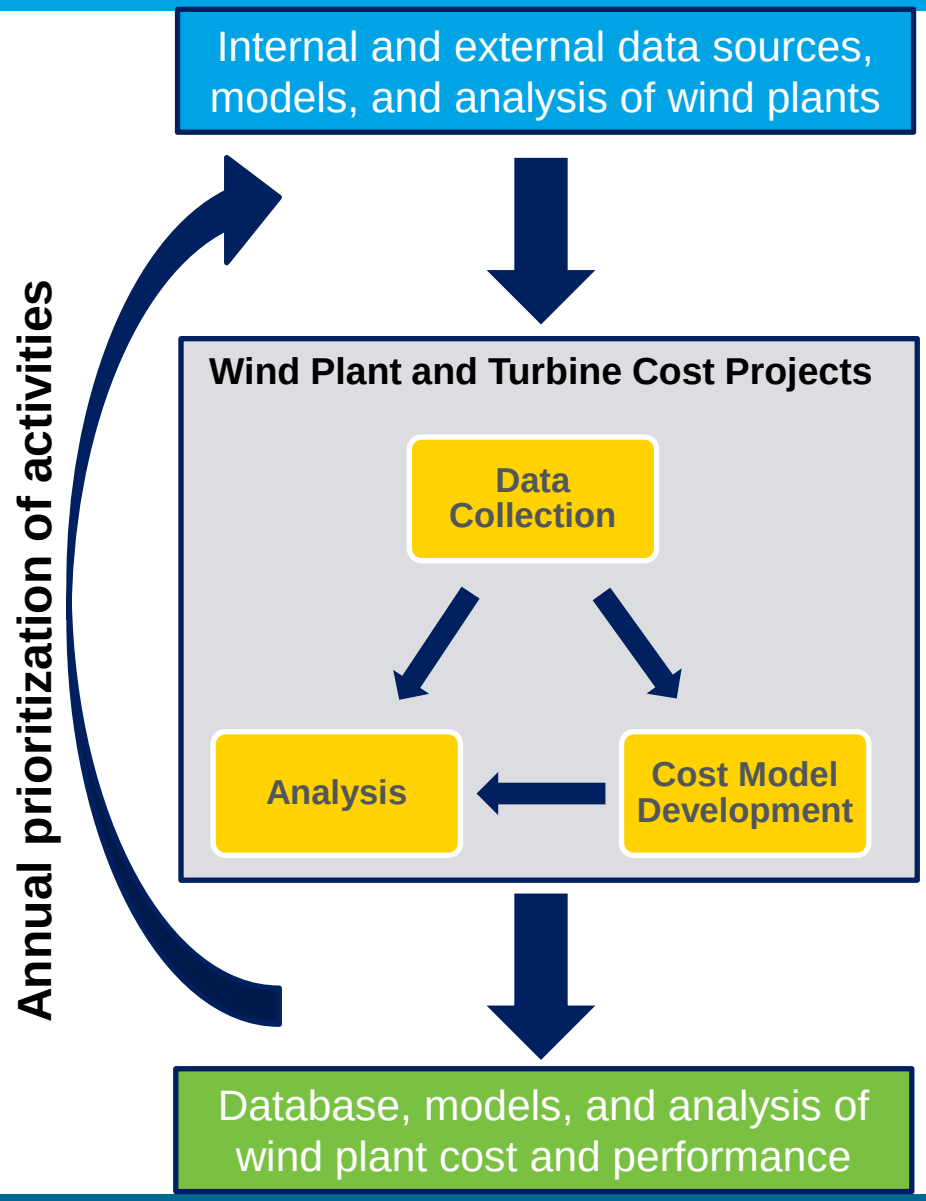
This project aligns with the following DOE Program objectives and priorities:

- **Optimize Wind Plant Performance:** Reduce wind plant levelized cost of energy (LCOE)
- **Modeling & Analysis:** Conduct wind techno-economic and life-cycle assessments to help program focus its technology development priorities and identify key drivers and hurdles for wind energy technology commercialization

[1] ***Budget/Cost-Share for Period of Performance FY2012 – FY2013***

Technical Approach

NREL Approach to LCOE Analysis

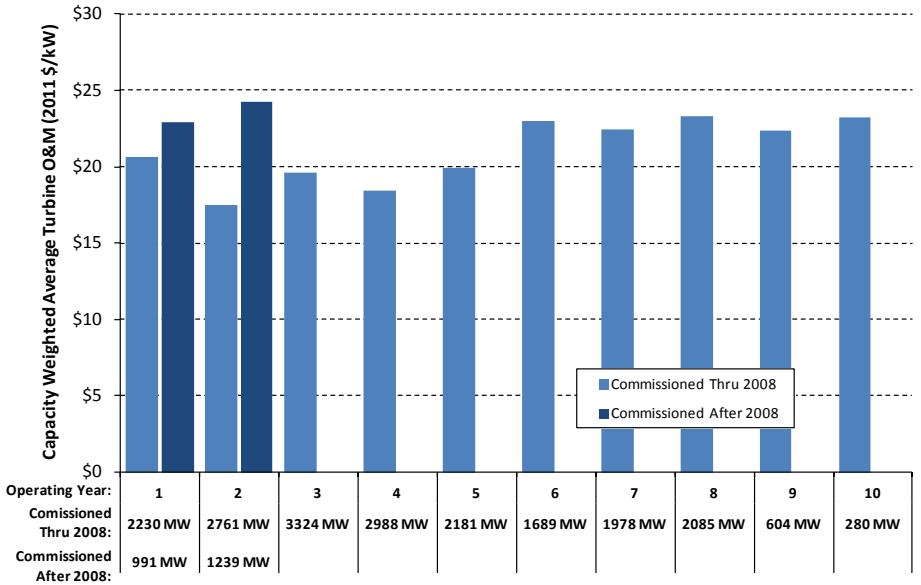


- Database of wind plant component cost organized with WWPTO Cost Breakdown Structure
- Models that allow scaling of turbine and plant to quantify sensitivity of cost to range of parameters
- Analysis using data and models to estimate wind plant cost and performance today and in the future
- Annual procedure for assessing data and modeling needs to support WWPTO R&D priorities to guide future year efforts

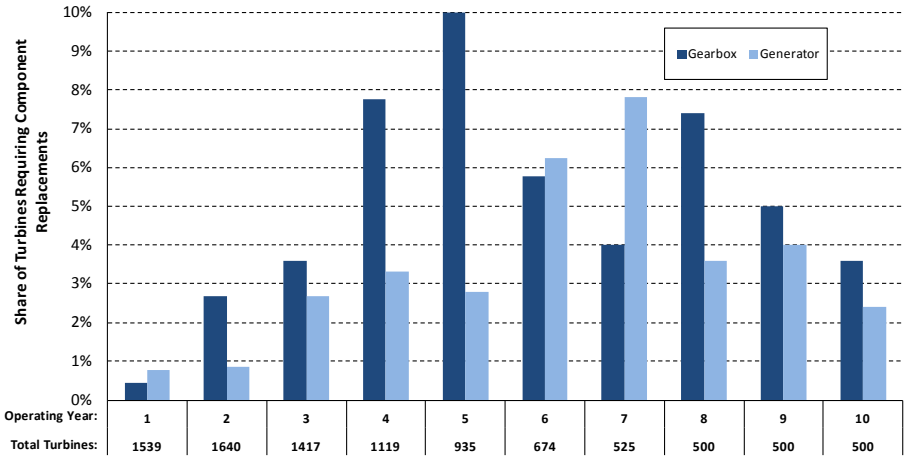
Accomplishments and Progress

O&M Cost and Reliability Data Collection

- Partnered with GL Garrad Hassan and DNV KEMA to assess operation expenditures over past decade representing ~ 10 GW of capacity
- Results reported at Wind Power 2013 and AWEA 2013 Finance & Investment Seminar
- Key observations:
  - Operational expenditure, as well as O&M cost, appear to be increasing over time
  - Major component annual replacement rates: blades averaged at ~2% with spikes in years 1 and 5; gearboxes averaged at ~5% with spikes in years 4, 5 and 8; generators averaged at ~3.5% with spikes in years 6 and 7.
  - Unscheduled maintenance remains a significant source of uncertainty; one challenge is absence of standardized reporting throughout the industry



Source: GL Garrad Hassan

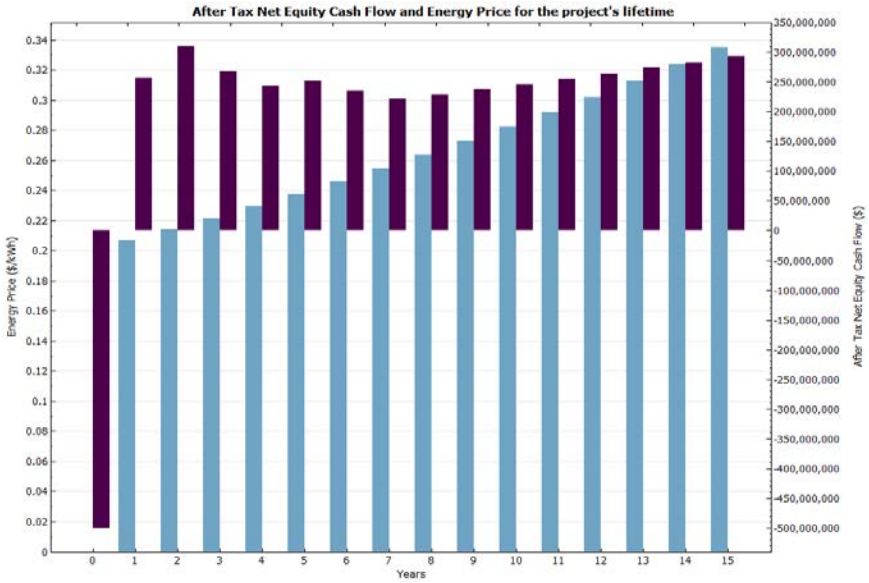


Source: DNV KEMA

Accomplishments and Progress
System Advisor Model (SAM)

SAM is a Renewable Energy Plant Performance model that was adapted to include wind technologies in FY12. As engineering cost models of wind plant components are developed, SAM will be modified to improve its capability to estimate wind plant cost.

Webinars provide user guidance; published documentation planned in FY14



System Advisor Model (SAM) Case Study: Cape Wind Nantucket Sound, MA

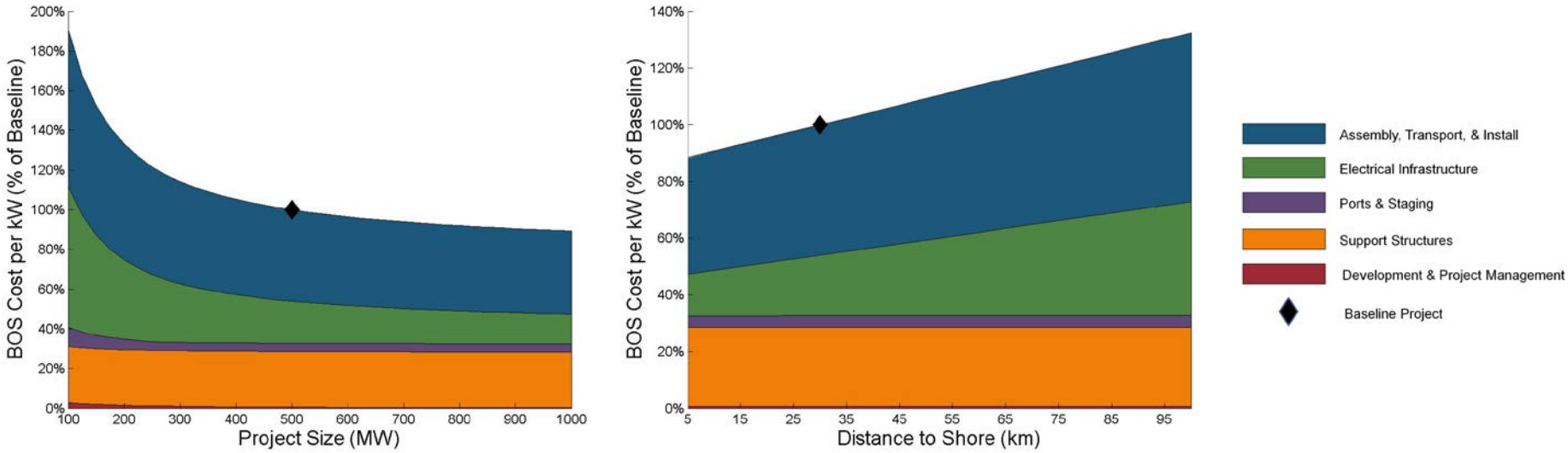
Reference Manual for the System Advisor Model's Wind Power Performance Model

SAM Wind Features:

- GIS-based Wind Resource Data
- Wake Models
- Cost and Scaling Model
- Weather Input Options
- Performance Adjustments
- Financial Model Analysis
- Five Publications and Two Case Studies

Accomplishments and Progress

BOS Model Sensitivity Analysis

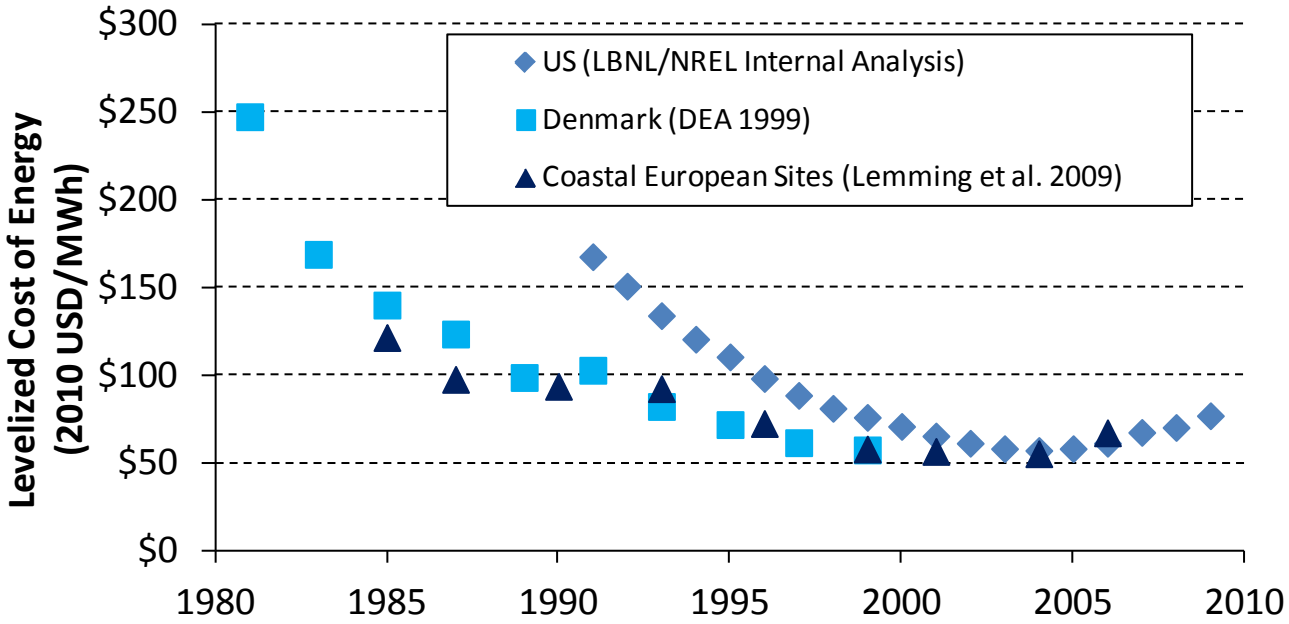


Source: Maples et al.; Offshore Wind Balance of System Cost Drivers and Sensitivity Analysis

- **The land-based and offshore BOS engineering cost models provide the capability to:**
  - Understand the impacts of innovative turbine component designs to the BOS costs as well as impacts of innovative BOS concepts for land-based and offshore wind plants
  - Understand the potential wind turbine design constraints, limited by BOS restrictions, at which innovative designs will be needed to continue wind turbine up-scaling
  - Understand the largest cost drivers associated with BOS costs
  - Understand varying costs as primary project parameters are changed

Accomplishments and Progress

IEA Wind Task 26 Cost of Wind Energy

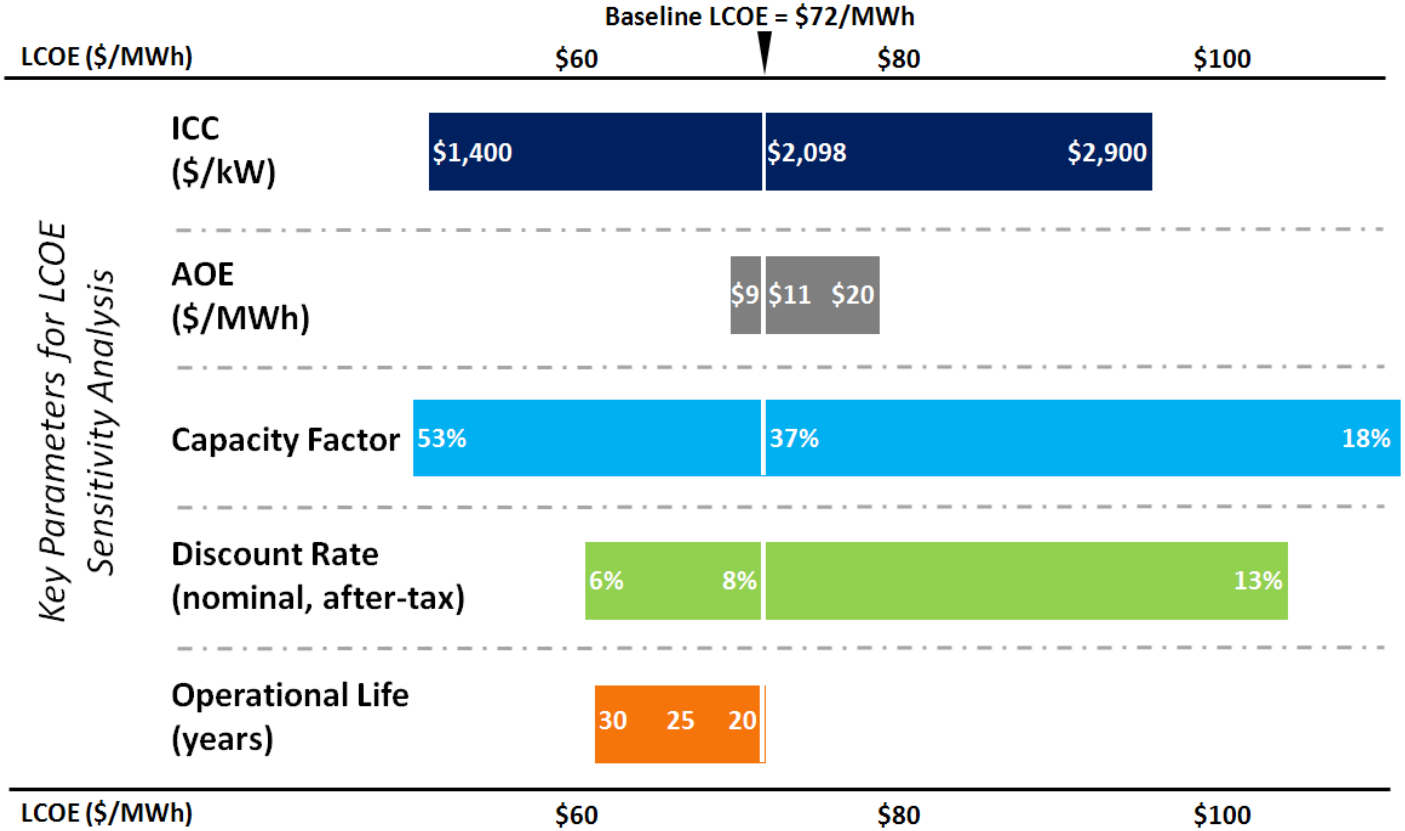


Source: Lantz et al.; IEA Wind Task 26 – The Past and Future Cost of Wind Energy

- International collaboration provides forum for sharing and comparing cost of energy data and analysis among several countries.
- Historic trend in land-based wind cost of energy decline was reversed in 2003 due to increased commodity and raw material prices, labor costs, improved manufacturer profitability, and turbine up-scaling. Since 2009, cost of energy is leveling off or possibly declining.

Accomplishments and Progress

Cost of Wind Energy Review



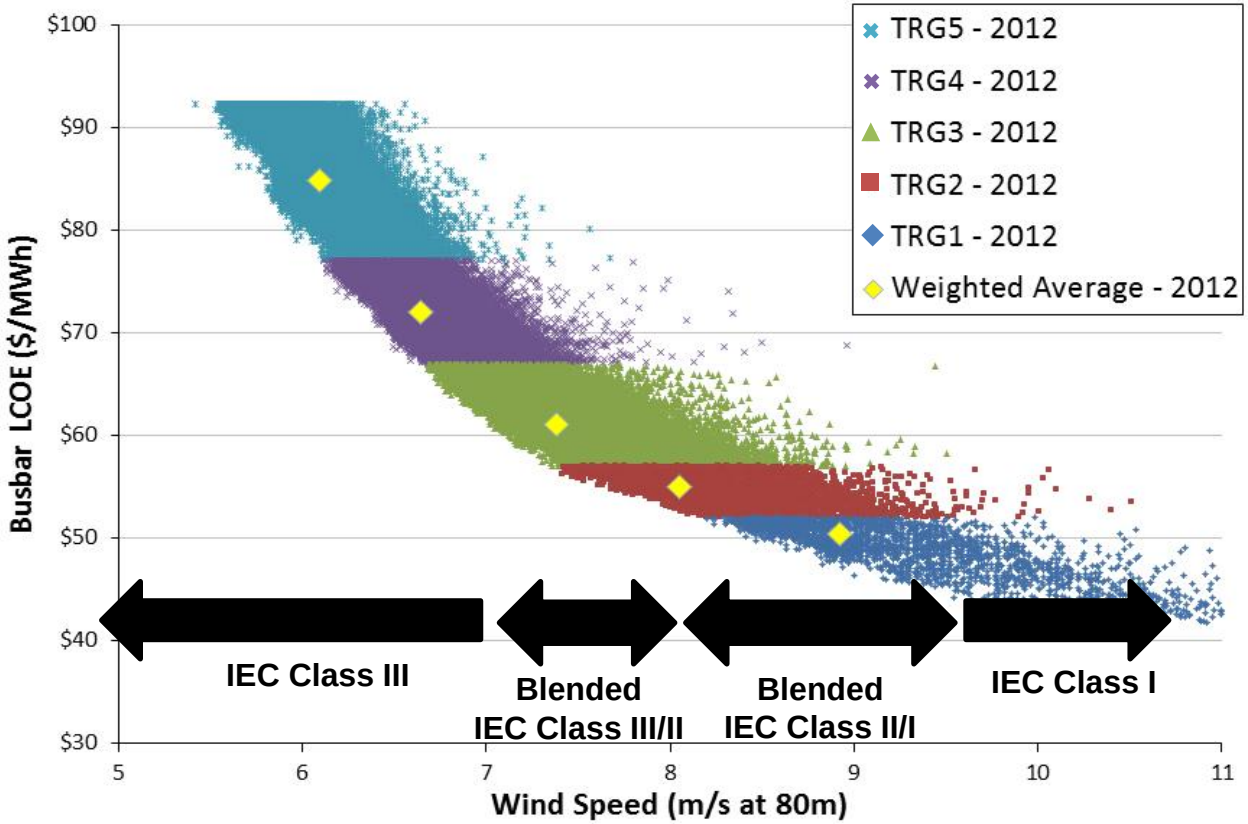
Note: LCOE = levelized cost of energy, ICC = installed capital cost, AOE = annual operating expenditures

Source: Tegen et al.; 2011 Cost of Wind Energy Review

- Demonstrates LCOE of "typical" U.S. wind plant relative to market-based range of observations for land-based and offshore wind technologies
- The report provides a basis for WWPTO Programmatic Analysis, representation of wind LCOE for scenario models, and reference to external stakeholders.

Accomplishments and Progress

Wind Vision Cost and Performance Assumptions



Source: Preliminary Wind Vision Modeling Estimates

- Range of turbine technology associated with site-specific wind resource to define five land-based wind Techno-Resource Groups (TRG) for use in Regional Energy Deployment System Model (ReEDS)
- Offshore wind plants represented by water depth, wind resource, and distance to shore in 10 TRGs

Project Plan & Schedule

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Summary	
WBS Number or Agreement Number	12.1.1
Project Number	
Agreement Number	

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

Task / Event	FY2012 Q1 (Oct-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Oct-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Oct-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Project Name: System LCOE Analysis												
Q1 Milestone: Develop project plan for Balance of Station (BOS) and O&M model development and analysis in coordination with system engineering sub-task (AOP Agreement 3.0).												
Q2 Milestone: Obtain data for development of offshore Balance of Station (BOS) model from subcontractor												
Q3 Milestone: Contribute 2011 US wind turbine manufacturing data and analysis to LBNL for inclusion in the Annual Wind Technologies Report												
Q4 Milestone: Draft report summarizing cost of wind energy in 2011 based on market data obtained, models developed, and analysis conducted throughout FY12.												
Q4 Milestone: Complete new capabilities in the System Advisory Model software release fall 2012, including: (a) inclusion of access to hourly data for offshore and missing land based areas, (b) update offshore modeling capabilities including O&M, BOS and equipment variations, (c) evaluation of ability to add network grid integration costs to model, (d) all related user support and documentation.												
Q1 Milestone: PPT briefing summarizing historical trends for land-based operation and maintenance cost based on data obtained through subcontract. December 15, 2012.												
Q2 Milestone: Complete a NREL technical report for publication summarizing cost of wind energy in 2011 based on market data obtained, models developed and analysis conducted throughout FY12.March 31, 2013. (PEMP/Key)												
Q4 Milestone: Draft PowerPoint summarizing cost of wind energy in 2012 based on market data obtained, models developed, and analysis conducted throughout FY13. September 30, 2013.												

Comments

- Ongoing project; milestones completed on schedule. In FY14 this project is combined with Offshore System Cost Analysis and separated into three tasks; FY14 plans described on subsequent slide.

Research Integration & Collaboration

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Partners, Subcontractors, and Collaborators: [

- Lawrence Berkeley National Laboratory, Sandia National Laboratories
- IEA Wind Task 26 (SINTEF [NO], Norwegian Water and Energy Directorate [NO], Ea Energy Analyses (DK), Deutsche WindGuard [DE], IWES Fraunhofer [DE], Dublin Institute of Technology [IE], TKI Offshore Wind [NL], European Commission [EU])
- Subcontractors (DNV-KEMA, GL Garrad Hassan)
- Collaborators (through the Wind Vision project and other contacts, a large number of wind industry participants have provided valuable insights across all primary industry sectors including manufacturers, developers, plant operators, other research entities)

Communications and Technology Transfer:

- Publications available at www.nrel.gov/publications
  - 2010 Cost of Wind Energy Review
  - 2011 Cost of Wind Energy Review
  - Past and Future Cost of Wind Energy – IEA Wind Task 26 Report
- Presentations available at www.nrel.gov/publications
  - O&M cost trends– AWEA Windpower 2013 and AWEA Finance and Investment Seminar 2013
  - Offshore BOS cost drivers and sensitivity analysis– AWEA Offshore Windpower 2012
  - Cost of wind energy – 2012 World Renewable Energy Forum, 2013 North American Wind Energy Association Symposium, 2nd NREL Wind Energy System Engineering Workshop
- Subcontractor reports for O&M cost trends and analysis, BOS model data
- System Advisor Model webinars and documentation

Next Steps and Future Research

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

FY14/Current research:

- Data
  - Develop and test database infrastructure (database, web interface, quality control mechanisms)
  - Collect data to maintain databases and address key knowledge gaps (desktop research, direct outreach, subcontracts, purchased databases)
  - Populate database, evaluate data quality, and plan future data collection activities
- Models
  - Verify land-based balance of system model with external contacts
  - Improve offshore wind balance of system model and verify with external contacts
- Analysis
  - Develop Wind Vision wind cost and performance assumptions
  - Publish Floating Wind Plant Economics report
  - Draft 2013 Cost of Wind Energy Review
  - Assess recent wind turbine technology trends to understand impact on LCOE
  - Contribute to IEA Wind Task 26 (international comparison of land-based and offshore wind LCOE)

Proposed future research:

- Continue to use data, models, and analysis to answer the WWPTO's key questions and support research objectives
- Systematically assess technology innovations needed to achieve cost of energy reduction goals:
  - High level analysis to identify cost drivers and sensitivity to technical and non-technical influences
  - Coordination with technology researchers to create/improve engineering cost models for land-based and offshore wind
  - Evaluate the potential LCOE impact of new technology solutions at the wind plant system level and implications for deployment in the United States

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Scenario Modeling and Model Improvement: Wind Deployment Barrier Reduction

Suzanne Tegen, Ph.D.

NREL

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March 27, 2014

Budget, Purpose, & Objectives

Total DOE Budget[1]: $0.693M

Total Cost-Share[1]:$0.000M

Problem Statement:

- When calculating LCOE, important issues in wind siting processes are often omitted. Siting complications can completely halt or greatly delay wind deployment, adding to time and money that developers spend on deployment.
  - How much does it cost to work on siting considerations?
  - How much time does it take?
  - Are areas no longer developable due to these siting considerations?
  - *What could DOE do to help enable appropriate wind deployment?*
- The more wind installed, the greater the siting considerations may be, given the proximity to:
  - People
  - Wildlife
  - Radar installations
  - Issues involved with transmission.

[1] ***Budget/Cost-Share for Period of Performance FY2012 – FY2013***

Budget, Purpose, & Objectives

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Impact of Project:

- Final product is a deeper understanding of the wind deployment process based on developer perspectives
- Maps of developable land
- Data will serve as layers for on-line maps for tools such as NREL's Wind Prospector and Sandia's radar-based tool
- Final internal report will contain recommendations on ways DOE can help enable appropriate wind deployment
- This work will eventually be published to help stakeholders and smaller developers

This project aligns with the following DOE Program objectives and priorities:

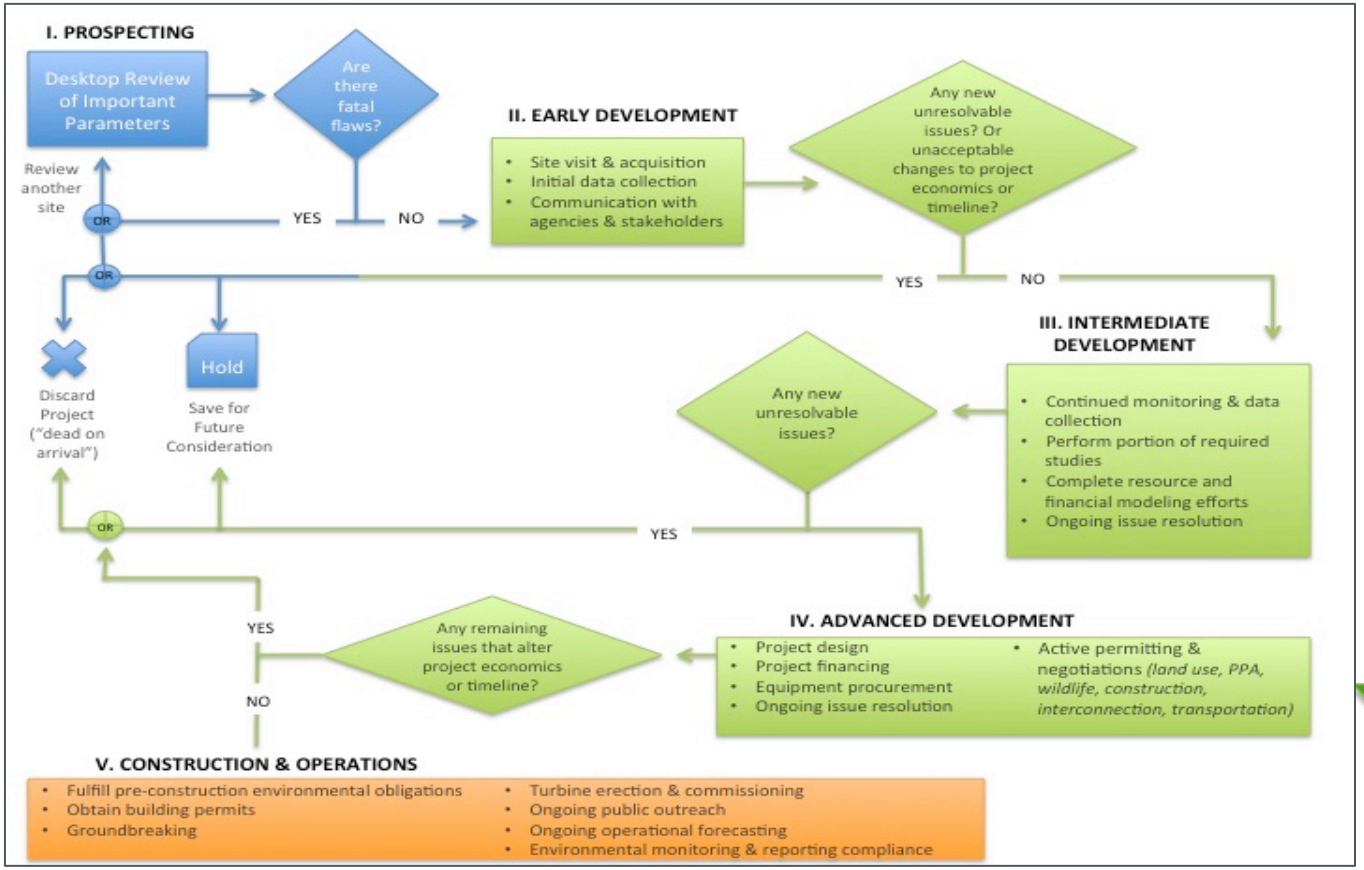
- **Mitigate Market Barriers:** Reduce market barriers to preserve or expand access to quality wind resources
- **Modeling & Analysis:** Conduct wind techno-economic and life-cycle assessments to help program focus its technology development priorities and identify key drivers and hurdles for wind energy technology commercialization

Technical Approach

- Collaborate with industry to obtain detailed information about siting issues, costs, and delays
- Top-down assessment of total resource potential impacts and electric system deployment
  - Define representations of land area and cost impacts to reflect high and moderate levels of impact on proximity to residences, wildlife habitat and migratory paths, radar interference and transmission expansion
  - Estimate impact on deployable land area and affected geographic areas
  - Develop supply curves for each representation demonstrating impact of incremental cost and land area
  - Conduct ReEDS scenario modeling to identify electric system cost and geographic shifts in large-scale wind deployment
- Bottom-up assessment of project case studies to characterize cost and time influence on go/no-go decisions and regional differences
- Multiple internal reports to DOE WWPTO summarizing results

Current: top-down assessment is complete, and we are working on the bottom-up assessment.

Wind Deployment Timeline



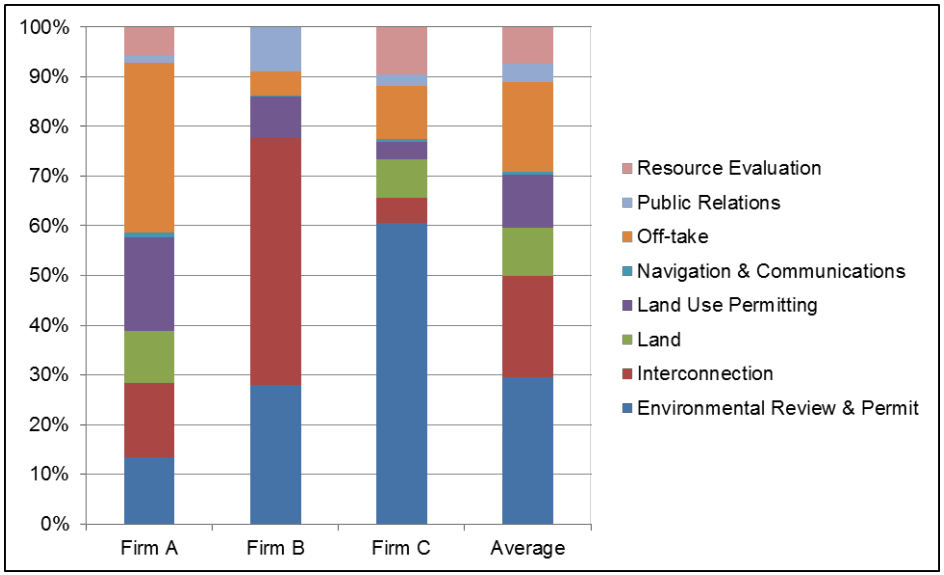
Siting considerations must be managed throughout the development process

Development timeline ranges vary greatly (5-12 years). Reducing project timeline *uncertainty even without reducing the actual timeline* could greatly benefit developers and accelerate (and possibly increase) deployment.

Accomplishments and Progress

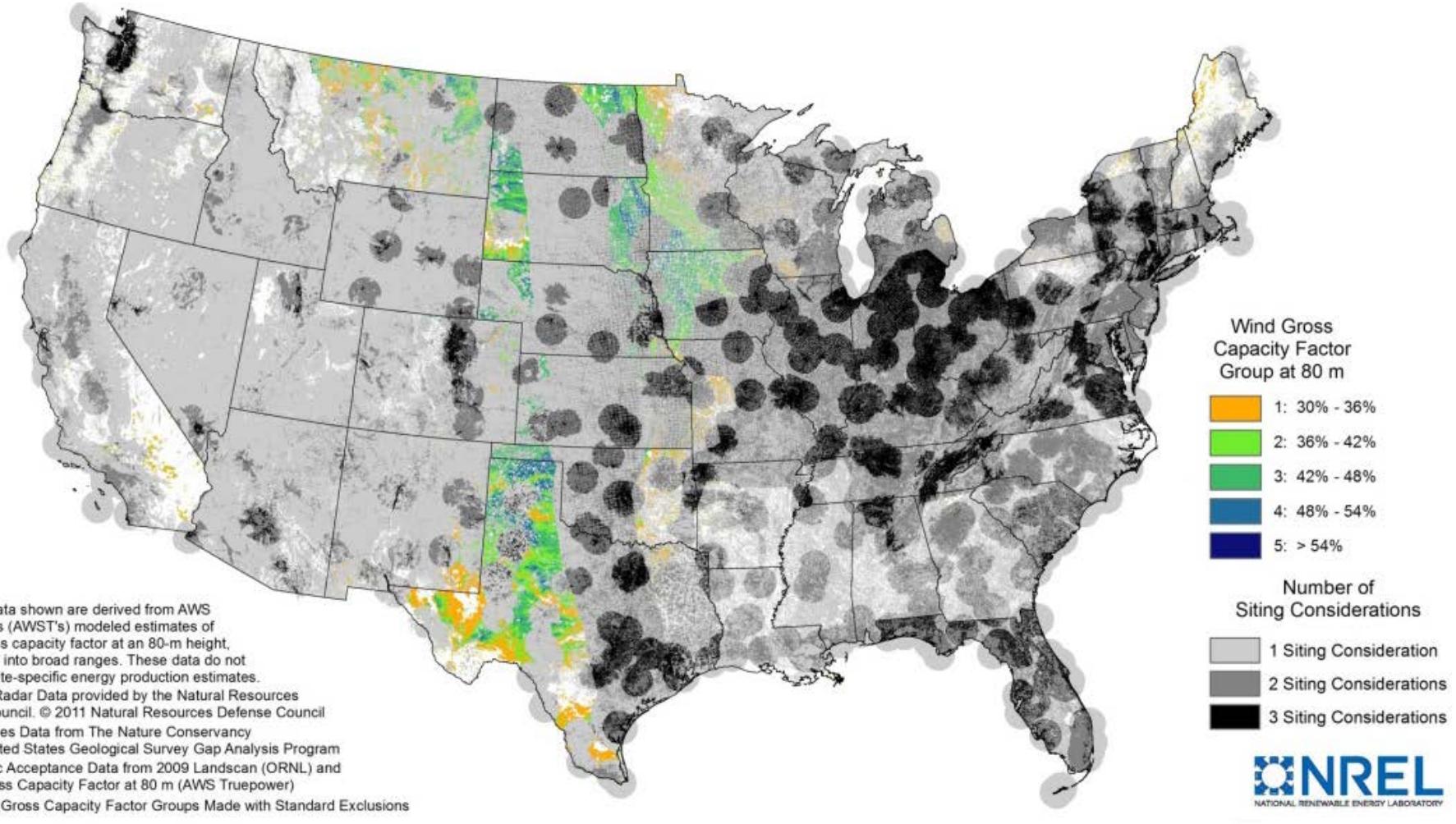
- This work has been presented to Secretary Danielson and to the International Energy Agency (public acceptance)
- The NREL team (GIS, ReEDS, finance, policy analysis, deployment) has presented various parts for different projects and has solicited feedback. We have provided internal briefings and reports to DOE and plan to publish information after validation through more developer interviews and analysis.

This figure shows direct cost data from three firms and an average to illustrate the high variability.



Accomplishments and Progress

This map shows areas where developers will likely encounter 1-3 of the following siting considerations (wildlife issues, proximity to homes, and radar)



Project Plan & Schedule

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Summary	
WBS Number or Agreement Number	
Project Number	
Agreement Number	

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

Task / Event	FY2012 Q1 (Oct-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Oct-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Oct-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Project Name: Scenario Modeling and Model Improvement												
Q1 : Initiate subcontracts with developers in two regions of the country to obtain data regarding deployment barriers												
Q2 : Preliminary report on initial findings of deployment impact on development, including go/nogo decision flow-chart for wind projects to help in quantifying extent and relative importance of siting barriers												
Q3 : Briefing of project status including GIS-based maps and initial quantification of deployment barrier impact												
Q4 : Briefing estimating potential impact of deployment barriers on future wind technology deployment.												
Q1 :Complete ReEDS modeling of a baseline scenario and compare it with the 20% Wind Energy by 2030 scenario												
Q2 : Briefing on ReEDS model results with the 20% Wind baseline scenario, four different barrier scenarios and a combined moderate scenario												
Q3 : Finalize a white paper on the impacts of barriers to wind deployment and coordinate with the programmatic and economic analysis area on metrics development.												
Q4 : Update Wind Prospector educational digital media tool												
Current work and future research												
Q1 : Identify at least three developers willing to work on in-depth analysis of their siting processes and decision making, including on-the-ground costs and time spent on real (and cancelled) projects.												
Q3 : Briefing on all deployment barrier project information collected to date												
Q4 : Complete Wind Prospector educational digital media tool												

Comments

- Project to be completed in FY14; milestones met on schedule with exception of white paper, due to review and revision cycle.

Research Integration & Collaboration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Partners, Subcontractors, and Collaborators:

NREL is working with numerous developers, engineering consulting firms, NGOs, and industry consultants who provide data used in this research. Information shared remains proprietary and is shown in an aggregated format. Collaborators include LBNL, USGS, and Sandia.

Communications and Technology Transfer:

The majority of findings from this work is currently internal to DOE and NREL, although some have been presented at a high level. DOE and NREL will work together to identify appropriate dissemination methods such as webinars, conferences, journal articles, or technical reports. The data layers from the maps will be made publically available on NREL's Wind Prospector tool.

Next Steps and Future Research

FY14/Current research:

- Interviews with additional developers to gain validation for initial direct and indirect cost estimates and to understand local deployment issues.
- Cost modeling and regular updates to DOE.
- From our findings, work with DOE and other labs to get information out through reports, articles, webinars, and tools.

Proposed future research:

- Publish research results, as appropriate
- Continued collaboration with industry to find out what is most useful to them (data, format)
- Work with Sandia and USGS and others to best assist federal agencies and developers in the deployment process
- Involvement with the RAPID Toolkit Project (Regulatory and Permitting Information Desktop).

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Programmatic and Economic Analysis

Eric Lantz

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March 27, 2014

Budget, Purpose, & Objectives

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Total DOE Budget[1]: $1.161M

Total Cost-Share[1]:$0.000M

Problem Statement: This project provides real-time analytic insights to WWPTO leadership and supports new analyses to inform emerging issues and new priorities

Project Impact: The project supports informed decision-making within and external to the program; specifically, it supports programmatic reporting, RDD&D decision-making, and responses to Congressional and Executive Management inquiries

This project aligns with the DOE Program objectives and priorities within:

Modeling & Analysis: Conduct wind techno-economic and life-cycle assessments to help the program focus its technology development priorities and identify key drivers and hurdles for wind energy technology commercialization

[1] ***Budget/Cost-Share for Period of Performance FY2012 – FY2013***

Technical Approach

- The technical approach associated with this project varies depending on the explicit needs
- The work of the project is carried out by dynamically assembling NREL and other laboratory experts to address high-priority topics that arise in the course of Program activities
- In the past, the project has entailed both analysis and logistical and project management support; more recently it provides analysis support only

Technical Approach

- Examples of the approach applied to projects completed during FY12 and FY13:
  - Logistical and project management support in the planning and execution of key Program meetings (e.g., FY12 Peer Review)
  - Data gathering and analysis to develop a national average wind power LCOE that conforms with the standardized approach adopted by EERE
  - Documentation and distribution of insights on life-cycle carbon emissions for wind, gleaned from a larger EERE research effort
  - LCOE sensitivity and bounding analysis to estimate the potential presented by specific innovation opportunities (e.g., tall towers)
  - Capacity expansion modeling with NREL's Regional Energy Deployment System (ReEDS) model to evaluate the effects of PTC extensions at various levels on wind capacity additions

Technical Approach

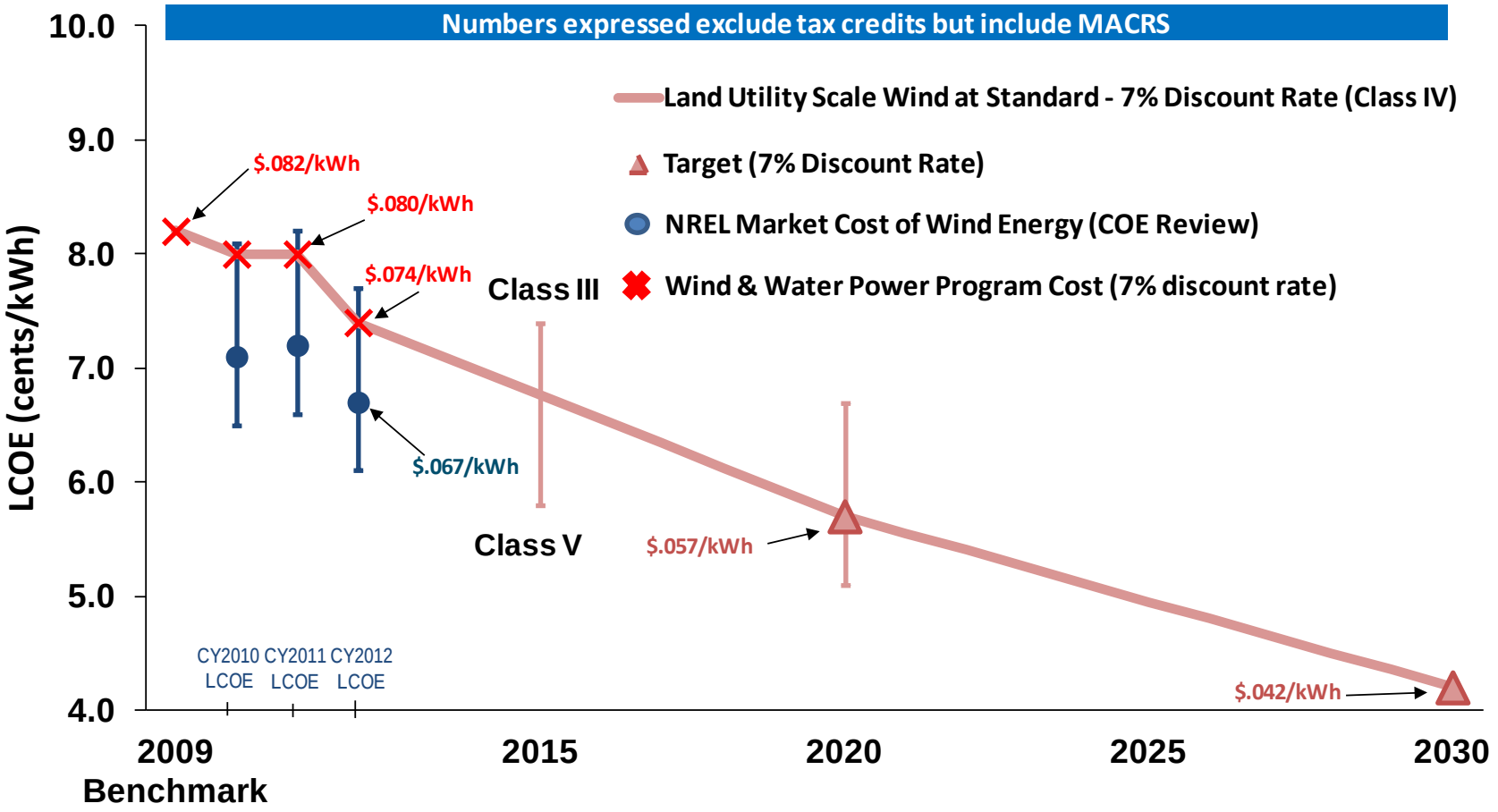
- Unique attributes:
  - The project relies on an inter-disciplinary understanding and working knowledge of real-time developments across technology, industry, and policy
  - The project must respond quickly and with varying degrees of confidence to diverse questions
  - The project leverages past and current work to provide the highest value information to decision-makers at multiple levels
  - The project combines the knowledge base of an industry consultant with the analytical depth and credibility associated with the WWPTO and its affiliated laboratories

Accomplishments and Progress

- FY12
  - Logistical support and project management assistance to the program in the organization and execution of the Wind Power Peer Review
  - Logistical and project management support in the organization and execution of an offsite WWPTO long-term planning meeting
  - Analysis support to the WWPTO for the purpose of characterizing and reporting progress towards the program's wind technology cost of energy goals
  - Synthesis of data and information to provide baseline cost of energy estimates as well as future technology cost and performance estimates
  - Analysis to characterize wind market barriers (e.g., public acceptance, wildlife, transmission, and permitting) and estimate potential impacts of specific market barriers
  - Analysis activities in support of RDD&D planning, budget analysis, and other inquiries
  - Analysis support to represent the cost of wind energy and the Program's cost of energy goals appropriately in other EERE directed analysis

Accomplishments and Progress

Trends in Wind LCOE



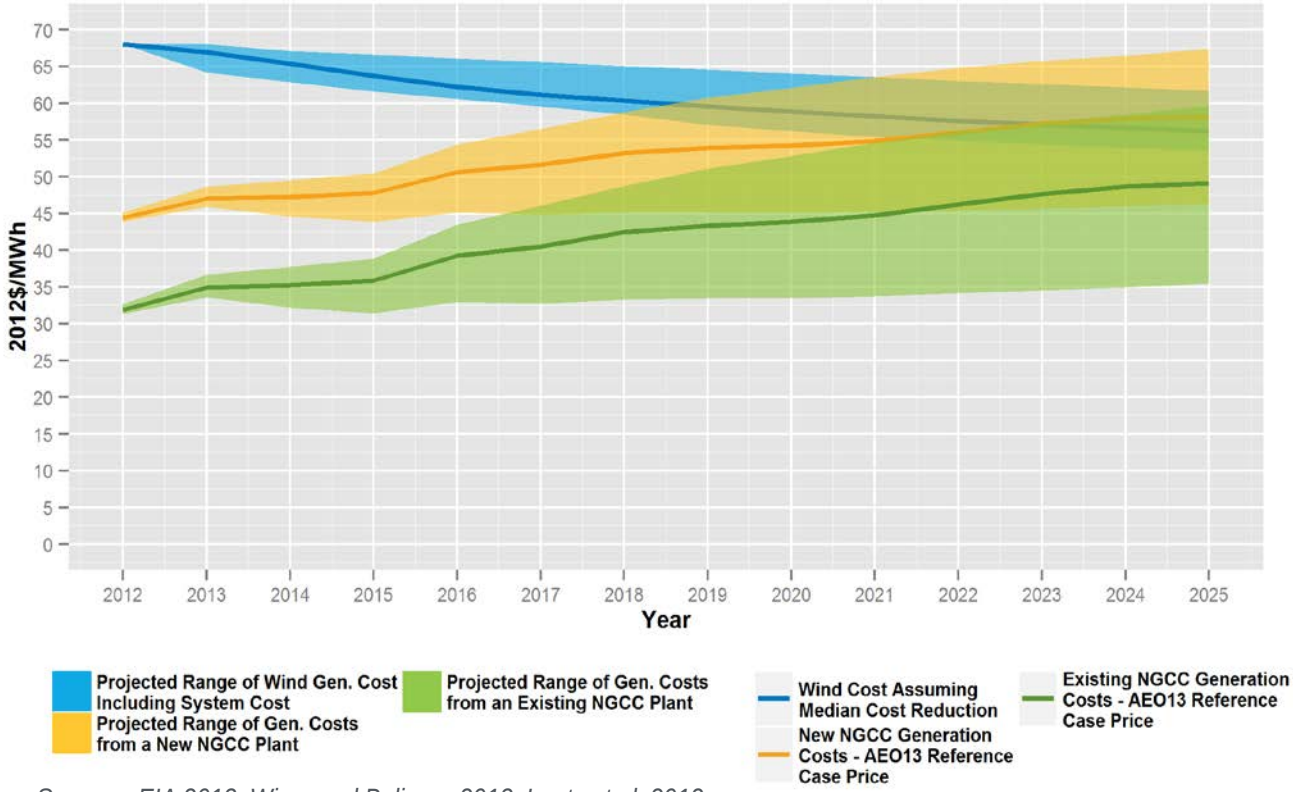
LCOE analysis tracks trends in cost of energy with a consistent methodology and standardized assumptions per EERE guidance and allows assessment of progress towards Programmatic Goals

Accomplishments and Progress

- FY13
  - Analysis support around programmatic cost of energy goals (in support of standard reporting requirements) and informing RDD&D decision-making was continued
  - Quick turn analysis to bound the opportunities presented by increased turbine hub heights
  - Fact sheet illustrating wind plant life-cycle carbon emissions relative to those of other generation technologies was developed and published
  - Assessment of relative wind and gas economics based on a median (2011/12) wind resource quality and appropriate technology selected for that wind regime (i.e., IEC Class 3)
  - ReEDS capacity expansion modeling effort to better understand the effect of various PTC levels and extension timeframes on future wind deployment per a request from the *Senate Energy and Natural Resources* committee staff

Accomplishments and Progress

Relative Wind and Gas Economics

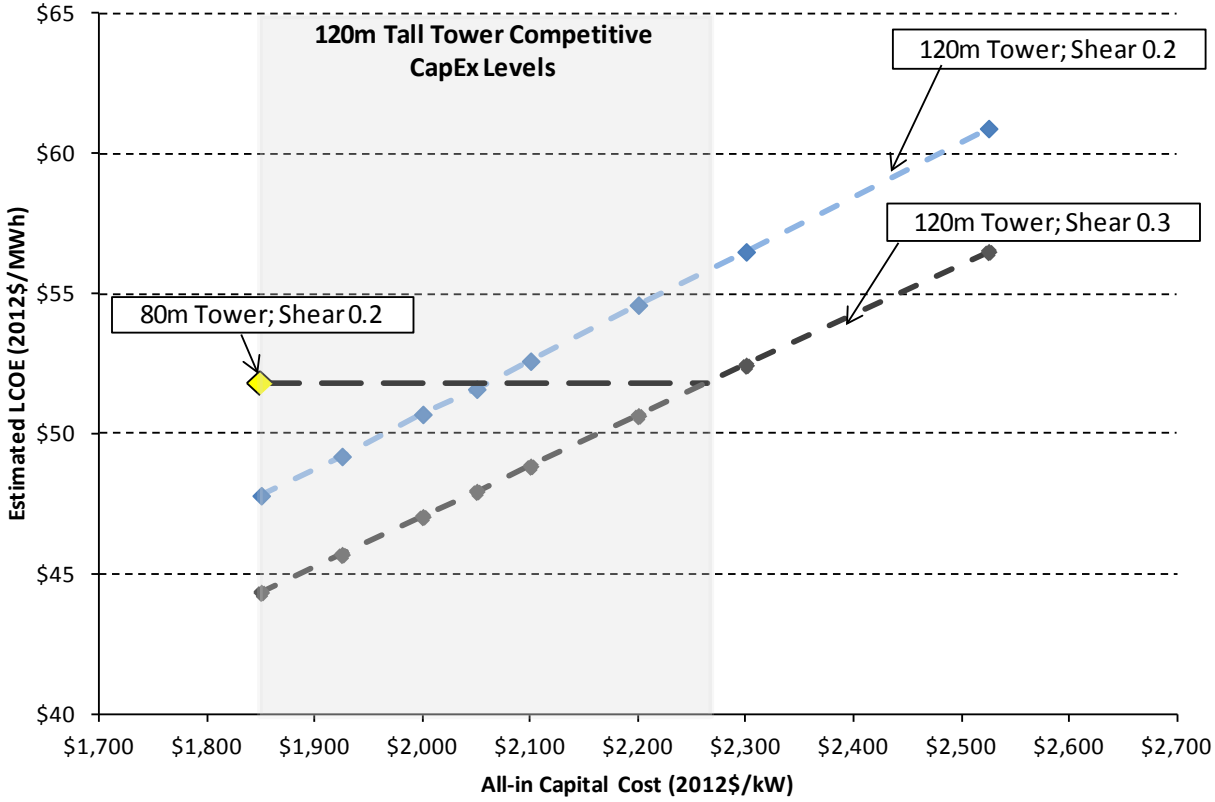


Sources: EIA 2013; Wiser and Bolinger 2013; Lantz et al. 2012

Note: Wind LCOE estimates exclude the PTC but include MACRS; they also include estimated resource adequacy and balancing costs

- **Analysis conducted within the larger *Senate Energy and Natural Resources* committee staff request**
- **<u>Key takeaway</u>: Absent policy support, a near-term (2014/16) gap of approximately $15-$25/MWh is expected between the cost of new wind plants and new and existing combined cycle gas-fired generation; this gap diminishes with time but persists through the early 2020s**

Simplified Opportunity Assessment for Tall Towers



- **Analysis response to WWPTO request for a high-level scoping of the opportunity provided by innovations that support tall tower technology**
- **<u>Key takeaway</u>: Innovations that allow access to 120-m hub heights and result in all-in CapEx levels below approximately $2,300/kW appear to be financially viable (when compared with 2012 average industry costs and technology)**

Project Plan & Schedule

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Summary	
WBS Number or Agreement Number	12.1.3
Project Number	
Agreement Number	

Legend

- Work completed
- Active Task
- Milestones & Deliverables (Original)
- Milestones & Deliverables (Actual)

Task / Event	FY2012 Q1 (Oct-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Oct-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Oct-Dec)	FY2014 Q2 (Jan-Mar)
Project Name: Programmatic and Economic Analysis										
Q1 Milestone: Revise wind energy "cost waterfalls" that graphically interpret cost of energy benchmarks, targets, and improvement opportunities.	◆									
Q2 Milestone: Develop agenda and facilitate program offsite meeting. Ensure execution of follow-up products – Meeting notes & Resource Mapping Tool.		◆								
Q3 Milestone: Organize and execute Wind Program peer review event (6/19/12 to 6/22/12).			◆							
Q4 Milestone: Letter report summarizing cost and performance assumptions utilized in annual DOE budget analysis modeling activities.				◆						
Q1 Milestone: Memo describing series of hourly wind resource profiles to represent typical wind project performance in U.S. December 31, 2012.					◆					
Q2 Milestone: Publish fact sheet summarizing life-cycle carbon emissions for wind projects. March 31, 2013.						◆	◆			
Q3 Milestone: Conduct mid-year project review with WWPP and provide power point briefing that documents the status of NREL analysis projects. June 30, 2013.							◆	◆		
Q4 Milestone: Milestones for this quarter will be dynamically assigned by WWPP.								◆		
FY14										
Q1 Project Milestone Description: Develop wind technology cost and performance inputs for analysis to support EERE Strategic Plan by December 31, 2013.									◆	
Q3 Project Milestone Description: Develop and test procedure for collecting high-priority, quick-response tasks, creating a response team, documenting the approach, and producing a result by June 30, 2014.										◆

Project milestones have been generally accomplished as planned

Research Integration & Collaboration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Partners, Subcontractors, and Collaborators: This project is led by NREL with support from other laboratory analysts (e.g., LBNL) and engineers (e.g., SNL) as needed

Communications and Technology Transfer:

- Project deliverables are typically for internal use only
- Some documents do make their way into the public domain
  - Life cycle carbon emissions fact sheet: http://www.nrel.gov/docs/fy13osti/57131.pdf
  - Implications of a PTC Extension on U.S. Wind Deployment (*forthcoming white paper*)

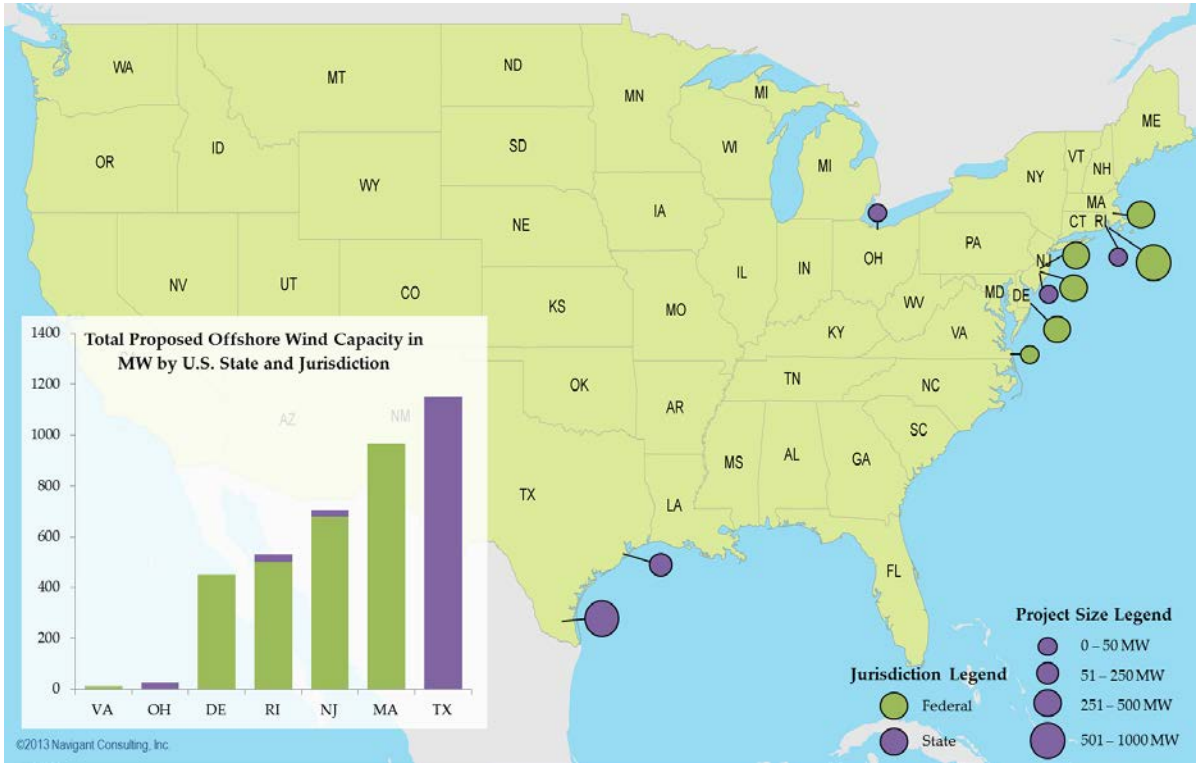
Next Steps and Future Research

FY14/Current research:

- Formalize procedures for receiving and executing priority inquiries
- Execute on new inquiries
- Deliver white paper to *Senate Energy and Natural Resources* committee staff

Proposed future research/actions:

- Leverage enhanced quantitative capabilities from other projects to develop better high-level assessments of the opportunity presented by potential programmatic investments (in particular, reflecting uncertainties throughout the system)
- Refine industry characterization methods to better represent a diverse industry with a broad range of costs as well as the real-time dynamism of the industry in a government/policy environment that tends to make decisions from single point characterizations



Offshore Wind Market and Economic Analysis

Bruce Hamilton

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March 27, 2014

Purpose & Objectives

Problem Statement: Provide stakeholders with a reliable and consistent data source with a comprehensive annual assessment of the U.S. offshore wind (OSW) industry.

Impact of Project: Serves as a road map for removing entry barriers and increasing U.S. competitiveness in the OSW market.

This project aligns with the following DOE Program objectives and priorities:

Mitigate Market Barriers: Reduce market barriers to preserve or expand access to quality wind resources.

Technical Approach

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Chapter	Data Sources	Methodology
1. Global Offshore Wind Development Trends	• Annual OSW survey • Navigant's OSW project data base • Previous research by NREL, OCC	• Review key literature
2. Analysis of Policy Developments	• Key industry reports	• List barriers and policy options based on Europe and US state experience • Evaluate options for effectiveness and cost
3. Economic Impacts	• NREL's OSW JEDI model	• Evaluate bottom-up cost of 500 MW reference plant
4. Developments in Relevant Sectors of the Economy	• Navigant's natural gas and electricity forecasts	• Research other economic factors

Accomplishments and Progress

Chapter	Accomplishments
1. Global Offshore Wind Development Trends	• Annual tracking of global OSW markets, technology, and advanced development of US OSW projects
2. Analysis of Policy Developments	• List and evaluation of OSW policies used in Europe and US states • OSW policy developments in 2013
3. Economic Impacts	• Bottom-up cost evaluation of 500 MW reference plant, as of 2012 and 2014 • US OSW jobs projected and actual as of 2012, 2013, and 2014
4. Developments in Relevant Sectors of the Economy	• Annual tracking of economic factors that affect US OSW development

Project Plan & Schedule

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Summary	
WBS Number or Agreement Number	
Project Number	EE0005360
Agreement Number	

Legend	
	Work completed
	Active Task
◆	Milestones & Deliverables (Original Plan)
◆	Milestones & Deliverables (Actual)

Task / Event	FY2012				FY2013				FY2014			
	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Offshore Wind Market and Economic Analysis												
Q1 and Q2 Milestones: Issue offshore wind survey	◆					◆				◆		
Q2 and Q3 Milestones: Offshore wind workshops		◆	◆				◆		◆	◆		
Q2 znd Q3 Activities: Develop and run offshore wind JEDI model												
Q4 and Q1 Activity: Internal and peer review of Technical Report												
Q1 Milestone: Technical Report delivered to DOE					◆				◆			
Current work and future research												
Offshore wind workshop											◆	
Technical Report delivered to DOE												◆

Comments

- Project original initiation date: 10/1/11
- Project planned completion date: 8/15/14
- Go/no-go decision points for FY12 and FY13: 10/12 and 10/13

Project Budget

Budget History					
FY2012		FY2013		FY2014	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$256K	-	$104K	-	$155K	-

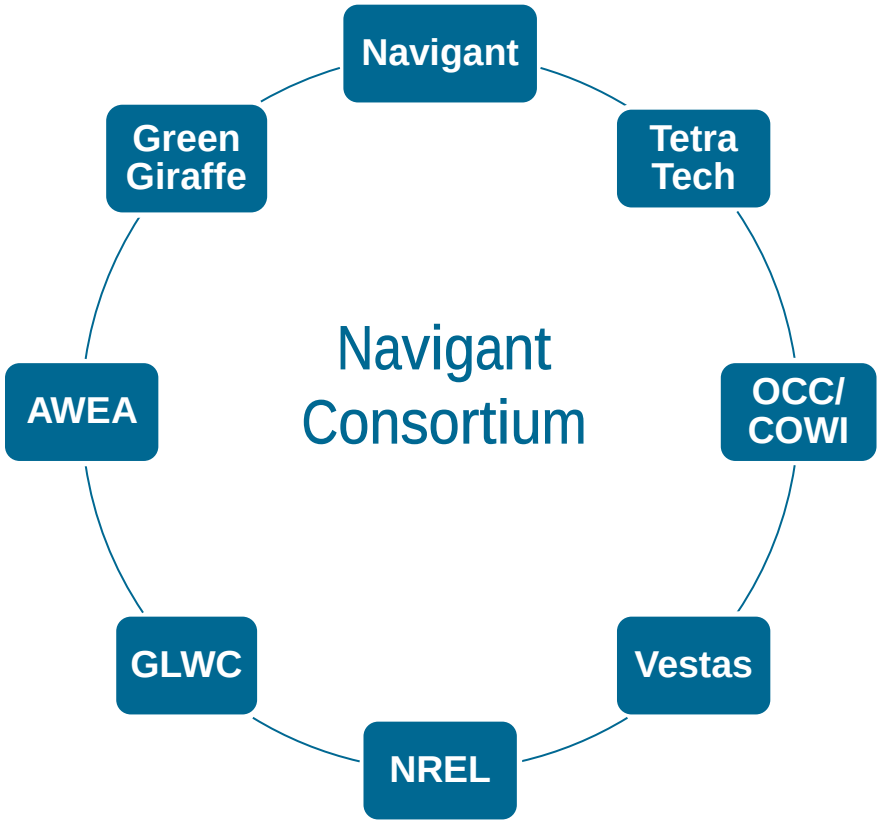
- Total budget = $515K (1)
- Expended through 12/31/13 = $381K
- Expected to complete on budget

Note 1: Excludes $85,000 for work performed by NREL as a DOE FFRDC.

Research Integration & Collaboration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Partners, Subcontractors, and Collaborators:



Communications and Technology Transfer:

- 6 workshops (market and technical trends, supply chain, economic impacts, and policy), plus guest speakers from other teams
- Portions of the reports presented at multiple webinars, podium and poster presentations
- Reports available at www.navigant.com.

Next Steps and Future Research

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

FY14/Current research:

- Workshops planned for 3/25/14 in Portland, ME and 5/5/14 in Las Vegas, NV
- Updating reference plant cost estimates and economic impacts based on 4 regional offshore wind JEDI models
- 3rd annual report on schedule to be issued in August

Proposed future research:

- Ongoing maintenance of offshore wind project and employment databases

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Offshore System Cost Analysis

Aaron Smith
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March 27, 2014

Budget, Purpose, & Objectives

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Total DOE Budget[1]: $0.699M

Total Cost-Share[1]:$0.000M

Problem Statement

Data, models, and analysis are needed to identify market conditions, cost-reduction opportunities, and deployment potential to identify the most valuable opportunities to influence the future U.S. offshore wind industry.

Impact of Project

Inform WWPTO and external stakeholders of developing and potential future trends to improve cost competitiveness of offshore wind technology

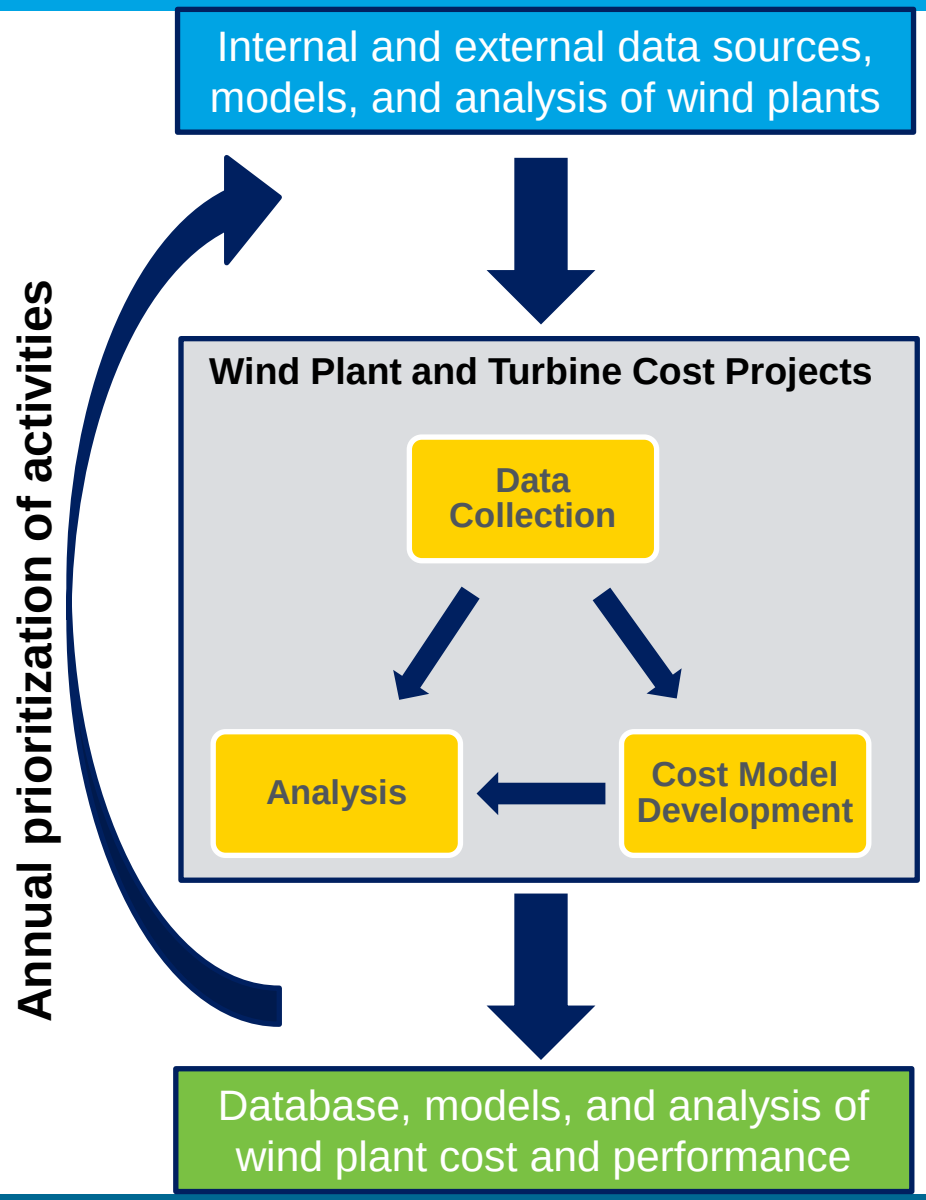
This project aligns with the following DOE Program objectives and priorities

- **Optimize Wind Plant Performance:** Reduce wind plant levelized cost of energy (LCOE)
- **Modeling & Analysis:** Conduct wind techno-economic and lifecycle assessments to help the Program focus its technology-development priorities and identify key drivers and hurdles for wind energy technology commercialization

[1] ***Budget/Cost-Share for Period of Performance FY2012 – FY2013***

Technical Approach

NREL Approach to LCOE Analysis



- Database of wind plant component cost organized with WWPTO Cost Breakdown Structure
- Models that allow scaling of turbine and plant to quantify sensitivity of cost to range of parameters
- Analysis using data and models to estimate wind plant cost and performance today and in the future
- Annual procedure for assessing data and modeling needs to support WWPTO R&D priorities to guide future-year efforts

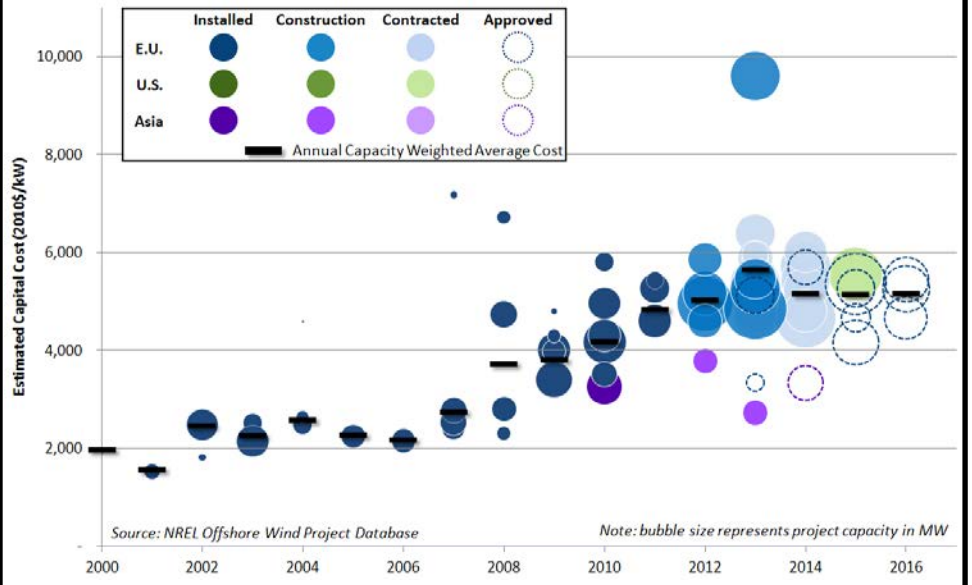
Accomplishments and Progress

Offshore Wind Databases and Analysis

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

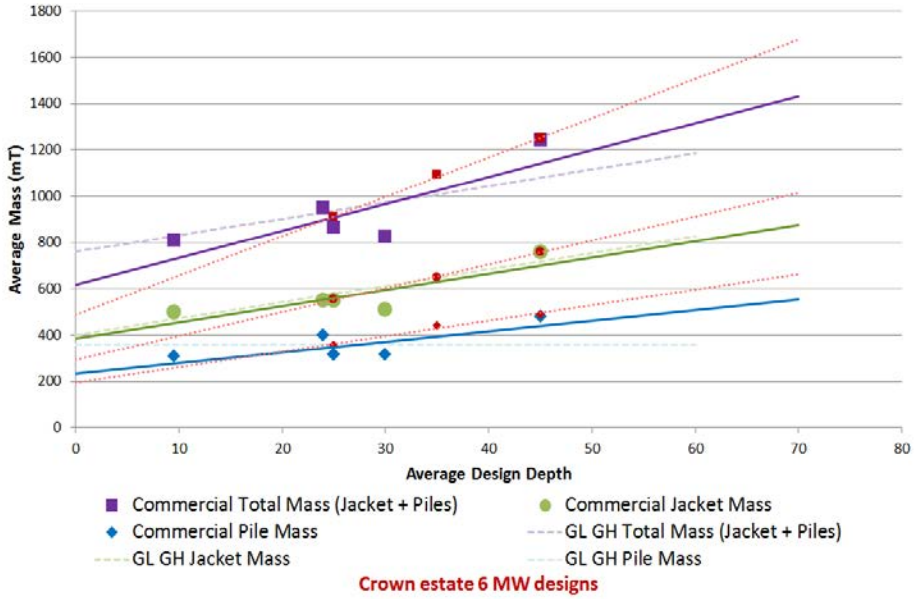
- NREL maintains offshore wind databases to store information about project characteristics, including technology, site parameters, costs, performance, and more to:
  - Identify important market and technology trends
  - Isolate cost and performance drivers
  - Develop and validate offshore wind cost models
- This information is used as the basis for the *Cost of Wind Energy Review*, an annual publication that supports WWPTO programmatic analysis and informs stakeholders

Offshore Wind Project Database



Example: Analysis of capital cost trends over time

Offshore Wind Component Database

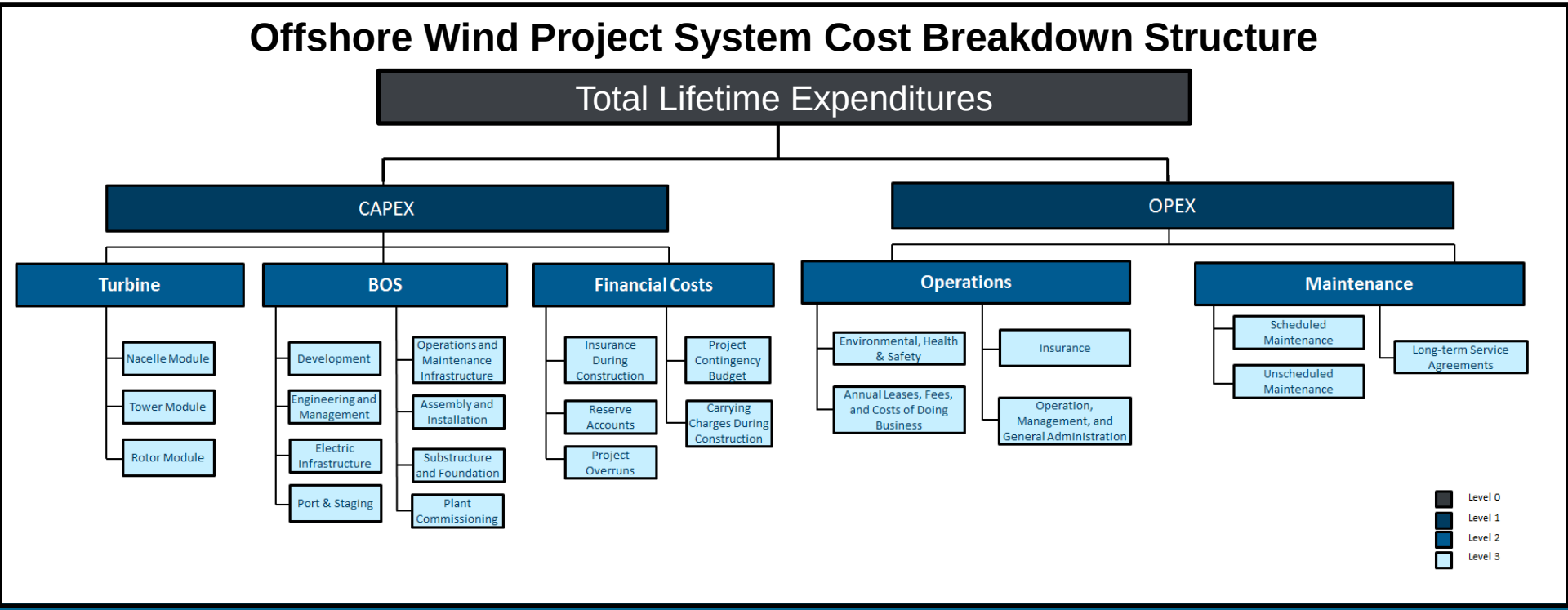


Example: Validation of substructure sizing relationships

Accomplishments and Progress

System Cost Breakdown Structure

- In FY13, a new initiative was introduced to explore options for creation of a central database to store information related to offshore wind projects
  - Development of System Cost Breakdown Structures
    - Offshore Wind
    - Land-based Wind
    - Coordination with MHK (NREL) and conventional hydropower (ORNL)



Accomplishments and Progress
Relational Database

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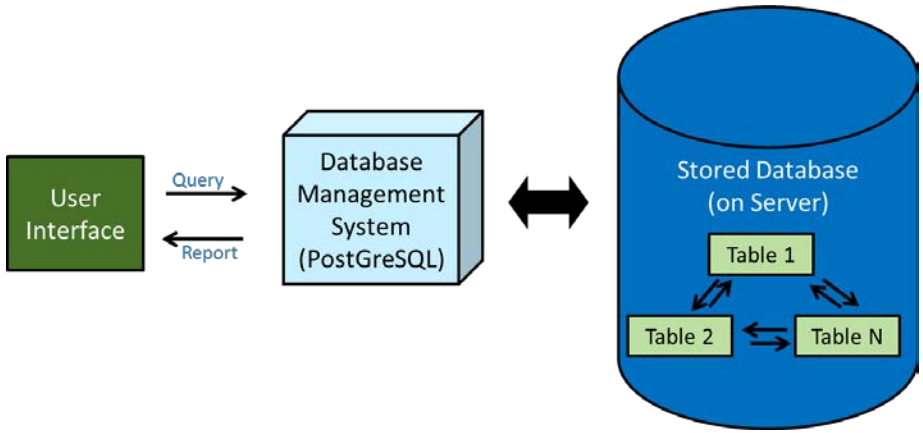
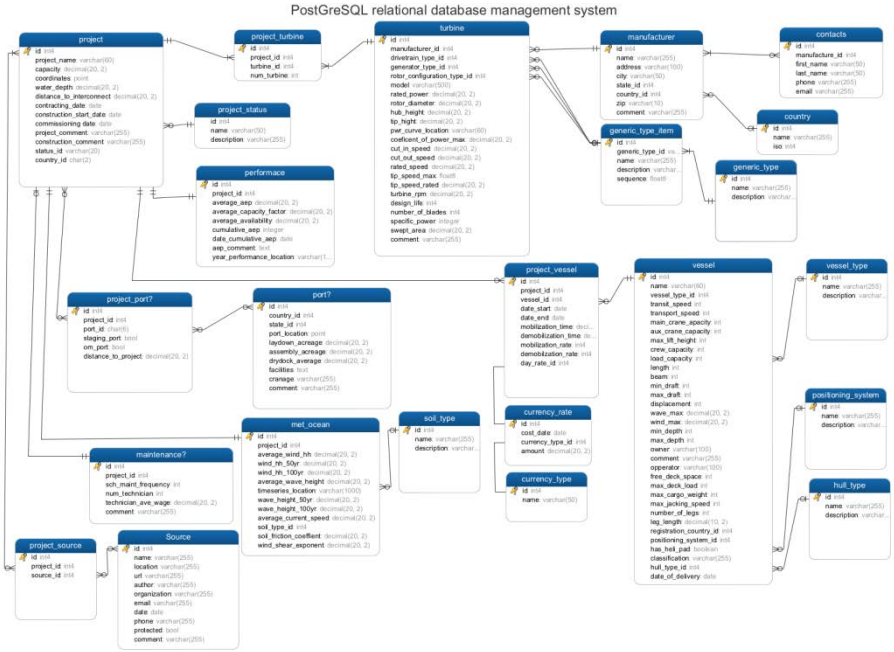
- In FY13, a new initiative was introduced to explore options for creation of a central database to store information related to offshore wind projects
  - Selection of a relational database concept (in PostgreSQL)
  - Design of initial database architecture based on System Cost Breakdown Structure
  - Plan for Web interface (remote create, read, update, delete capabilities)

Relational Database



Offshore Wind Database Architecture



Accomplishments and Progress

Floating Technology LCOE Analysis

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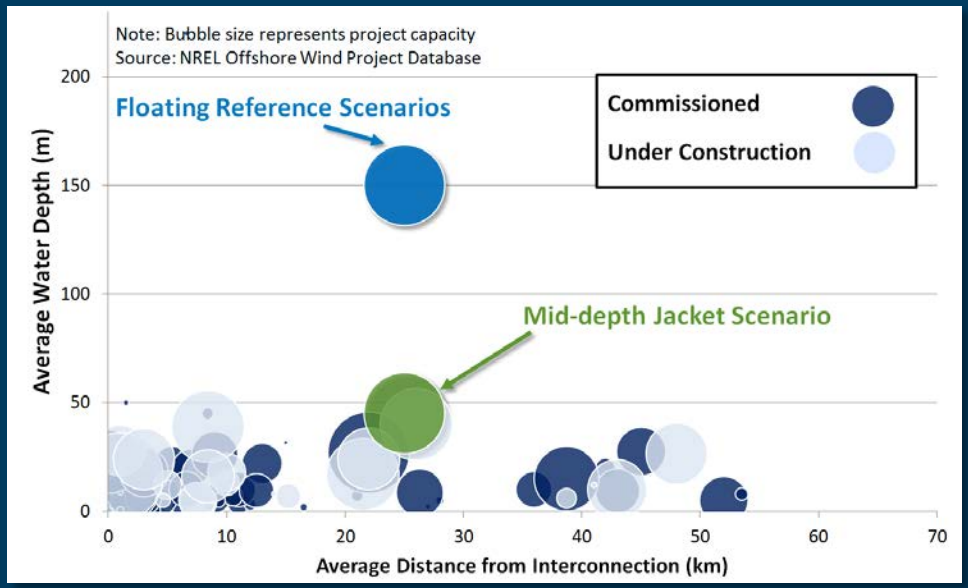
Analytical Reference Project: Constant Parameters

Category	Parameter
Wind Plant Rating (MW)	500
Number of Turbines	100
Turbine	NREL 5 MW Reference
Turbine Rating (MW)	5
Rotor Diameter (m)	126
Hub Height (m)	90
Drivetrain Type	Geared
System Design Life (years)	20
Distance to Port (km	25
Distance to Interconnect (km)	25
Electric Collection System (kV)	33
Electric Export System (kV)	132



Floating Reference Scenarios

Fixed-Bottom Benchmark Scenarios

Spar (150 m water depth)

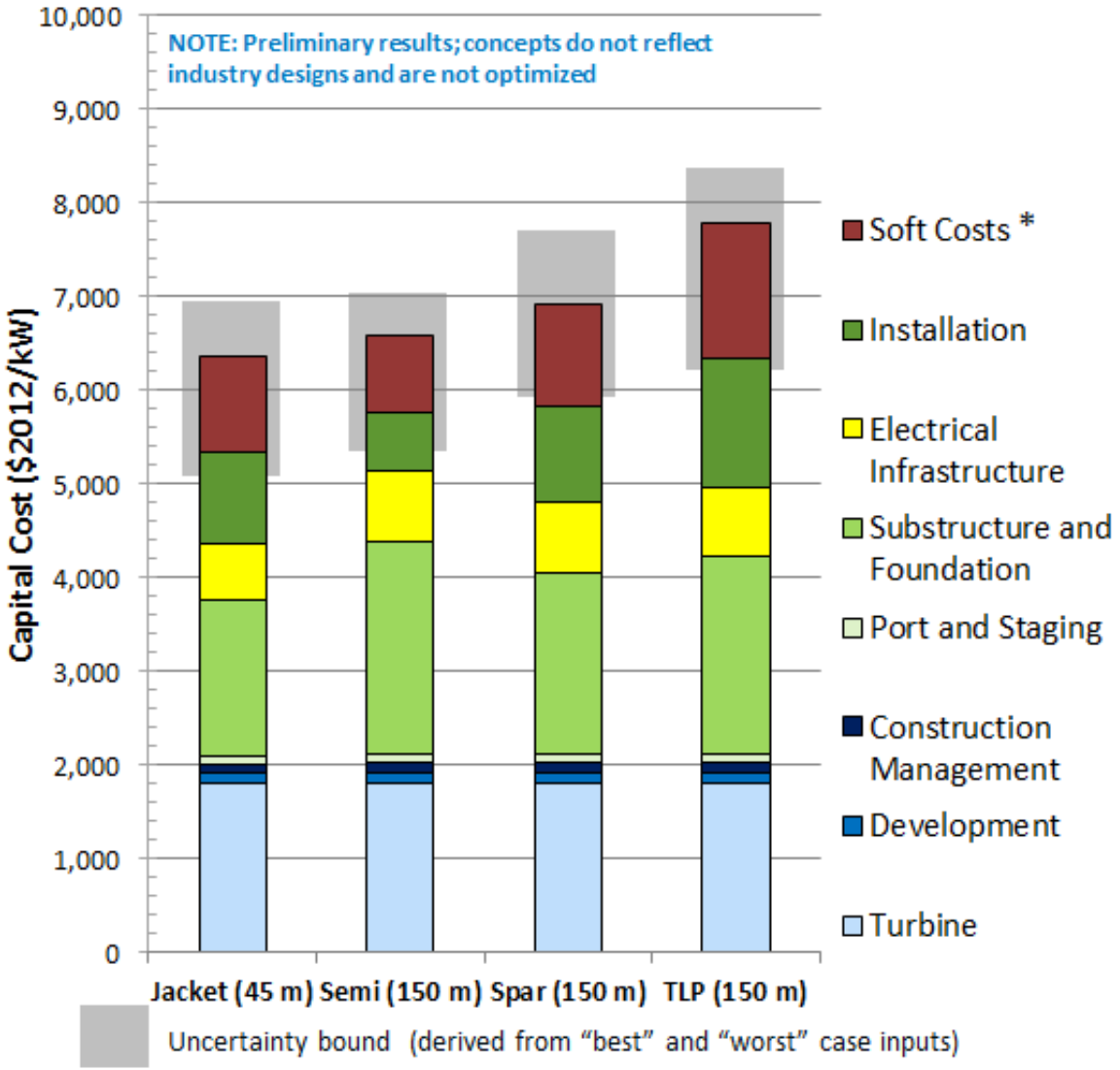
Semi (150 m water depth)

TLP (150 m water depth)

Mid-Depth Jacket (45 m water depth)

Accomplishments and Progress

Floating Technology LCOE Analysis



- Initial results presented at AWEA Offshore Wind 2013
- Report is currently under peer review by industry and academic subject-matter experts
- Preliminary CAPEX estimates provide a starting point for programmatic analysis of floating technologies

* Soft Costs include insurance, contingency, decommissioning, and construction finance

Project Plan & Schedule

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Summary	
WBS Number or Agreement Number	5.1.2
Project Number	
Agreement Number	

Legend
Work completed
Active Task
Milestones & Deliverables (Original Plan)
Milestones & Deliverables (Actual)

Task / Event	FY2012 Q1 (Oct-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Oct-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Oct-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Project Name: Offshore System Cost Analysis												
Q1 Milestone: Initiate subcontract for Offshore Jobs and Economic Development (JEDI) model development and maintenance. The outcome will enable project level jobs analysis for U.S. Offshore wind projects.	◆											
Q3 Milestone: Draft paper describing risk allocation mechanisms to be submitted to DOE			◆	◆								
Q3 Milestone: Final draft report of "Assessing the Potential for Offshore Wind Deployment in the United States" prepared as a DOE internal report"			◆	◆								
Q4 Milestone: Draft internal report summarizing floating offshore wind technology baseline cost of energy estimate.				◆								
Q1 Milestone: Submit an internal report to DOE documenting the development of the offshore component cost database by December 31, 2012. The database will consolidate numerous costs obtained from industry partners and other sources and is necessary to validate NREL cost models.					◆							
Q2 Milestone: Document the peer-reviewed offshore Jobs and Economic Development Impact (JEDI) model for offshore wind and post the document on the NREL website by March 31, 2013.						◆						
Q3 Milestone: Submit final report to DOE on floating offshore wind economics, summarizing baseline cost of energy estimates for three floating configurations by June 30, 2013. This milestone advances the accuracy of the draft report submitted in Q4 of FY12 by validating assumptions, conducting sensitivity studies, and conducting peer reviews.							◆					
Q4 Milestone: Draft PowerPoint summarizing cost of offshore wind energy in 2012 based on market data obtained from the Navigant Annual Offshore Market Report and the NREL Offshore Wind Project Database, models developed, and analysis conducted throughout FY13 to support Wind Vision modeling inputs. September 30, 2013.								◆				

Comments

- Ongoing project; majority of milestones completed on schedule, although some brief delays due to schedules for peer review and communications. In FY14, this project is combined with System LCOE Analysis; FY14 plans described on subsequent slide.

Research Integration & Collaboration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Partners, Subcontractors, and Collaborators

- Navigant FOA 414 Consortium (Navigant, OCC, GLWN, AWEA, Green Giraffe, Tetra Tech)
- IEA Wind Task 26 (SINTEF [NO], Norwegian Water and Energy Directorate [NO], Ea Energy Analysis (DK), Deutsche WindGuard [DE], IWES Fraunhofer [DE], Dublin Institute of Technology [IE], TKI Offshore Wind [NL], European Commission [EU])
- Subcontractors and Subscriptions (Fishermen's Energy, DeepWater Wind, 4C Offshore, MAKE Consulting)
- Collaborators (Lawrence Berkeley National Laboratory, Oak Ridge National Laboratory , Sandia National Laboratory, Cape Wind, Arcadia Offshore Wind, LEEDCo, American Wind Energy Association, Offshore Developers Coalition, Principle Power, Statoil, Glosten Associates, University of Maine, DONG Energy, RWE, Siemens, AREVA)

Communications and Technology Transfer

- Publication: 2010 Cost of Wind Energy Review, available at http://www.nrel.gov/publications/
- Publication: 2011 Cost of Wind Energy Review, available at http://www.nrel.gov/publications/
- Publication: Offshore Wind Market Overview, available at http://www.nrel.gov/publications/
- Offshore Wind JEDI Model and Documentation, available at http://www.nrel.gov/analysis/jedi/download.html
- Presentation: "The Business Case for Offshore Wind in the United States" presented at GreenPower Offshore Wind 2013
- Presentation: "A Preliminary Assessment of Floating Offshore Wind Capital Expenditures" presented at Offshore WINDPOWER 2013

Next Steps and Future Research

FY14/Current research:

- Data
  - Develop and test database infrastructure (database, web interface, quality control mechanisms)
  - Collect data to maintain databases and address key knowledge gaps (desktop research, direct outreach, subcontracts, purchased databases)
  - Populate database, evaluate data quality, and plan future data collection activities
- Models
  - Verify land-based balance of system model with external contacts
  - Improve offshore wind balance of system model and verify with external contacts
- Analysis
  - Develop Wind Vision wind cost and performance assumptions
  - Publish Floating Wind Plant Economics report
  - Draft 2013 Cost of Wind Energy Review
  - Assess recent wind turbine technology trends to understand impact on LCOE
  - Contribute to IEA Wind Task 26 (international comparison of land-based and offshore wind LCOE)

Proposed future research:

- Continue to use data, models, and analysis to answer the WWPTO's key questions and support research objectives
- Systematically assess technology innovations needed to achieve cost of energy reduction goals:
  - High level analysis to identify cost drivers and sensitivity to technical and non-technical influences
  - Coordination with technology researchers to create/improve engineering cost models for land-based and offshore wind
  - Evaluate the potential LCOE impact of new technology solutions at the wind plant system level and implications for deployment in the United States

Wind Power Peer Review

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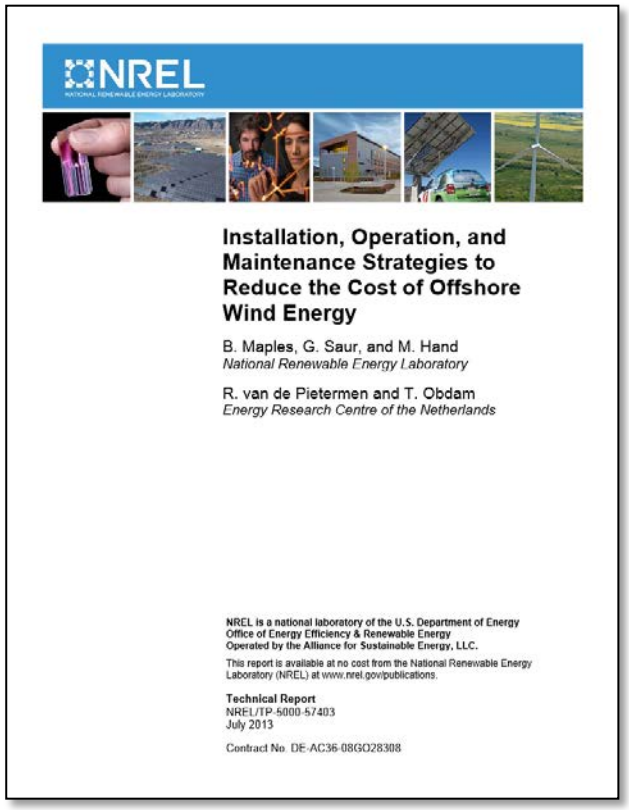

NREL

Installation, Operation, and Maintenance Strategies to Reduce the Cost of Offshore Wind Energy

B. Maples, G. Saur, and M. Hand
National Renewable Energy Laboratory

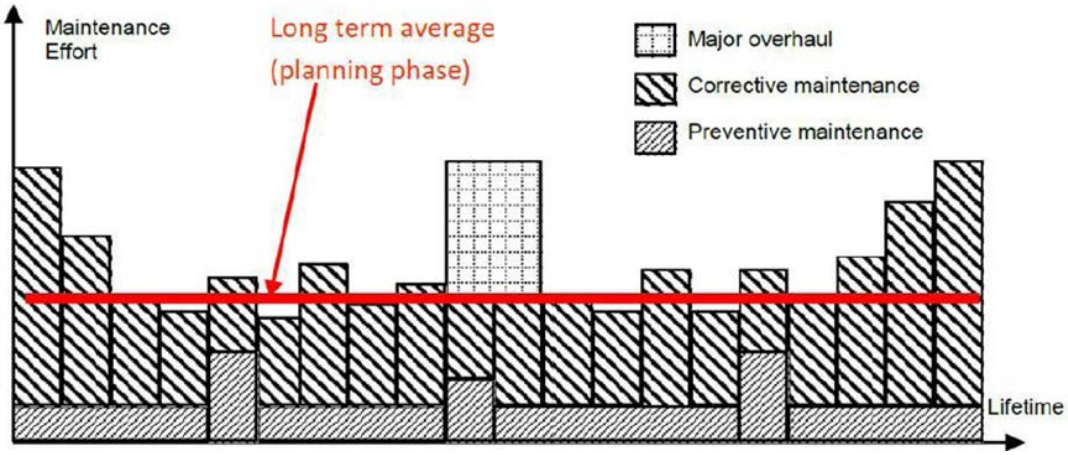
R. van de Pietermen and T. Obdam
Energy Research Centre of the Netherlands

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC.

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Technical Report
NREL/TP-5000-57403
July 2013

Contract No. DE-AC36-08GO28308



Obdam, T. S., Braam, H., & Rademakers, L. (2011). *User Guide and Model Description of ECN O&M Tool Version 4.*

Reduce LCOE

DE-FOA-0000414/U.S. Offshore Wind: Removing Market Barriers
Optimized Installation, Operation and Maintenance Strategies

Ben Maples

National Renewable Energy Laboratory
Ben.Maples@NREL.GOV (303) 384-7137
March 24, 2014

Budget, Purpose, & Objectives

Total DOE Budget [1,2]: $0.00M

Total Cost-Share[1]:$.000M

Problem Statement: Carry out analysis and modeling to identify the most practical means of reducing LCOE through innovative installation, operation and maintenance techniques.

Impact of Project: By identifying technology improvement opportunities the project provides a basis for evaluating subsequent innovative engineering and scientific concepts.

This project aligns with the following DOE Program objectives and priorities:

- **Optimize Wind Plant Performance:** Reduce Wind Plant Levelized Cost of Energy (LCOE)
- **Modeling & Analysis:** Conduct wind techno-economic and life-cycle assessments to help program focus its technology development priorities and identify key drivers and hurdles for wind energy technology commercialization.

[1] *Budget/Cost-Share for Period of Performance FY2012 – FY2013*
[2] *Project remained active using DOE funds received prior to FY2012*

Technical Approach

- Identify and analyze innovative IO&M strategies for a case study by developing models for U.S. offshore wind.
- Partnered and consulted with industry leaders, which ensured focus on issues and innovations that were informed by international experience. This ensured that the results of the project were accurate and pertinent to industry.

NREL

- Project lead
- Installation model development and analysis
- Final LCOE analysis and reporting.

Energy research Centre of the Netherlands (ECN)

- Primary project partner
- O&M model development and analysis
- Use of ECN offshore O&M model.

Expert Panel

- Project advisory role
- Provide innovative IO&M strategies
- Provide feedback and validation on project analysis.

Technical Approach

The work is divided in two major tasks:

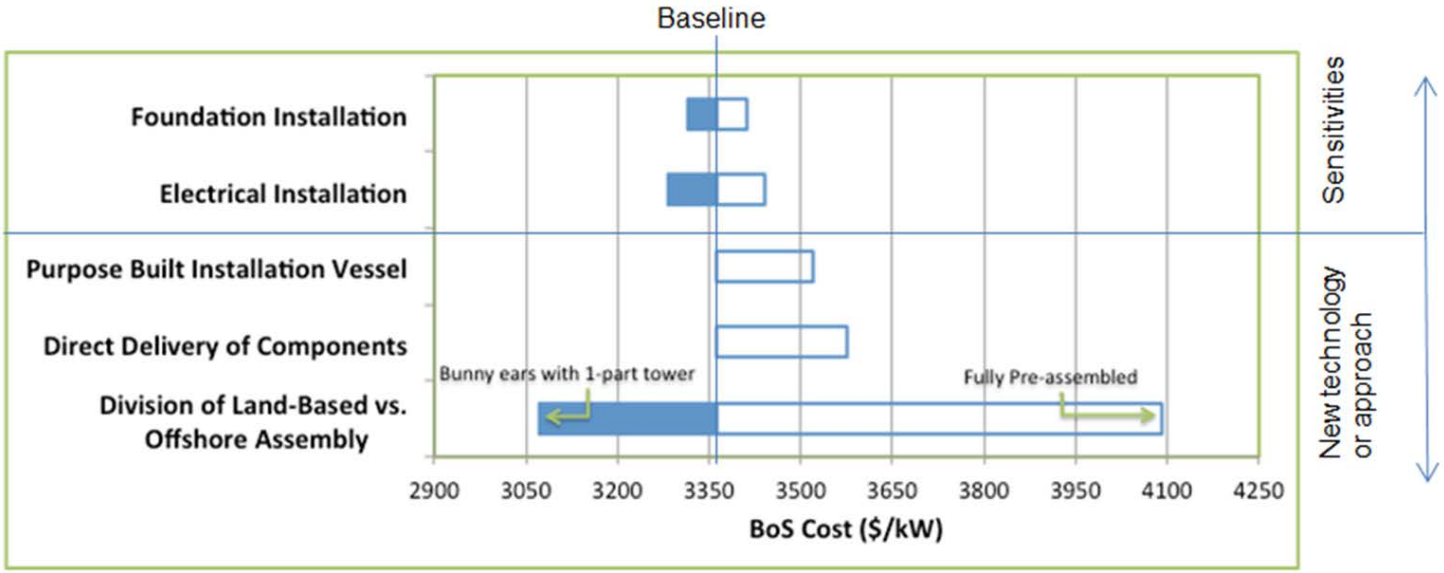
- **Model Development and analysis**
  - Develop a turbine installation module for offshore wind that will integrate into a balance-of-station model.
  - Contract with ECN to adapt its commercially available O&M Tool to model U.S. site conditions.
  - Use real-world wind and wave condition data to identify the most practical means of reducing offshore wind LCOE through advanced IO&M techniques, integrated service providers, and preferred supporting infrastructure.
- **Case Study**
  - Apply the most impactful combination of the advanced IO&M strategies to a hypothetical offshore wind plant in order to present a preferred overall IO&M approach for that facility.
  - Include all cost elements to demonstrate the impact of the preferred IO&M approach by comparing to a baseline LCOE.

Technical Approach

Credit: Universal Pictures

- IO&M strategies were analyzed to show the upside or added value to a strategy (e.g., increased energy production), and not the potential downside (e.g., added capital cost of new hardware).
- Therefore, results can be used to take the cost savings presented and add revised technologies costs to arrive at a net decrease or increase in cost of energy.
- This allows many technologies that target the same improvement area to be evaluated subsequent to this study.

Installation

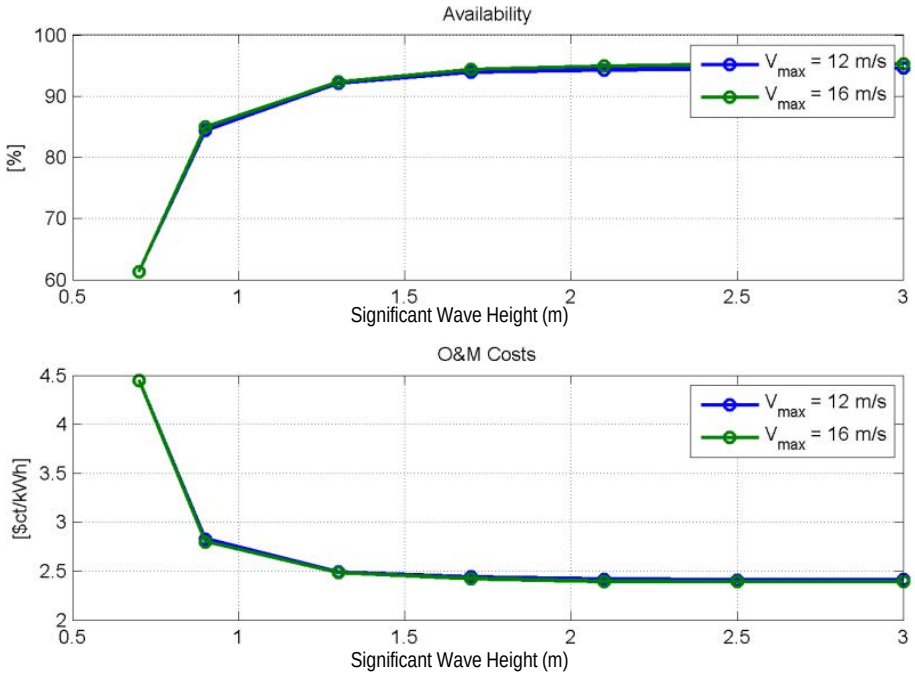


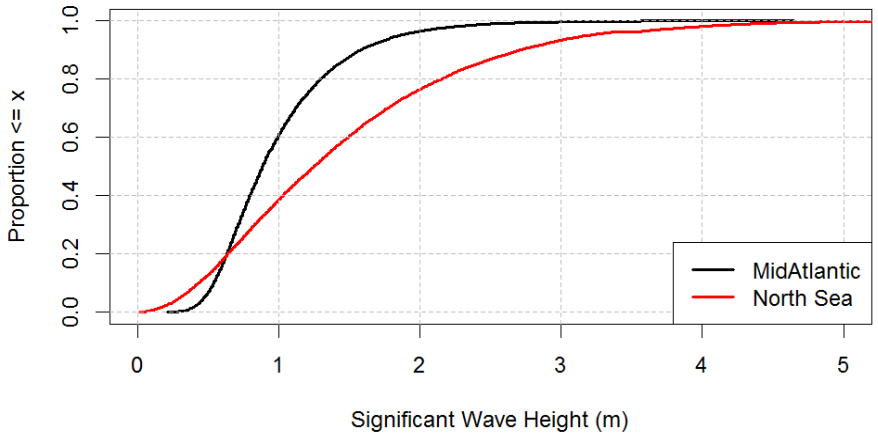
- Foundation and Electrical installation show both increase and decrease to BOS costs due to the nature of a sensitivity analysis.
- Purpose built vessel and direct delivery of components only increased costs for this scenario.
- Division of land-based vs. offshore assembly shows a range of outcomes.

O&M

For O&M access vessels:

- Effect of significant wave height (Hs) limits on accessibility is significant
- Effect of wind speed is not significant
- 1.5-m significant wave height appears to be an optimal design point for these wind/wave conditions.





The influence of significant wave height restrictions on O&M access vessels is very much dependent on the site under consideration.

Preferred IO&M Strategy

- The primary improvement was in the reduction of waiting time from the improved O&M crew transfer vessel (0.9-m to 1.5-m wave restrictions).
  - Increased availability by more than 10%
  - Increased AEP by almost 12%.
- Ports & Staging costs went up more than 300% due to the advanced installation strategy, but because of its minor contribution to LCOE, the 15% reduction in Vessel costs outweighed its cost increase.
- A 14% reduction in LCOE could be achieved with two simple changes in IO&M strategy.
- **Careful planning at the beginning of a project can yield significant cost reductions.**

	Baseline	Preferred	Impact
AEP (MWh/MW/yr)	3267	3648	+11.7%
Availability (%)	84.5	93.3	+10.4%
O&M ($/kWh)	0.0283	0.0248	-12.4%
Ports & Staging ($/kW)	26	79	+304%
Installation Vessels ($/kW)	1240	1055	-15%
LCOE ($/kWh)	**0.233**	**0.200**	**-14%**

Project Plan & Schedule

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Summary	
WBS Number or Agreement Number	WE 5.1.22
Project Number	
Agreement Number	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

	FY2012				FY2013				FY2014			
Task / Event	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: IO&M Strategies to Reduce the Cost of Offshore Wind Energy												
Hold Kickoff Meeting												
Installation Model Development												
O&M model Updates												
Establish Baseline for Case Study												
Identify Cost Drivers												
Collect Input from Expert Panel												
Evaluate Alternative IO&M Strategies												
Complete Case Study Analysis												
Draft Report												
Publish Report												

Comments

- Project original initiation date: February, 2012
- Project planned completion date: February, 2013
- Analysis completed on schedule, final report delivery delayed due to report editing and revisions.

Research Integration & Collaboration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Partners, Subcontractors, and Collaborators

Primary project partner (subcontractor):

Energy research Centre of the Netherlands (ECN)

In-kind Contributors:

- GE Energy
- Siemens Energy
- Global Marine Energy
- Douglas Westwood
- Romax Technologies
- GL Noble Denton
- Knud E. Hanson
- Vattenfall

Communications and Technology Transfer

- **Results presented at the Navigant Workshop in conjunction with the 2013 AWEA WINDPOWER event in Chicago, IL.**
- **Final Report has been published on the NREL website and can be found here: http://www.nrel.gov/docs/fy13osti/57403.pdf**
- **Installation module of BOS model to be publicly available once all portions of the BOS model are complete and integrated in the System Advisor Model (SAM).**

Next Steps and Future Research

FY14/Current research:

The project was completed in June 2013.

Proposed future research:

- Continued work focusing on how the underlying assumptions and unknown capital costs impact the conclusions of the study is important.
- Additional efforts to look at unique installation methods for electrical and foundations would likely prove valuable, based on the initial results seen in this study.
- Furthermore, estimating the “break even” cost/benefit curves for various technologies may be valuable.