Appendix E – GPRA07 Wind Technologies Program Documentation

Introduction

GPRA benefits for the Wind Technologies Program are estimated primarily from model projections of the market share for wind technologies, based on their economic characteristics. Two models are utilized for this purpose: NEMS-GPRA07 (a modified version of the National Energy Modeling System), and MARKAL-GPRA07 (a modified version of standard MARKAL). This document describes the inputs and assumptions that are used by the models to calculate those benefits.

FY07 Program Goals Assessed

Program Objective

The mission of the Wind Technologies Program is to "*lead the Nation's research and development efforts to improve wind energy technology through public/private partnerships that enhance domestic economic benefit from development, and to address the barriers to the use of wind energy in coordination with stakeholders, resulting in greater energy security through more diverse, clean, reliable, affordable and secure domestic supply*." To achieve the mission, the Wind Program portfolio includes both short-term and long-term research and outreach to solve technology and institutional issues. Balancing this portfolio effectively will help maintain U.S. wind industry momentum.

Program Performance Goals

The Wind Program's Multi-Year Program Plan [6] contains the following goals[1]:

- By 2012, reduce the cost of electricity (COE) from large wind systems in Class 4 winds to 3.6 cents/kWh for onshore systems (from a baseline of 5.5 cents/kWh in 2002)
- By 2014, reduce the COE from large wind systems in Class 6 winds to 5 cents/kWh for shallow water (depths up to 30 meters) offshore systems (from a baseline of 9.5 cents in FY 2005)
- By 2016, reduce the COE from large wind systems in Class 6 winds to 5 cents/kWh for transitional (depths up to 60 meters) offshore systems (from a baseline of 12 cents in FY 2006)

[1] Onshore system COEs are stated in 2002 dollars for consistency with other Wind Program documents. However, to be consistent with AEO 05 assumptions used in NEMS, the onshore COE figures should be converted to 2003 dollars using the GDP deflator of 1.018312. Likewise, offshore COE figures above are stated in 2005 dollars, and a deflator of 0.960338 should be used to convert those to 2003 dollars.

- By 2007, reduce the COE from distributed wind systems to 10-15 cents/kWh in Class 3 wind resources, from a baseline of 17-22 cents/kWh in 2002.
- By 2010, facilitate the installation of at least 100 MW of wind in at least 30 states from a baseline of eight states in 2002.

Resource Assumptions

The Fiscal Year 2007 budget request[2] for Wind Energy is $43.8 million, a nearly $5 million increase over the Fiscal Year 2006 Appropriation. A summary of the recent and requested budget, by major activity area, is shown in Table 1. The table shows a large portion of the appropriated FY 2006 budget for congressionally directed activities ($12.87 million).

Table 1. FY 2007 Budget Request for Wind Energy Program

Funding ($ in thousands)			
Activity	**FY 2005 Approp.**	**FY 2006 Approp.**	**FY 2007 Request**
Technology Viability..........................	25,961	18,353	35,905
Technology Application.....................	10,111	7,634	7,914
Congressionally Directed Activities....	4,559	12,870	0
TOTAL..	**40,631**	**38,857**	**43,819**

An estimated breakout of the FY 2007 requested budget by program performance goal categories is shown Table 2. Figures are based on preliminary assessments.

Table 2. Estimated FY 2007 Budget By Performance Goal Category

Performance Goal Category	Estimated 2007 Budget ($ million)
Low Wind Speed Technology	19.4
Offshore Wind Technology	15.0
Distributed Wind Technology	1.0
Wind Grid Integration/Systems Integration	4.1
Technology Application/Technology Acceptance and Coordination	3.9
Small Business Innovative Research (not a specific category)	0.9

Funding for congressionally directed activities for FY 2007 and beyond is assumed to be zero. Future program funding is assumed to remain level at the FY 2007 request level through completion of offshore wind turbine R&D in 2016. The program estimates the annual industry cost-sharing level for all private/public partnerships to be approximately 50%. Figure P.1 in the Preface to the main report depicts the logical flow of all generalized aspects of the program.

[2] EERE's FY07 "Budget in Brief" may be accessed at http://www1.eere.energy.gov/ba/pba/budget_07.html.

Significant Changes

The program's 2012 goal for onshore low wind-speed technology (LWST) was revised in FY06 from 3.0 cents/kWh to 3.6 cents/kWh in Class 4 sites.[3] The leading factor for this revision was the reduction in discretionary FY06 funding, which caused a large reduction in research and industry subcontracts for onshore technology development.

As a result of funding reductions, several full system and component development projects had to be rescoped or terminated. Even if full funding were to be restored to these projects in future years, significant project momentum has been lost, thus reducing the likelihood of timely COE impacts. A closely related factor is the balance between the Wind Program onshore and offshore activities in a constrained funding environment. The values used for the wind technology cost and performance projections in the GPRA benefits analysis are consistent with this new goal.

The assessment of current status and future trends for offshore wind energy technology, and the formulation of R&D goals, has been under development for the past two years. The Wind Program continues to develop data and analysis toward that end. For this year's GPRA analysis, cost and performance estimates for offshore wind technology include a combination of shallow water technology (depths of 30 meters and less), which is competitive in near term; and transitional water technology (depths of 30-60 meters), which will be competitive beginning in the midterm, have been determined that are consistent with program goals. This is a change from the FY 2006 GPRA analysis, which used a combination of shallow and deep water technology, the latter in water from 60 to 900 meters. These depth figures were developed by the program. The program views this revised strategy as one of incremental technology development—moving from the better understood shallow water technologies to the transitional depth; and, finally, utilizing the accumulated knowledge base from those two applications for eventual deep water technology development.

Target Markets (The Base Case)

Target market Description

Large-scale wind energy is expected to penetrate in two market segments: the least-cost (competitive bulk power) power market and the segment comprising a combination of voluntary (green power) and mandatory (green power or renewable portfolio standards) market programs or requirements. Because of the geographic diversity of the resource, wind energy is also available in any combination of grid-integration scenarios, including large or small plants at long or short distances from transmissions and distribution tie-in points. For instance, large amounts of offshore wind energy is available near load centers in the Northeast Region, whereas the wind resource in the Southeast region is relatively far from the largest load centers in the western part of that.

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[3] COEs are stated in constant 2002 dollars, to be consistent with other program documents. To be consistent with the AEO 05 assumptions used in NEMS modeling for this GPRA report, the onshore COE figures should be converted to 2003 dollars using the GDP inflator of 1.018312. Thus, 3 and 3.6 cents/kWh become 3.05 and 3.67 in 2003 dollars.

Currently, wind turbines in Class 6 wind sites (6.4 – 7.0 m/s at 10 m height) compete well against conventional power producers such as gas, oil, and hydro; and the costs are becoming increasingly competitive with coal-fired power production. However, as the industry grows, the areas with excellent Class 6 wind resources located close to load centers are dwindling; and wind growth is hampered as it expands to the more remote, windy regions of the country, such as the Great Plains. In many of these windier (Class 6) locations, grid connection is problematic because they are so far from load centers and because of capacity constraints on existing transmission lines. A recent study illustrates this for North and South Dakota. [8]

Class 4 wind sites (5.6 – 6.0 m/s at 10 m height), covering a much broader area of the nation, are on average five times closer to load centers and represent 20 times more wind resource. [7] Modeling for the FY 2006 GPRA report showed that with successful implementation of the Wind Program activities that provide industry with the means to develop Class 4 sites, the annual generating capacity for land based wind applications could be more than 90 gigawatts (GW) by 2025. However; the only way wind can currently take advantage of Class 4 sites economically is with the support of the Federal production tax credit (PTC). The PTC has been available only intermittently. Through 2005, the PTC has been extended for no more than two years at a time, and there have been periods of uncertainty when the PTC has lapsed, which retards the development of a solid manufacturing base in the United States. The Energy Policy Act of 2005 extended the PTC through 2007, but it is unclear whether it will be extended beyond that time. The uncertain availability of the tax credit forces the wind industry into a boom or bust cycle, reducing efficiency and increasing costs. Reducing wind energy cost to levels that are competitive without dependence upon tax incentives is one of the drivers of the wind program.

The shallow water technology goal of 5 cents/kWh in class 6 winds by 2014 would achieve commercial costs at approximately 10% of U.S. sites between 5 and 50 nautical miles from shore, specifically in the constrained electricity markets along the east coast. Estimates place these resources at approximately an additional 90 GW for regions that have been surveyed. [6] A paper that further examines these estimates is due to be published in FY 07. [10] Gaining access to the shallow offshore market will allow wind technologies to supply low-cost energy to this congested region.

In the midterm, offshore technology development will focus on turbine support structures for installations at depths up to approximately 60 meters and technologies to offset inherent adversities such as increased distance from shore, decreased accessibility, and more severe environmental conditions. This technology development pathway is planned to begin in FY 2007 with a goal of 5 cents/kWh in Class 6 winds by 2016. If this technology is fully developed, then a total of 25% of surveyed resources between 5 and 50 nautical miles from shore would be available for wind deployment. Estimates of these resources add approximately 180 GW to the available development potential in the surveyed regions.

Distributed and small wind applications have also played a key, although smaller, role within the DOE's Wind Program. Focusing primarily on wind turbines rated less than 100 kilowatts (kW) in size, the needs of this market are expected to be met by approximately 13,000 units worldwide in 2005, of which about half will come from U.S.-based suppliers. Continued downward trends in the cost of energy (COE) of these turbines and expanded state-based subsidies are expected to greatly expand this market through 2011. Distributed Wind Technologies are currently not assessed as part of the GPRA benefits analysis.

Baseline Technology Improvements

The GPRA FY 07 baseline trajectory is based on the assumption that wind energy technology will continue to improve over time without EERE-sponsored R&D. The wind energy industry is comprised of several major international manufacturers and many smaller manufacturers, consultants, and government and university researchers. In addition to the United States, the primary expertise currently lies in Europe. Additionally, Japan—and, increasingly, India and China—will also provide expertise for future technology development. The baseline projections for onshore technology include only incremental improvements for higher wind-speed technology. The assumption for low wind-speed technology is that somewhat more R&D will be applied by non-EERE entities to continue to bring cost of energy down. Europe has much less land available in all wind classes than the United States, but especially in the higher classes. Therefore, they may be expected to focus some R&D on lower wind-speed technology. Additionally, since low wind-speed technology increases the international market potential, manufacturers should be interested in continuing improvements. Finally, because past R&D has focused on higher wind-speed technology, there is more potential for technical improvements to low wind-speed technology. However, current market trends demonstrate more interest among European turbine manufactures in considering shallow water offshore technologies operating in higher wind resource areas in place of further investments in low wind-speed technologies. Additionally, the European renewable electricity sector has a large environmental component, which allows wind technologies to be cost-competitive at a higher cost than would be acceptable in the U.S. market. Both of these factors indicate that although technology improvement in Europe will impact the U.S. market, they are unlikely to address several issues specific to the U.S. market.

More than 700 megawatts of offshore wind energy capacity is operating in shallow waters off the shores of several European countries, and some of these countries are pursuing plans for major expansions of offshore wind power. [6] Offshore turbines have been operating in Europe for more than 10 years, primarily using marinized versions of onshore wind turbines installed on monopile tube towers in shallow waters (under 20 meters). The primary drivers have been the limited availability of suitable land-based sites in Northern Europe and favorable wind energy pricing. Early efforts to develop offshore wind energy were not considered relevant to the United States, because of widely available U.S. onshore wind resources. However, the lack of low-cost environmentally friendly energy supply options, especially in the Northeast; positive market incentives; and the scarcity of excellent wind sites in proximity to load centers along the coasts, have made offshore wind technologies an increasingly economically competitive electric power generation technology.

European offshore conditions are fairly dissimilar to those in the United States. The continental shelf typically drops off much faster from our coasts. Without R&D support from EERE, European offshore technology can only be used for shallow water sites in the United States. The GPRA baseline assumes that there would be a 10-year lag in technology development for transitional depth technologies because, without the need for that technology in Europe, its development would be dependent on manufacturers, developers, installers, and operators first obtaining substantial experience with shallow water technology in the United States. The Wind Program based that estimate on expectations for a shallow water market to develop over the next 10 years. Given the difficulties faced by offshore projects in overcoming a variety of barriers to market acceptance during the past several years, and those projected for at least the next few years, the 10-year estimate may be a slight underestimate.

Baseline Market Acceptance

The U.S. large turbine wind energy market has been characterized by boom and bust cycles driven by the instability of the federal production tax credit (PTC). Table 3 shows the incremental installed wind capacity since 2000 and illustrates the sensitivity of annual installed capacity levels to the PTC, which was in place in 2001, 2003, and 2005. It also demonstrates the mainstream acceptance of wind energy technology in the current market. The American Wind Energy Association is predicting several more years of installation rates above 2,000 MW/year.

Table 3. U.S. Installed Wind Energy Capacity 2000–2006

	Annual Installed Capacity (MW)	Cumulative Installed Capacity (MW)
2000	67	2,578
2001	1,697	4,275
2002	446	4,685
2003	1,687	6,372
2004	389	6,740
2005	2,431	9,149
2006	3,000+	12,150+

References: Press Releases, American Wind Energy Association, May 12, 2005, and January 24, 2006

Key Factors in Shaping Market Adoption

Price

Through program-sponsored research, wind technology is projected to improve significantly over the next decade. This improvement is represented in the GPRA07 modeling effort by a declining capital cost trajectory, lower O&M costs, and increased performance. These projections match the program's performance goals, as described above. The Wind Energy Program forms its goals using a probabilistic modeling technique.[4] The projected COEs

[4] The technique first requires a reference set of performance and capital and operating cost characteristics for wind plants, using a composite of leading-edge technology for the reference year. It next defines a set of Technology Improvement Opportunities (TIOs) that may lead to lower levelized cost of energy (COE). A set of quantitative estimates of improvements to COE equation inputs (e.g., turbine cost, net annual energy) are then made for each TIO. A wind plant COE spreadsheet model is then run using Monte Carlo simulation add-on software to obtain a probabilistic evaluating of COEs for possible turbine technology configurations, or "pathways," resulting from successful implementation of all possible combinations of those improvements. This approach captures the uncertainty of both R&D outcomes (potential sizes of various improvements) and the probability of achieving any improvement, (R&D "success"), regardless of the improvement size.

resulting from the cost and performance trajectories therefore represent figures that are close to the mean expected value, not the most optimistic or most conservative possible.

Although there is a standard mathematical formula for characterizing cost reductions in manufactured goods from "learning effects," there is no standard definition of the term, i.e. what effects it includes; nor is there an accepted single set of assumptions and overall methodological approach for calculating or predicting learning curve (sometimes referred to as "experience curve") impacts. While some cost reductions may result from "learning" that is dependent on cumulative volume levels, other cost reductions may be obtained from economies of scale due to levels of *annual* volume of production. Therefore, the program's analysis reflects the potential, on a probabilistic basis, for corresponding cost reductions that would result from both learning curve effects and economies of scale, the latter including discounts for large- volume purchase of materials, parts and components.

The Wind Program's "pathways analysis" assumes that there is at least a chance that the annual level of wind turbine manufacturing output will increase over time, along with cumulative volume. The program represents cost reductions from both annual and cumulative volume in a single number, for which an estimated range is discussed in the remainder of this section. The bottom end of that range is low enough (2%) to represent reductions from any combination of annual or cumulative volume increases. A complete discussion of cost-reduction potential from learning effects and economies of scale can be found in "Wind Energy Technology Pathways Analysis Methodology and Baseline Report" to be published by NREL in FY 2006.

Among the parameters affecting the magnitude of the learning rate for a global technology are: exchange rates, choice of inflators to correct for inflation, use of production costs versus market prices, choice of market boundaries and subsequent inclusion or exclusion of imports or exports from cumulative production levels, definition of production units (e.g., energy production, capacity or number of turbines), and cost or price (e.g., $/turbine, $/kW, $/wind plant, $/kWh produced). In addition, off-the-shelf components of wind energy plants that are already mass-produced will tend to show much less cost decrease over time than lower volume, custom-designed and -built components, because the former have already "come down" the learning curve.[4] The assumed mix of these two different types of components will impact the learning rate. There is also uncertainty concerning whether learning rates remain constant over time or tend to decrease, causing cost reductions to diminish as market diffusion increases. There are arguments to support the possibility of either case occurring.[5]

Although the application of learning curves to wind energy cost contains a large number of uncertainties, there have been many recent attempts to construct such curves from the growing set of empirical market data. Those data shows that most reductions in cost for the various markets studied have been from 2% to 15% for every doubling of cumulative installed capacity. Despite the difficulties in applying learning curve theory to projection of future costs, the relatively narrow range of results across those many studies can be used to develop a reasonable range of estimates for potential cost reductions from learning. Accordingly, the Wind Program chose a range of 2% to 15% cost reduction for overall capital cost-reduction potential from learning by 2012 for onshore wind plants, with the expected value of 5% chosen to skew the distribution of values toward the conservative side. In addition, lower rates of cost reduction were chosen for balance of station costs, O&M costs, and replacement costs, because it was assumed that a larger percentage of leaning from onshore experience transfers in these areas than in the specialized platforms that contribute heavily to the initial capital cost.

The program's projected cost reduction from learning and increased economies of scale can result from a wide range of assumptions for the combination of the learning and market diffusion rates (i.e. doublings of wind turbine production and increase in annual production levels). Even the maximum level of cost reduction estimated by 2012, 15%, can be met by quite conservative combinations of those factors. In addition, the small, incremental cost reductions beyond 2012 for onshore wind plants, and in the later years for offshore plants (i.e. in years past, the point where the have met the program goals), can be easily justified by conservative assumptions regarding learning effects and economies of scale.

Nonprice Factors

In addition to competing on an economic basis with other electricity generation technologies, wind capacity may be partly valued for its environmental attributes. Renewable energy credit markets, green power programs, and renewable portfolio standards are all examples of ways such value is beginning to be recognized in the market.

Electricity produced from offshore locations is expected to be of higher value than many onshore locations in many cases, because proximity of several major load centers to the coasts could reduce transmission constraints and costs facing large-scale onshore power generation.

Methodology and Calculations

Inputs To Base Case

The GPRA07 Baseline is a modification of the *AEO2005* Reference Case for onshore technologies. Offshore wind technology currently is not included in the AEO reference case, and so the program decided to use the technology characteristics (capital and operating costs, and energy production) equivalent to the preliminary program case values developed in June 2005[5], but lagged by 10 years. In other words, progress in offshore wind technology in the absence of program R&D was assumed to be slower but eventually achieve the program goals. The onshore wind technology representation was modified to reflect the fact that the Wind Program has a different view of the characteristics of current technology than that in the AEO, as well as the trajectory over time. The program estimates of wind capacity factors are 12% to 13% higher than EIA's (e.g. 0.47 for Class 6 versus 0.41), and their 2005 capital costs are just slightly lower. Justification for Wind Program estimates for both current and future technology characteristics for turbines in Class 4 sites are contained in a report expected to be published by NREL in FY 2006, tentatively titled, "Low Wind Speed Turbine Pathways Analysis Report," which updates earlier, preliminary documentation.[1]

[5] Note, as a result of the emerging nature of the offshore program, its goals were later modified; but the GPRA Baseline was not revised due to timing constraints. The revised program cost and performance goals are less aggressive than the original ones. This discrepancy will be addressed in the FY 2008 GPRA analysis.

In addition, the *AEO2005* assumed that any cost improvement over time results only from a learning (or experience) effect that lowers cost proportional to the increase in cumulative installed volume, but not from R&D advances. Because the AEO projects a small amount of penetration (additional cumulative volume), the capital cost decrease in the AEO projections is negligible. Under that assumption, the onshore costs eventually become greater than the Wind Program's projected offshore costs because the rate of offshore improvements is higher than for the onshore. Although such a relative cost relationship in the long-term is not yet intuitively understood by researchers, the assumption used for this GPRA analysis is that offshore costs should remain higher than those for onshore. Studies initiated by the program are currently addressing this area in detail, and assumptions will be revisited for the FY 2008 GPRA analysis.[6]

A new baseline onshore cost trajectory was constructed to address those issues. The initial point in 2005 reflects an average of the program and AEO points. The levelized cost of energy (COE) trajectory then declines, so that by 2050 the onshore cost remains below the offshore costs by a ratio equivalent to that of the Program Case. Capital costs, O&M costs, and capacity factors were modified proportionally to achieve the target COE. The resulting COEs for Class 6 are illustrated in Figure 1. Table 4 provides the baseline values for the all the wind classes and technology types required for NEMS and MARKAL modeling.

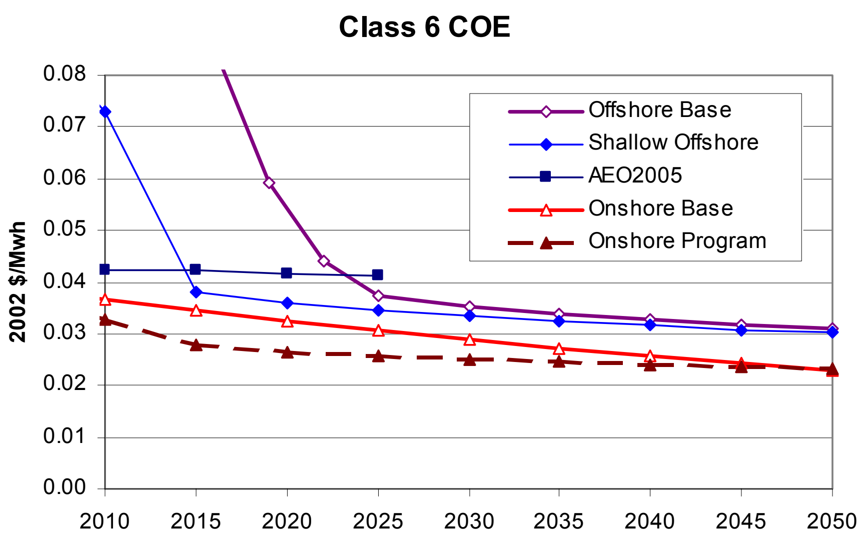

Figure 1. Class 6 Baseline and Program COE Trajectories

[6] While cost characteristics for offshore wind turbine components will differ somewhat from their offshore counterparts, due to potential size differences and to unique requirements for reliability, durability, and serviceability in the marine environment, many aspects of the two systems will continue to be similar and are expected to track each other in terms of future cost reductions. However, the platform and anchoring components for offshore systems are unique to that application, and will be subject to steeper cost reductions from learning, relative to the rest of the plant equipment, as designs enter the market and subsequent cumulative volume increases.

Table 4. GPRA07 Baseline Technology Characteristics (Model Inputs)

2003 Dollars		2005	2010	2015	2020	2025	2030	2040	2050
Capital Costs*									
Onshore	Class 5&6	1069	1026	985	946	907	872	802	739
	Class 4	1123	1087	1051	1016	984	951	890	833
Offshore	Shallow	2132	2132	1691	1334	934	905	818	771
	Transitional	2519	2519	2203	1905	1143	953	905	858
O&M Costs									
Onshore	All Classes	25.5	23.6	21.9	20.3	18.7	17.4	15.0	12.8
Offshore	Shallow	45.2	45.2	45.2	41.9	36.5	33.8	32.1	30.3
	Transitional	67.9	67.9	67.9	73.9	44.5	35.6	32.1	30.3
Capacity Factors									
Onshore	Class 6	0.440	0.448	0.457	0.466	0.476	0.485	0.504	0.525
	Class 5	0.402	0.412	0.423	0.434	0.446	0.458	0.482	0.508
	Class 4	0.348	0.356	0.364	0.372	0.381	0.389	0.407	0.425
Offshore	Class 6	0.391	0.405	0.428	0.467	0.500	0.500	0.500	0.500
Shallow	Class 5	0.358	0.380	0.389	0.403	0.430	0.430	0.430	0.430
	Class 4	0.264	0.317	0.332	0.356	0.400	0.400	0.400	0.400
Offshore	Class 7	0.468	0.484	0.485	0.486	0.549	0.556	0.600	0.600
Transitional	Class 6	0.382	0.394	0.396	0.399	0.421	0.463	0.500	0.500
	Class 5	0.340	0.358	0.357	0.355	0.394	0.398	0.430	0.430

*Includes 1.05 contingency factor for onshore systems and 1.07 for offshore systems. [1] [2] [6]
Onshore cost were converted from 2002 dollars using GDP inflator of 1.018312. Offshore costs were converted from 2005 dollars using GDP deflator of 0.960338

Technical Characteristics

Description of Key Elements of the National Energy Modeling System (NEMS) Approach to Modeling Wind

The electricity-sector module performs an economic analysis of alternative technologies in each of 13 regions. Within each region, new capacity is selected based on its relative capital and operating costs, its operating performance (i.e. capacity factor, which reflects energy conversion efficiency, and both resource and plant availability), the regional load requirements, and existing capacity resources. NEMS-GPRA07 characterizes wind by three wind classes, each with its own capital costs and resource cost multipliers. Different wind classes are used for different technology applications—classes 4, 5 and 6 for land-based technologies, and 5, 6, and 7 for offshore technologies. The regional resource cost multipliers increase capital costs as increasing portions of a wind class are developed in a given region to reflect 1) declining natural resource quality, 2) required transmission network upgrades, 3) competition with other market uses, including aesthetic or environmental concerns. As the cost in that region increases, it may be more cost-effective to consider installing wind turbines in areas of lesser wind resource, but with lower ancillary costs and less costly access to the grid, as reflected in the model by the capital cost multipliers.

Other key assumptions that can affect projections include a limit on the share of generation in each region that can be met with intermittent technologies. The *AEO2005* assumption that wind may provide only a maximum of 20% of a region's generation was maintained, even though the program disagrees with that characterization. NEMS-GPRA07, as in the *AEO2005*, also assumes that the capacity value of wind diminishes with increasing levels of installed wind capacity in a region. Finally, another constraint on the growth of wind resource development is how quickly the wind industry can expand before costs increase due to manufacturing bottlenecks. The *AEO2005* assumption that a cost premium is imposed when new orders exceed 50% of installed capacity was maintained for the benefits analysis.

As part of the development efforts for the offshore wind energy activates, the program is currently working to upgrade the NEMS software to more accurately model offshore wind technologies. The first stage of these efforts is represented in the FY2007 version of the software, and additional improvements are expected to be made in the FY2008 GPRA analysis.

Further detail on the representation of wind power in NEMS may be found in Chapter 2.

Wind Program Case Assumptions

The assumptions about capital costs, capacity factors, and O&M costs—which are used as inputs into the NEMS-GPRA07 model for the Program Case—are provided in Table 5. These projections match the program's performance goals, as described above. Projections for onshore wind plants are consistent with the analysis described in [6]. The capital costs include a contingency factor of 5% for onshore wind and 7% for offshore wind, similar to other electric-generating technologies. The current technology characteristics in Table 5 represent leading-edge technology available in the market. The projected characteristics for low wind speed onshore wind plants result from the probabilistic path analysis approach described on Page 7 of this appendix. Estimates for future technology characteristics are consistent with mean values from that analysis or values that are between the mean and the best. However, they are always significantly below the best (at least 30% in the worst case). As the program develops further data on offshore technology, a similar path analysis is expected to be conducted in FY06 or FY07.

The Program Case wind capital costs were updated in December 2005 to reflect the impact of earmarks on existing and planned projects related to meeting the program goal. Long-term costs were also increased by 5% over FY 2006 values to reflect higher estimates of developer fees, based on analysis of confidential market data. It was too late to change the Baseline as well, so the long-term capital costs are slightly lower in the Baseline than the program case. However, because technologies compete on the basis of cost of energy in the market models, and the higher capacity factors in the program case dominate the difference in COE between the two cases, the impact on the benefits estimate for the program R&D is small.

Program analysis and documentation for offshore technology characteristics is an evolving process as offshore R&D activities ramp up. To develop the offshore cost and performance inputs shown in Table 5, program analysts scaled capital costs over six periods from 2006 to 2025, using learning rates (i.e., capital cost reductions for each period corresponding to a doubling of installed capacity) typical of wind industry experience, and that are assumed to include improvements in technology, production volume, learning curve effects, and improvements in operational proficiency. The doubling periods and learning rates used in the cost calculations were derived from IEA and European reports [3]. The learning rate was augmented by a one-time additional 10% reduction in capital cost in year 2015 due to technology R&D. The resulting levels of improvements to wind plant COE served as an upper boundary for Program Case estimates. That is, the Program Case projections in Table 5 are all within the bounds established by the cost-scaling exercise. The next analytic step for the program will be to apply its Wind Energy Technology Pathways Analysis methodology to transitional water depth offshore technology to obtain probabilistic data for technology characteristic projections.

Table 5. Program Projections for Capital Costs, Capacity Factors, and O&M Costs for Onshore and Offshore Wind Plants

2002 Dollars		2005	2010	2015	2020	2025	2030	2040	2050
Capital Costs*									
Onshore	Class 5&6	1050	982	893	872	866	840	819	798
	Class 4	1103	1034	971	945	919	893	872	851
Offshore	Shallow	2220	1816	1009	969	941	916	866	842
	Transitional	2623	2321	1211	1059	1015	990	941	916
O&M Costs									
Onshore	All Classes	25.0	20.0	16.0	15.0	14.2	13.8	13.2	12.8
Offshore	Shallow	47.1	47.1	38.7	35.8	34.9	33.9	32.1	30.2
	Transitional	70.7	66.0	47.1	37.7	34.9	33.9	32.1	30.2
Capacity Factors									
Onshore	Class 6	0.440	0.475	0.500	0.511	0.517	0.519	0.523	0.525
	Class 5	0.402	0.445	0.470	0.482	0.490	0.492	0.497	0.500
	Class 4	0.348	0.400	0.460	0.469	0.472	0.474	0.479	0.480
Offshore	Class 6	0.405	0.435	0.500	0.505	0.510	0.511	0.513	0.515
Shallow	Class 5	0.380	0.400	0.430	0.435	0.440	0.441	0.443	0.445
	Class 4	0.317	0.355	0.400	0.405	0.410	0.411	0.413	0.415
Offshore	Class 7	0.484	0.486	0.516	0.544	0.556	0.574	0.574	0.574
Transitional	Class 6	0.381	0.387	0.458	0.478	0.494	0.511	0.513	0.515
	Class 5	0.304	0.356	0.394	0.412	0.426	0.441	0.443	0.445

*Includes 1.05 contingency factor for onshore systems and 1.07 for offshore systems. [2] [3]

It was necessary to make one major modification to the offshore wind resource inputs for the NEMS model. The current NEMS-GPRA07 projections include very high offshore wind penetration in the Southeastern Electric Reliability Council (SERC) region. The NEMS model splits the United States electricity market into 13 North American Electric Reliability Council (NERC) regions. The SERC region includes the Virginia-Carolinas sub-region (VACAR), the TVA sub-region (Tennessee and adjacent portions of Alabama, Georgia, Kentucky, and Mississippi), and the Southern sub-region (Georgia, Alabama, part of Mississippi, and the panhandle of Florida), and is the largest of the NERC regions in terms of electricity sales (almost 23% of total U.S. sales[7]). All electricity technologies represented in NEMS compete within these 13 regions for market share.

[7] Energy Information Administration, Annual Energy Outlook 2005 Supplemental Tables (Tables 60-72).

Updated resource curves for the SERC region are being used for the FY 2007 GPRA NEMS analysis. The resource curves provided by NREL for the SERC region account for offshore wind classes 5 and above that are located off the shores of Virginia, North Carolina, and South Carolina. Because SERC includes many inland areas far from these offshore wind resources, one can argue that there might be significant portions of the region where the transmission of electricity produced by these wind resources would be cost-prohibitive. However, because the NEMS model treats the region as one market, transmission costs are assumed to be equal throughout the region. This explains why the model tends to produce offshore wind penetration levels in the SERC region much higher than expected.

In order to address this issue within the current GPRA cycle, a short-term solution was developed; namely, to adjust the SERC offshore wind data to reflect the portion of the region that is in close enough proximity to the resources for cost-effective transmission. The latest electricity sales data by state from EIA[8] indicates that the three states nearest to the offshore wind resources (Virginia, North Carolina, and South Carolina) account for roughly 38% of total sales in the SERC region. Because a small portion of southwestern Virginia is located in the East Central Area Reliability Council (ECAR) region, it was assumed that only 95% of Virginia's sales are included in SERC. This 38% market share then is used to adjust the SERC offshore wind resource data.

MARKAL

The program goals are represented in the MARKAL-GPRA07 model by changing the capital and O&M costs and capacity factors for wind turbines to match the program goals as represented in Table 5.

The discount rate for wind generators is set at 8% (instead of the utility average of 10%) to reflect the accelerated depreciation schedule available for renewable generation technologies. Wind generators are modeled as centralized plants to compete with fossil fuel-based plants. The potential contribution of wind systems to meeting peak power demand is limited to 40%, reflecting the intermittent nature of the technology. As with PV systems, this disadvantages wind generators, as additional reserve capacity is needed to meet peak power requirements. However, this disadvantage is offset by the reduction in capital cost and performance improvements projected for wind technologies by the program. As a result, wind generators near the central grid can be competitive with fossil fuel-based power plants.

[8] Energy Information Administration, Electric Power Annual 2003 – Spreadsheets (sales_state.xls).

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