

APPENDIX E – WIND TECHNOLOGIES PROGRAM INPUTS FOR FY 2008 BENEFITS ESTIMATES

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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 used for this purpose: MARKet ALlocation (MARKAL) and a modified version of the National Energy Modeling System (NEMS). This document describes the inputs and assumptions that are used by the models to calculate those benefits.

Program Summary

The Wind Program is one component of the Wind and Hydropower Technologies Program under the Office of Energy Efficiency and Renewable Energy (EERE) within the U.S. Department of Energy. The Wind Program focuses on two key areas for its mission—increasing the Technical Viability of wind systems through support of research and development and increasing wind energy deployment in the emerging marketplace through Technology Application activities. **Figure E-1** depicts the five projects within the two key areas that comprise the Wind Program.

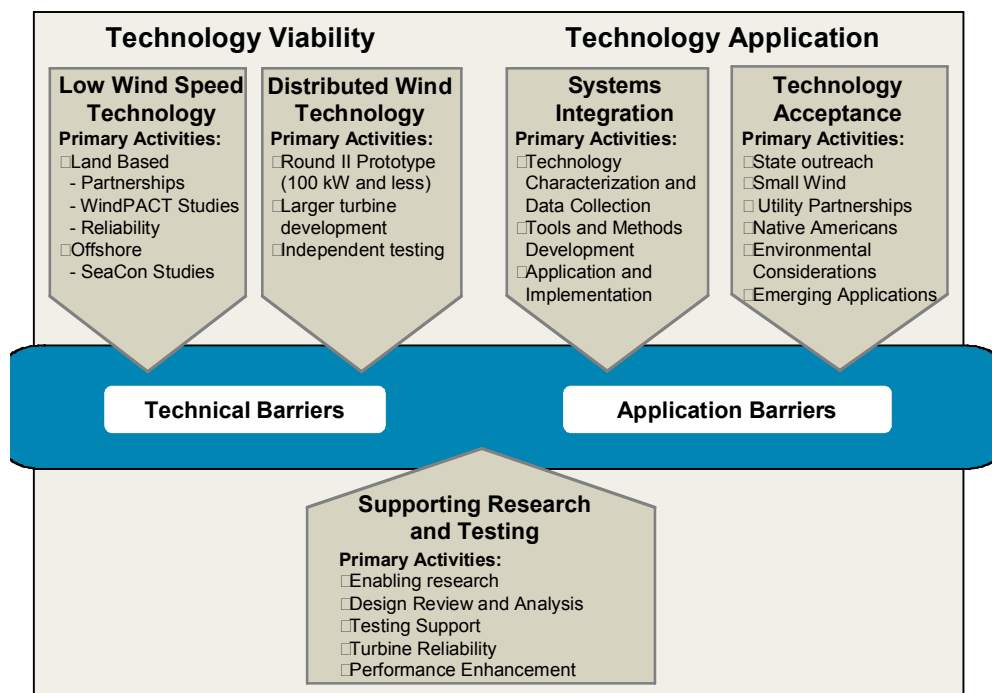


Figure E-1. Structure of the Wind Program

Under Technical Viability, the program sponsors R&D projects in Low Wind Speed Technology (LWST), Offshore Wind Technology, and Distributed Wind Technology. All three projects are integrated with Supporting Research and Testing activities such as enabling technologies and testing support. The Wind Program’s research portfolio includes both near-term and long-term focused research to provide a balance between the need to work with industry to solve pressing short-term technical issues and the need to maintain U.S. industry momentum as a technological

innovator. Balancing this portfolio and ensuring a variety of approaches to achieve the goals are the challenges of the program-planning function.

To allow for increased use of wind systems, the Technology Application key activity sponsors research on Systems Integration and Technology Acceptance. These programs address many of the critical market challenges to the use of wind energy, including transmission constraints, interconnection, environmental impacts, and public acceptance. **Figure E-1** also lists the key activities being undertaken by each of the program areas.

Within the context of this document, only areas addressed in Low Wind Speed Technology, both offshore and land-based, are covered within the context of the GPRA analysis. For this reason, the following text focuses primarily in these areas. More information on other program areas can be found in the Multiyear Program Plan (MYPP). (U.S. Department of Energy 2007)

Significant Changes from Previous Analysis

Offshore cost of energy (COE) goals have been revised, per below, from the FY 2007 analysis, and the program-case cost and performance tables have been revised to correspond to the new goals and funding assumptions.

- By 2014, reduce the COE from large wind systems in Class 6 winds to 7 cents/kWh (previously 5 cents/kWh) for shallow water (depths 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 7 cents/kWh (previously 5 cents/kWh) for transitional (depths to 60 meters) offshore systems (from a baseline of 12 cents in FY 2006).

The corresponding program and funding assumption is that more initial research must be undertaken to determine the government role in the future development of an offshore wind industry. This approach will expend limited effort until a programmatic go/no go decision is made in 2009. In addition, an evaluation of market risks for offshore technologies may also be a consideration. For this GPRA analysis, the program is assuming that, following a positive decision regarding the viability of this market area, a funding level per year will be split between the two technologies from 2011 onward with a shift from shallow to transitional technologies over time. (The amount of the request is confidential until after the budget submission to Congress.)

While MARKAL and NEMS currently do not have the capacity to model market penetration for distributed (small) wind turbines, that technology is nonetheless an important element of the DOE Wind Program. The current program goal for distributed wind is stated below.

- By 2007, reduce the COE from distributed wind systems in Class 3 winds to 10–15 cents/kWh in constant 2002 dollars.

The Baseline (“without DOE RD3” case)

The GPRA FY 2008 baseline case cost and performance trajectory assumes that wind energy technology will continue to improve over time without EERE-sponsored R&D. The wind energy industry comprises several major international manufacturers and many smaller manufacturers, consultants, and government and university researchers. Apart from the United States, the primary expertise currently lies in Europe. In addition, Japan, and, increasingly, India and China, will also provide expertise for future technology development. The baseline case projections for land-based technology include the assumption that somewhat more R&D will be applied by non-EERE entities to continue to bring the cost of energy down. Europe has much less land available in all wind classes than the United States, but this is especially true in the higher classes. Therefore, European countries may be expected to focus some R&D on lower wind speed technology, although a portion of that R&D will be transferable to turbines designed for higher wind speed regimes. In addition, because 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 in low wind speed technology.

Despite the rationale for further development of low wind speed turbine technology, current trends among European turbine manufactures are toward improving shallow water offshore technologies that are suitable for higher wind resource areas, instead of further investments for R&D in low wind speed, land-based technologies. In addition, the European renewable electricity sector has long held incentive programs for environmentally friendly energy technologies, which allow 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. Some of these countries are pursuing plans for major expansions of offshore wind power (U.S. Department of Energy 2007). Offshore turbines have been operating in Europe for more than 10 years, primarily using marinized versions of land-based 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. The motivation to develop offshore wind energy technology was not considered relevant to the United States because of widely available U.S. land-based wind resources; however, the high cost of accessing these remote sites to provide power to coastal high-load centers has increased the desire to obtain a better understanding of the U.S. offshore potential. However, the lack of low-cost environmentally friendly energy supply options (especially in the Northeast); stable, positive market incentives; and the scarcity of excellent wind sites in proximity to load centers along the coasts have all increased the prospect of offshore wind technologies as an economically competitive electric power generation technology.

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 region.

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 hydropower; and the costs are becoming increasingly competitive with coal-fired power production. However, as the industry grows, the areas with 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 locations, grid connection is problematic because they are so far from load centers and because of capacity constraints on existing transmission lines. A 2005 study illustrates this for North Dakota and South Dakota (ABB 2005).

Class 4 wind sites (5.6–6.0 m/s at 10 m height) cover a much broader area of the nation, are on average five times closer to load centers, and represent 20 times more wind resource (Goldman 2002). 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), which has been available only intermittently. 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 impedes the development of a solid manufacturing base in the United States. The Energy Policy Act of 2005 extended the PTC through calendar year 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 on tax incentives is one of the drivers of the Wind Program.

Shallow-water sites between 5 and 50 nautical miles from shore, specifically in the constrained electricity markets along the East Coast, offer additional resources for wind power application. Estimates place these resources at approximately 900 GW for regions that have been surveyed, assuming conservative restrictions, although only a fraction of that would likely be developed (U.S. Department of Energy 2007). A white paper including a detailed look at the state of the offshore industry, its development potential, and a further examination of the above estimates is due to be published by NREL in FY 2007 (Musial 2006). Gaining access to the shallow offshore market will allow wind technologies to supply competitive energy to the congested regions along the eastern seaboard.

In the mid- to longer term, offshore technology development will be focused on turbine support structures for installations at depths to approximately 60 meters; and technologies to offset inherent adversities such as increased distance from shore, decreased accessibility, and more

severe environmental conditions. Pending a decision in 2009 by DOE to proceed, this technology development pathway would begin with a goal of 7 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 (Musial 2004).

Distributed and small wind applications have also played a key, although smaller, role within the Wind Program, focusing primarily on wind turbines rated less than 100 kW in size. Continued downward trends in the 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 Market Acceptance

In the United States, the large turbine wind energy market has boomed over the past few years, which is due, in large part, to the PTC and high conventional energy prices. Over a longer time frame, however, this market has been characterized by boom and bust cycles driven by the instability of the Federal PTC. **Table E-1** 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 general mainstream acceptance of wind energy technology in the current market. When the technology is cost-effective, resulting from incentives such as the PTC, it is generally installed in relatively large and increasing numbers. With the extension in the PTC, the American Wind Energy Association (AWEA) is predicting several more years of installation rates greater than 2,000 MW/year. This, however, should not discredit the efforts that must continue to be applied to wind technology application as turbines are installed more broadly and closer to population load centers.

Recent increases in the cost of wind energy are not currently reflected in the cost figures used in either the baseline or program case analysis. Although cost increases are well documented, they are generally attributed to short-term market trends including the tightness of the turbine market due to the PTC, high foreign exchange rates between the United States and Europe, and currently high commodity prices. All of these items are not expected to impact the cost of wind technology compared to other energy technologies over the long term.

Table E-1. 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	2,750(est.)	12,000(est.)
2007	3,000-3,500(est.)	15,000+ (est.)

References: News Releases, American Wind Energy Association, May 12, 2005; January 24, 2006; October 24, 2006

Representation of Program-Relevant Technologies in the AEO Reference Case

The Annual Energy Outlook (AEO), the Energy Information Administration's (EIA) 2006 Reference Case, assumes that any cost improvement over time results only from a learning (sometimes called "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 (and therefore little additional cumulative volume), the capital cost decrease in the AEO projections is negligible. The Reference Case also assumes no future improvements in energy production from R&D (input to NEMS in the form of a capacity factor).

The capacity factors for Wind Classes 4–6 in the AEO are determined using data provided to the Energy Information Administration (EIA) by wind plant operators. Although these reported values represent the electricity produced by that wind plant over the previous period, there are several reasons why the Wind Program thinks it's difficult, and potentially misleading, to match them with a specific wind resource level. First, these data represent a wide variety of wind resources geographically distributed over the country, which means characteristics of the wind, such as the shape of the wind speed distribution (the amount of time during the year that the wind is blowing at each discrete wind speed) and the level of wind shear (how wind speed changes with height), can vary widely. Second, wind resource data for a given wind plant is generally not publicly available because it is considered proprietary data. Therefore, correlation between the reported capacity factor data and wind power class associated with that turbine performance is quite difficult. Third, in many regions of the country, transmission systems are constrained such that, on occasion, wind plants might be required to curtail output at certain times. For plants that experience such a curtailment, this reduced power output affects the total production data reported to EIA, but is not identified separately. Although this might not affect many wind plants, it is unknown how many may be reporting less than their full potential output.

Finally, the wind characteristics of any given site vary naturally from year to year. Reported capacity factor data includes such variations. For example, climatic oscillations such as the Madden-Julian Oscillation or the El Niño Southern Oscillation cause interannual variability of wind resources. For any or all of these reasons, the reported data may not adequately capture the actual performance capability of the present wind turbine technology averaged over a longer time frame. Preliminary, ongoing measurements appear to be confirming that commercial energy production levels are indeed closer to the predicted value than characterized in *AEO2006*. However, this work is not yet publicly available (Hand 2006).

Baseline Adjustments to the *AEO2006* Reference Case

The GPRA 08 baseline case for land-based wind power technology is a modification of the *AEO2006* Reference Case. That modification reflects that the Wind Program has a different view of the cost and performance characteristics of current technology, as well as the projected trajectory for future characteristics. While EIA indicates that the AEO projections reflect impacts of R&D in line with historical levels, the projections show almost no improvement in cost or performance in future wind power technology from R&D. The Wind Program's projections for future wind plant capacity factors and capital costs reflect larger improvements, compared to those in the AEO, i.e., capacity factors are higher and costs are lower. The Wind Program,

therefore, believes that its trajectory would form a more appropriate Reference Case for the AEO, because historic rates of technology improvement have included impacts of DOE R&D. Detailed rationale and analysis for the Program Case is presented in the “Immediate Outcomes” section later in this appendix.

To calculate the benefits from the DOE Wind Program, the GPRA 08 baseline case, unlike the AEO Reference Case, must reflect the absence of DOE-sponsored R&D. For the GPRA 08 Baseline Case, the *AEO2006* Reference Case capital cost is assumed for 2005 as the starting point. The 2005 capacity factor is the midpoint between the AEO value and the program value, as in past GPRA analyses. To remove the impacts of Wind Program activities from the Program Case, a cost/performance trajectory was created, whereby industry is assumed to achieve 60% of the COE reduction projected by the program at each five-year interval for all wind classes. This COE reduction level is supported by a preliminary analysis conducted by NREL staff that projected physical characteristics and performance levels of wind turbines likely to result if Federal research investment is discontinued. That analysis builds off of the extensive analysis underlying the Program Case. While the program focus is on low wind speed technology, much of the research is transferable to higher wind speed designs. Also, over the long term, industry is assumed to invest in higher wind speed R&D, if needed. Therefore, as a first-order approximation, the 60% value is assumed for turbines designed for all wind power classes.

For both the Program and the Baseline Case, capacity factors are calculated for each five-year period using technical characteristics for a generic wind turbine comprising a composite of state-of-the-art designs operating in generic wind regimes. A spreadsheet-based model developed by NREL was used for these calculations (Laxson 2006). The model performs power and energy calculations for individual wind speed increments, or “bins” of 0.25 m/sec. Turbine parameters such as the rotor diameter, hub height, power rating, and maximum power coefficients are used by the model. The generic wind regimes are represented by Rayleigh probability distributions of wind speed with a mean value corresponding to each of the wind power Classes 4–6 (and 7, for transitional offshore resources in the program case). Vertical shear is assumed to follow the 1/7 power law. Losses associated with drivetrain efficiency are applied as a function of wind speed, and other losses associated with blade soiling, array effects, and availability are also applied. Availability is the percent of time the turbine is able to generate power when the wind is sufficient. The capacity factors represent the idealized performance of the generic wind turbines in each generic wind regime. **Table E-2** shows the turbine characteristics used for the GPRA 08 baseline capacity factor calculations.

Table E-2. Wind Turbine Characteristics For GPRA Baseline Case (No Federal R&D)

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Turbine Rating (kW)	1500	2500	3000	3000	3000	3000	3000	3000	3000	3000
Diameter (m) (Class 4)	77	93	103	103	103	103	103	103	103	103
Diameter (m) (Classes 5–6)	77	90	96	96	96	97	97	97	97	97
Hub Height (m) (Class 4)	80	100	100	100	100	100	100	100	100	100
Hub Height (m) (Classes 5–6)	80	90	100	100	100	100	100	100	100	100
Net Losses	0.12	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Availability	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98

The Federal investment during the Low Wind Speed Turbine (LWST) program (2002 to present) is just beginning to be brought to commercial reality, so this investment will continue to reduce cost and improve performance in the next decade. Although it is assumed that the turbine size will continue to grow without Federal R&D, the aggressive rotor growth achieved through advanced controls will be muted. Development of self-erecting towers without Federal support is unlikely to see strong commercialization in the near term, therefore restricting tower heights. Other technology development such as conversion to medium voltage, use of Silicon Carbide, inclusion of advanced gearing, and switching to super-conducting generators may occur; but there will probably be a delay in the adoption of these technologies. Improvements in drivetrain efficiency, while not as large as those from longer rotors and taller towers, are also assumed to be delayed or not implemented without federal R&D support. Learning effects are assumed to reduce the installed capital cost by 0.5% to 1% over each interval with a cumulative reduction of about 6% by 2050. **Table E-3** shows the baseline case model inputs, including capital and operation and maintenance (O&M) costs, and capacity factors. The table contains all baseline case inputs required for NEMS and MARKAL modeling.

Table E-3. Baseline Case Model Inputs

2004 \$/kW*		2005	2010	2015	2020	2025	2030	2040	2050
Capital Costs									
Land-Based	Classes 5&6	1167	1013	982	961	956	950	945	935
	Class 4	1167	1113	1061	1040	1024	1019	1008	998
Offshore	Shallow	2118							
	Transitional	2803							
O&M Costs									
Land-Based	All Classes	27.6	25.2	24.2	24.2	23.1	22.1	22.1	22.1
Offshore	Shallow	81							
	Transitional	81							
Capacity Factors									
Land-Based	Class 6	0.432	0.468	0.475	0.477	0.477	0.485	0.490	0.490
	Class 5	0.399	0.433	0.440	0.442	0.442	0.450	0.455	0.455
	Class 4	0.350	0.401	0.423	0.426	0.426	0.426	0.426	0.426
Offshore	Class 6	0.384							
Shallow	Class 5	0.337							
	Class 4	0.298							
Offshore	Class 7	0.423							
Transitional	Class 6	0.384							
	Class 5	0.337							
*Does <i>not</i> include a 1.05 contingency factor for land-based systems and 1.07 for offshore systems (Cohen 2004, Musial, 2004; U.S. Department of Energy 2007). Land-based costs were converted from 2002 dollars using a GDP inflator of 1.05. Offshore costs were converted from 2005 dollars using a GDP deflator of 0.97.									

Using these assumptions, the land-based COE in 2050 is approximately equal to the shallow offshore case with continued Federal funding, as shown in **Figure E-2**, using Class 6 wind resources to demonstrate (the same relationship holds for all wind classes). This also indicates that the industry (U.S. and/or international) will continue to lower the cost of land-based wind turbine systems in the absence of DOE assistance.

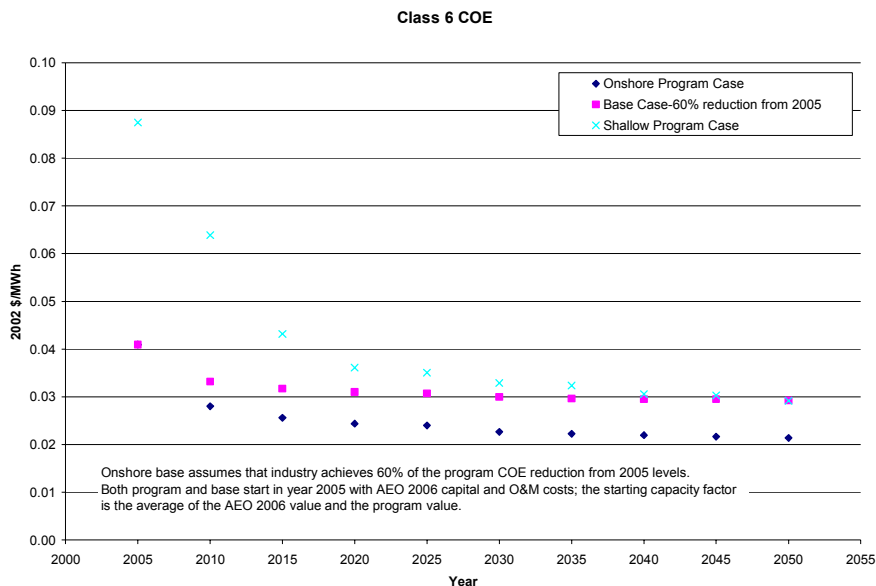


Figure E-2. Comparison of Base and Program Case COEs

Although the Baseline Case is tied to the current Program Case, the program does not expect to adjust these values if the program modifies the current goals based on funding changes. Such a scenario would, thus, create an indirect tie between the Baseline Case and the new Program Case. That is, the baseline inputs have been established so as to be realistic on their own, even though they were developed using the program case as a relative benchmark.

Offshore turbines were assumed to begin at a rating of 5 MW in 2005, scaling to 10 MW in future years. Availability of offshore turbines was assumed to begin at 85% in 2005, increasing to 95% as the technology matures. The wind resource characteristics were also altered from a power law exponent of 1/7 (0.14) to 0.12, and a K factor of 2.0 (representing a Rayleigh Distribution) to 2.2, based on preliminary resource data obtained by NREL.

Because the FY 2006 AEO does not model offshore wind technologies, and there are no domestic offshore installations, the program estimates for 2005 costs were based on installations in Europe. In GPRA 07, the offshore baseline simply assumed that the technology would follow the program cases, offset by 10 years. Tying the baseline case to the program case with an offset suggests that when the program case changes, the industry responds, which is not accurate. For GPRA 08, the direct connection between the program and baseline case has been removed, so that the program case can now be changed without affecting the baseline case.

The program uses the NEMS “revolutionary” technology learning rate to represent shallow offshore wind technology in the baseline case, starting at the 2005 program level. In this case, “Revolutionary” refers to technologies new to the market that are unlike existing or historical technologies, and therefore are subject to steeper rates of cost decline from learning by designers, manufacturers, installers, or operation and maintenance personnel, because there is more opportunity to find ways to reduce costs compared to better understood technologies. This reflects the program’s belief that domestic shallow offshore installations are likely to occur very

slowly, if at all, without investment from the Federal Government. In view of the significant European market for shallow offshore technologies, some of the related European R&D activities could reduce the cost for the technology in the United States. However, the costs and difficulties associated with permitting and environmental assessment, and the differences between European and U.S. environmental conditions and policies, would likely slow the implementation of shallow-water offshore wind technologies dramatically in the absence of Federal R&D support. European offshore installations are heavily subsidized, and it is highly unlikely that a U.S. offshore industry would develop without some sort of subsidy. The NEMS results show that the cost of shallow-water offshore wind technology never becomes generally competitive without Federal support.

Currently, three offshore projects are proposed in Massachusetts and New York that take advantage of prime locations and locally high base energy costs. Additional projects are proposed for the Gulf Coast, but wind resource assessment must be completed before NEMS can be used to model these facilities. The three proposed projects in the Northeast include Cape Wind at 468 MW, Hull Municipal Utility at 14.4 MW, and Long Island Offshore Wind Initiative at 140 MW. To spur some offshore wind development in NEMS, 250 MW was specified to come online in 2009 in the Northeast region, and 75 MW was specified to come online in the New York region. However, this did not stimulate significant cost reductions in offshore wind costs and so did not affect the simulation, which does not add any additional offshore wind energy generation beyond the 325 MW by 2030.

The shallow technology baseline case inputs were developed by assuming that capital costs and O&M costs would decline according to the NEMS revolutionary technology learning rate, which results in a 20% cost reduction by 2025. The capacity factors for the technology in 2025 were developed using a wind turbine performance model developed at NREL, assuming that the technology cost and performance are tied. Linear interpolation was then used to determine the capacity factors at intervals between 2005 and 2025. The values at 2030 were linearly extrapolated.

The program also uses the NEMS revolutionary technology learning rate to represent transitional offshore wind technology in the baseline case, starting at the program level of 12 cents/kWh in 2005. Although European governments and companies are actively pursuing shallow offshore technology, they are only timidly pursuing transitional depths on any scale that might transfer technology to the United States. Based on its different ocean seafloor topography, the United States has much more transitional water depth resource than is found in European coastal water. Considering the higher costs and risks, transitional offshore technology is very unlikely to occur without Federal investment in R&D activities. The other baseline case inputs were developed similarly to those for the shallow offshore technology inputs.

Program Outputs

The program combines industry input, technical assessment, and peer review as central pillars of its efforts to ensure that resources are applied to important activities and industry-applicable results. The general approaches are used; and a strategic program review process combines with a detailed portfolio decision-making process. **Figure E-3** provides an overview of the portfolio

assessment process, while multiyear efforts are directed through coordinated strategic planning meetings with industry and departmental senior staff. As shown, the program uses an ongoing technical assessment process to monitor the status of wind technology and progress in achieving program cost goals, evaluate that status within the context of marketplace needs, and identify technological pathways that will lead to successful marketplace competition. The program also uses a formal peer review process to benefit from the guidance of industry and the research community and to provide an outside view of the program. As shown in **Figure E-3**, both the technical assessment and peer review processes provide inputs that the program management team considers in making decisions about strategic program directions and funding priorities.

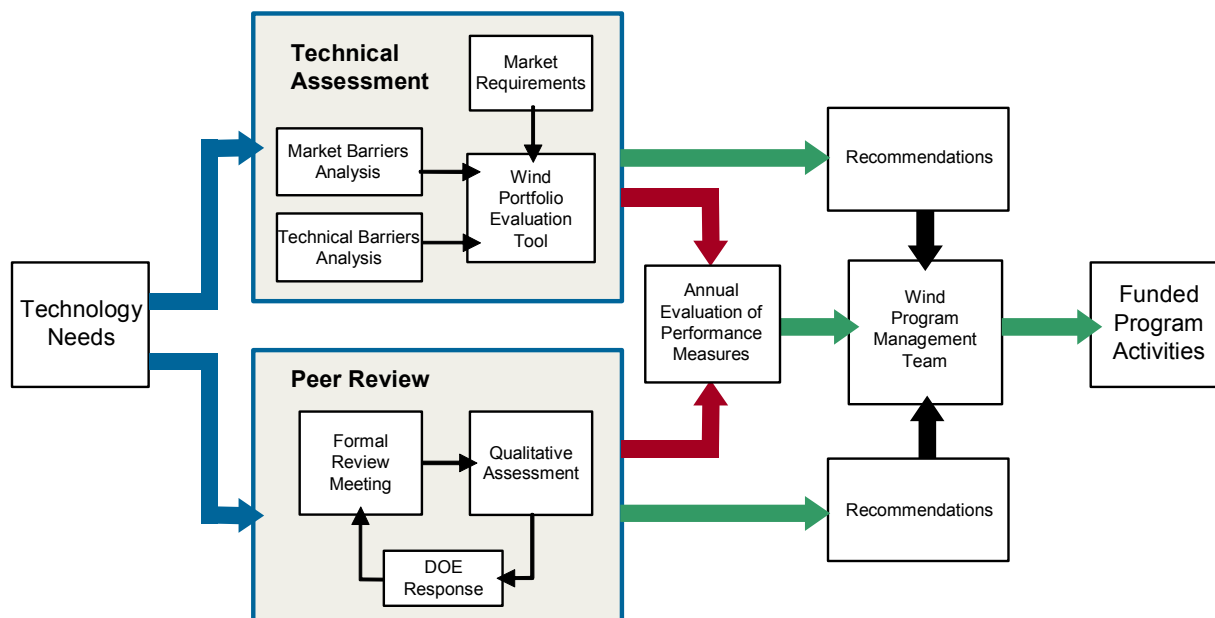


Figure E-3. Wind Program Strategic Planning Framework for Technical Needs

Assumed Budget Projections

The FY 2008 budget request is \$40.069 million, a \$3.75 million decrease from the FY 2007 request. A summary of the recent and requested budget by major activity area is shown in **Table E-4**. Funding for congressionally directed activities for FY 2007 and beyond is assumed to be zero.

Table E-4. FY 2008 Budget Request for Wind Energy Program

Funding (\$ in thousands)			
Activity	FY 2006 Approp.	FY 2007 Request	FY 2008 ^a Request
Technology Viability	18,353	35,905	27,200
Technology Application	7,634	7,914	12,869
Congressionally Directed Activities	12,870	0	0
TOTAL	38,857	43,819	40,069

An estimated breakout of the requested FY 2008 budget request by sub-key activity is shown in **Table E-5**. Figures are based on preliminary assessments.

Table E-5. Estimated FY 2008 Budget by Performance Goal Category

Performance Goal Category	Estimated 2008 Budget (\$K) ^a
Low Wind Speed Technology	5,843
Distributed Wind Technology	3,850
Supporting Research and Testing	16,850
Wind Grid Integration/Systems Integration	5,950
Technology Application/Technology Acceptance and Coordination	6,919
Small Business Innovative Research (not a specific category)	657

Assumed future funding for fiscal years 2008–2012 is provided in **Table E-6**; it is assumed to remain level through completion of offshore wind turbine goals in FY 2016. The program estimates the annual industry cost-sharing level to be approximately 50% of funds going to Low Wind Speed and Distributed Wind Technologies.

Table E-6. Planned Program Funding Through FY 2012 by Key Activity^a

	Fiscal Year Funding in \$K				
	FY08	FY09	FY10	FY11	FY12
Technology Viability	27,200	26,000	25,250	27,364	28,064
Technology Application	12,869	14,069	14,819	12,705	12,005

Description of Key Activities

The Wind Program seeks to improve the applicability of wind energy technologies through a coordinated program of applied research, cooperative technology development, strategic barrier removal, and dissemination of information and operating practices.

As discussed above, the program maintains two key focus activities, Technology Viability and Technology Application. The first activity consists of three sub-key activities, and the second activity consists of two sub-key activities. The development of strategic partnerships is a focus of both key activities. The program relies on cost-shared partnerships with industry for the development of new wind turbine designs, supported by applied research conducted through national laboratories and universities, and detailed testing of equipment in both controlled and field environments. Part of the role of R&D is also to minimize various aspects of market risk.

In the application of wind energy technologies, the program works closely with industry and community groups to remove barriers facing wider acceptance. Through collaborations with organizations such as the Utility Wind Interest Group (UWIG) and the National Wind Coordinating Committee (NWCC), the program addresses specific areas of concern, such as systems integration, transmission limitations, and environmental impact, while working to educate the general public and state and local leaders on the opportunities and true impacts of wind energy technologies.

Through continued coordination with the National Wind Technology Center (NWTC) at NREL, Sandia National Laboratories (SNL), and the DOE Project Management Center in Golden, Colorado, the program has developed the approach of coordinated partnerships as the most effective method through which it can achieve the desired program goals. From a technology perspective, as the wind turbines become larger and more complex, it has become impossible for the program to support the development of new technologies without heavy industry collaboration. For example, testing facilities for wind turbine blades and drivetrains were initially sponsored by DOE, but the facilities are now supported through partnerships with industry. In addition, working in close partnership with private entities allows the new technology and enabling research developed through the program to be quickly applied in the commercialization and deployment of new wind turbine designs. This approach bridges the gap between technology R&D and commercialization that has plagued many R&D efforts.

Because of the cost focus of the GPRA modeling process, only key activities under the Low Wind Speed Technology, for both land-based and offshore technologies, and Supporting Research and Testing key sub-activities are incorporated. This subset of activities is discussed here. The complete set of program activities are described in detail in the Wind Program's Multiyear Program Plan (U.S. Department of Energy 2007).

The activity covering Low Wind Speed Technologies is subdivided into three specific project areas, land-based, offshore, and emerging applications, of which only the first two are addressed in GPRA. In these areas, the program primarily focuses on providing assistance to the wind turbine industry through cost-shared development partnerships and providing baseline research in support of program goals. DOE-EERE program management has directed the program to critically consider the need of the mainstream wind industry in determining the amount and relevance of DOE cost-shared technology development partnerships. As an alternative, DOE is considering other partnership approaches including collaborative research and development agreements (CRADAs) for the further development of innovative wind turbine technologies.

Land-Based Wind Technologies

This activity continues the existing development partnerships focused on advancing the development of large-scale wind power systems to primarily compete in Class 4 wind regimes. Current partnerships focus on component and full-scale turbine development projects. The program plans to reduce funding for all cost-shared collaborative partnerships following the completion of existing component and prototype development activities. A new series of Wind Partnerships for Advanced Component Technology (WindPACT)¹ assessment efforts will be started in FY 2008 to help define program direction before the completion of the program goals in FY 2012.

¹ WindPACT assessment reports: <http://www.nrel.gov/wind/windpact/>.

Offshore Wind Technologies

All current efforts will focus on the development of a basic understanding of the offshore market segment, including analysis of resources, resource impacts, technology, and markets. Most of these studies will be conducted through a series of Sea-based Concept Studies (SeaCon), which focus on offshore elements of wind technology. Through FY 2009, the program is planning on minimal expenditures for offshore wind technology partnerships and, accordingly, is showing limited technology improvements within the framework of the GPRA process.

In FY 2009, a programmatic decision will be made to determine whether there is a significant market and governmental role for offshore wind technologies. If a clear government role can be defined, a similar path of phased solicitations will be proposed to facilitate development of offshore technology. This activity requires a long-term, diverse technical focus that can only be achieved through multiyear phased solicitations to accommodate a range of concept design studies, component development and testing efforts, and full turbine prototype development activities. Based on the high-risk nature of development in offshore environments, the program expects to use cost-shared development partnerships as has been done successfully in the land-based applications.

Supporting Research and Testing

Through the Supporting Research and Testing (SR&T) effort, research staff members at the NWTC and SNL perform wind technology research targeted to help industry improve the performance, operation, and cost of components and fully integrated turbine systems best suited for U.S. applications. To that end, program researchers work closely with industry to define and prioritize those research and testing activities that address long- and short-term requirements. Considering the complexity of the advancing technology and the size of new equipment that must be designed and tested, it appears unlikely that industry would make the advances similar in magnitude to past advances without Federal assistance.

Each of the general activities carried out under SR&T focuses on advancing technologies that have the potential to reduce the COE of large utility-scale and smaller distributed wind systems. The main areas are discussed below.

Turbine Reliability

Modern wind technology deployments are relatively young, with a fleet average age of less than five years. Although wind turbines are designed with a 20- to 30-year operational life, and some components have undergone equivalent life-cycle testing, many questions remain regarding the life of specific high-use components. To address the reliability of land-based, offshore, and distributed wind turbine technologies, this activity brings specialized technical expertise, comprehensive design and analysis tools, and unique testing facilities to bear on problems encountered in introducing new wind technology to the marketplace. It also includes the development of associated required testing capabilities and equipment needed to support turbine technologies as they grow in size.

Technology Development and Validation

Technology Research and Development uses a technical pathway analysis to show impact of private/public partnerships and ensure that research activities can show direct applicability to specific Technical Improvement Opportunities (TIOs) that were identified through detailed market and technical assessments (Schreck and Laxson 2005). Research work covered by the area of Technology Development and Validation follow the same improvement opportunities and support the development of technology through the following laboratory-based research activities:

Advanced Rotor Development: The rotor of a wind turbine is a unique component. The rotor's blades control all the energy capture and almost all the loads, and are, therefore, a primary target of research to enable advanced rotor development. The challenge is to create the scientific knowledge base and engineering tools to enable blade designers to achieve optimum performance at the lowest possible cost, using new materials, advanced controls techniques, improved manufacturing processes, and enhanced design tools.

Site-Specific Design: Future wind energy installations will be in areas of significantly different wind resource potential and terrain roughness. Installations of land-based turbines will need to move into areas with lower wind speeds, using taller towers and longer blades to harvest more energy. Every structural strength requirement throughout the system is based on the expected maximum event and turbulence at the site. To continue to design for loads characteristic of more energetic sites would drive up the cost unnecessarily and limit wind's cost-effectiveness in other areas. Therefore, this subtask covers two areas. The first is the development of systematic methods for specifying site energy and load conditions. The other area is to conduct the field measurements that validate the methods, and to work in public-private partnerships to collect site-specific information in important regions of the country.

Generator, Drivetrain, and Power Electronics Efficiency Improvements: The generator, gearbox, and power converter represent roughly 25% of the installed capital cost of a modern wind turbine. Generators have historically been based on wound rotors or squirrel-cage induction designs, but such generator designs may not be ideal for wind turbines of the future. Because wind turbines operate for the largest percentage of their time at less than rated power, future designs of generators and power converters must be specialized and tailored to wind turbine operation. Of further importance is reliability of all components, because the generator and power converter are key points of failure in the total system. This task explores key enabling research areas that will contribute to improvements in converter and generator designs, focusing on generator and converter architecture, controls, and reliability.

Design Review and Analysis: As the Wind Program invests in the development of new technology through cost-shared contracts with industry, it will also be providing oversight and technical support to those activities. The Design Review and Analysis effort provides a means whereby the program can provide specialized expertise to industry-led activities. It also provides support to the necessary proposal evaluation process. The support and oversight not only assists industry, but also protects the Wind Program's investments in these partnerships by providing clear stage-gates in the development process and enhancing their chance of success.

Testing Support: The Wind Program has unique facilities specifically developed to provide the testing capabilities needed to achieve LWST Project goals. Testing is conducted on full-scale LWST turbine systems installed in the field and on myriad turbine components and subsystems. Component testing includes utilizing the NWTC's specialized blade and dynamometer test facilities. Tests performed support research and development, certification, modeling and model validation, and technology characterization. Field-testing of turbine loads, power performance, power quality, and acoustic emissions are conducted in accordance with standards developed under the International Electrotechnical Commission (IEC).

Environmental Support: Wind energy is viewed by many segments of society as having a positive impact on the environment. It uses no fuel, produces electricity without producing greenhouse gases, and uses no fresh water for cooling or processing. However, as with any man-made technology, it does have an effect on the environment in which it operates. These effects are still under study and are being quantified to allow for intelligent mitigation. The program leads peer-reviewed research efforts to understand, avoid, and minimize these impacts, and will continue to do so as deemed appropriate.

Performance Enhancement

As the U.S. installed wind capacity increases over time, important lessons can be learned from long-term tracking and monitoring of turbine performance and reliability. This activity provides a means of linking with turbine manufacturers and wind plant operators to ensure that issues affecting performance and reliability of wind technology are addressed and incorporated into the Wind Program's R&D portfolio.

Milestones

The program has defined goals for its Technology Viability and Technology Application activities that will position wind as an attractive advanced technology option for the 21st century. These goals were:

- By 2012, reduce the COE from large wind systems in Class 4 winds to 3.6 cents/kWh in 2002 constant dollars, for land-based systems.
- By 2014, reduce the COE from large wind systems in Class 6 winds to 5 cents/kWh in 2005 constant dollars for shallow water (depths to 30 meters) offshore systems (from a baseline of 9.5 cents/kWh in 2005 in 2005 constant dollars).
- By 2016, reduce the COE from large wind systems in Class 6 winds to 5 cents/kWh in 2005 constant dollars for transitional (depths to 60 meters) offshore systems.
- By 2007, reduce the COE from distributed wind systems in Class 3 winds to 10–15 cents/kWh in constant 2002 dollars.
- By 2012, complete program activities addressing electric power market rules, interconnection impacts, operating strategies, and system planning needed for wind energy to compete without disadvantage to serve the Nation's energy needs.
- By 2010, facilitate the installation of at least 100 MW of wind energy in 30 states.

The program has also defined major and minor milestones, including annual targets that assist the program in measuring progress toward the overall program goals. The annual targets for 2006 are:

- Annual targets: COE of 4.2 cents/kWh (2002 constant dollars) for land-based Class 4 winds and 9.3 cents/kWh (2005 constant dollars) for offshore systems in Class 6 winds.
- Annual targets: Increase the number of states with more than 100 MW in installed capacity to 19.

In 2006, the program achieved the major milestones for low wind speed technologies, including the completion of concept studies and the fabrication and testing of turbine prototypes. Specifics include:

- Complete final report on Germanischer Lloyd AG certification for the FAST (Fatigue, Aerodynamics, structures, and Turbulence) design code and ADAMS® simulation prototyping.
- Complete Preliminary Design Review for second LWST Prototype.
- Complete fabrication of TPI Composites, Inc. subscale blade demonstrating structural-aerodynamic optimization.

For Technology Application, the expected outputs will be in the form of information and technical support needed to address integration barriers such as market rules, interconnection impacts, operating strategies, and system planning. Also needed is the reduction of legal, institutional, and zoning barriers to the use of wind, allowing more informed decision-making associated with land-based, offshore, and distributed wind applications. Technology Application milestones in 2006 included:

- Complete one Native American outreach and technical assistance activity.
- Complete one public power outreach and technical assistance activity.
- Complete one multistate outreach and technical assistance activity.

Because these tasks do not specifically support analysis conducted under GPRA, further details of these outputs are not provided in the text. However, it is important to note that they do significantly reduce market risk. More detail on these issues is available in the Program's Multiyear Plan (U.S. Department of Energy 2007)

Program Outputs

The major outputs for the Wind Program are the development of new lower-cost technology and the ability to deploy this technology as barriers are addressed. Some of these outputs are reflected in the major milestones discussed above, whereas others represent major program successes such as the activities that contributed to the development of the General Electric's (GE's) highly successful 1.5-MW turbine that supplied more than half of the capacity added to the U.S. grid in 2003; led to the development of the 2.5-MW Liberty turbine by Clipper Windpower, which began manufacturing in 2006; led to the development of the SkyStream 1.8-kW wind turbine by Southwest Wind Power; and facilitated the more than quadrupling of the number of states with more than 100 MW of installed wind generation since 1999. Key program outputs are:

- U.S.-developed wind turbine technologies for low wind sites that compete in the full range of electricity markets.
- Offshore wind technologies that bring wind's benefits to coastal load centers, while limiting environmental and aesthetic impacts.
- Advanced, cost-effective small wind technologies for use in distributed markets.
- Techniques and knowledge to fully and equitably integrate wind systems into the national grid.
- Reduced institutional and informational barriers that would impede wind's use.
- In collaboration with other Federal organizations, develop transmission systems to bring wind energy from remote high resource areas to load centers.

Further details of the activities that impact the portions of the program that are covered under GPRA are provided in **Table E-7**.

Table E-7. Program Outputs, Activities, and Milestones

Output	Associated Activities	Associated Milestones
U.S.-developed wind turbine technologies for low wind sites that compete in the full range of electricity markets	Key activities	Complete final report on GL certification for the FAST & ADAMS design codes (12/30/05)
	1. IEC Accredited of Clipper 2.5 MW LWST turbine	Complete hub construction, power electronics installation, and begin commissioning process for CART III turbine. (2/28/2006)
	2. Certification of wind turbine design codes	Complete Preliminary Design Review for second LWST Prototype. (3/31/06)
	3. Development of Northern Power Systems Variable Speed Generator	Begin laboratory testing of subscale blades demonstrating structural-aerodynamic optimization. (4/30/06)
	4. Development of new turbine blades with structural-aerodynamic optimization	Complete fabrication of TPI subscale blade demonstrating structural-aerodynamic optimization. (6/30/06)
	5. Aeroelastic and Coupled Dynamic Response	Conduct accredited field-testing of Clipper 2.5 MW LWST turbine to IEC standards. (9/30/06)
	6. Design Code Development and Support	
	7. Turbulence Modeling and Array Effects	
	8. International Collaboration Support	
	9. Testing	
	10. Environmental Support	
Offshore wind technologies that bring wind's benefits to coastal load centers, while limiting environmental and aesthetic impacts	Key activities	Publish and Present AIAA Paper on Offshore Model Development and Verification. (1/31/06)
	1. Advancing the development of technology that will allow offshore wind to compete in bulk power markets	Complete map validations for two offshore areas. (8/31/06)
	2. Laboratory-based technical support to provide continuous technical oversight of subcontracted research, development, and testing activities	Complete LWST Offshore SR&T subcontract awards. (9/30/06)
	3. Sea-based Concept Studies (SeaCon) for large wind systems.	Begin NEPA review process for 6-MW Offshore Turbine. (9/30/06)
	4. Technology Assessment and Market Analysis	Draft "Large-Scale Development of Offshore Wind Power in the United States" white paper. (9/30/06)
	5. Offshore Turbulence Modeling and Array Effects Analysis	
	6. Platform Model Development and Analysis	
	7. Integrated Controls, Condition Monitoring, and O&M	
	8. LWST Offshore Resource Assessment	
	9. International Collaboration Support	

Translating Program Outputs to Market Outcomes

By working directly with industry and other Federal, state, and local leaders, the program focuses on ensuring that program outputs lead directly to market outcomes. The specific nature of all program activities, from the coordinated public/private partnerships to targeted outreach, are focused on supporting wind technology integration into the energy sector. Through the strategic planning, peer review, and portfolio balancing processes, even research activities are

closely aligned with industry and market development needs. The primary program outputs introduced above, reductions in cost of wind technologies for wind systems (both centrally stationed and distributed), and the increased deployment of wind technologies across the country by nature lead directly to market outcomes.

Key Factors in Shaping Market Adoption of EERE Technologies

Price

Through program-sponsored research, wind technology is projected to improve significantly during the next decade. This improvement is represented in the GPRA 08 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 Program forms its goals using a probabilistic modeling technique.² The projected COE numbers 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. Although some cost reductions may result from "learning" that is dependent on cumulative volume levels, other cost reductions may be obtained from economies of scale resulting from 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 larger-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 *Low Wind Speed Technology Pathways Analysis Methodology and Baseline Report* to be published by NREL in FY 2007.

² 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) is 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 evaluation 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.

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 vs. 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 custom-built components, because the former have already “come down” the learning curve (Brock 1995). The 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 (Junginger 2005).

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 show 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% for overall capital cost reduction potential from learning by 2012 for land-based 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 learning from land-based 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 cumulative 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 land-based wind plants, and in the later years for offshore plants (i.e., in years past, the point where they have met the program goals), can be easily justified by conservative assumptions regarding learning effects and economies of scale. However, one phenomenon that has recently surfaced that goes against the trend toward lower costs from increased production is that, in an expanding market, costs have been found to increase due to supply constraints. While reported by at least one manufacturer recently, this issue was not considered in the evaluation of impacts from learning.

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

Non-price Factors

Federal and State Policy

Renewable energy credit (REC) markets, green power programs, California's mandatory carbon cap-and-trade system and other voluntary systems, and renewable portfolio standards (RPS) are all examples of ways such value is beginning to be recognized in the market. Currently, the major market driver for the development of wind technologies is the Federal production tax credit, which was extended through the end of 2007 by the Energy Policy Act of 2005. Additional installations of wind are being driven by state-based renewable portfolio standards, which are currently in effect in 20 states and the District of Columbia.

Transmission/Integration

The electric industry is in a challenging period characterized by changing, diverse, and nonuniform market rules and regulatory oversight, corporate restructuring, high competition, and technological change. The integration of renewable energy – including wind energy – into the supply mix is one of many issues the industry is grappling with before it can adopt this more competitive market structure. However, the utilities are concerned about possible impacts on system operations when a large amount of wind power is introduced into the electric power system, despite the fact that, by the end of 2005, approximately 58,000 MW of wind-generating capacity had been installed worldwide, and wind energy and cogeneration sometimes total as much as 100% of instantaneous generation in Denmark. Utility decision makers, state regulators, and investment bankers are unfamiliar with wind; and, therefore, they are overly cautious in their view of wind power as a generation asset. Principal among their concerns are potential system effects due to limitations in wind forecasting and the potential electrical system stability and dispatch implications. Their concerns, if not adequately addressed, could limit the development potential of wind power in this country. Recent developments, such as the release of the Utility Wind Integration State of the Art report by the Utility Wind Integration Group, cosigned by American Public Power Association (APPA), Edison Electric Institute (EEI), and National Rural Electric Cooperative Association (NRECA), however, demonstrate that wind power has entered the mainstream of national power generation, and multiple parties are working to address the key issues facing further wind integration.

The transmission of wind-based energy is also seen as a near-term challenge to the wider use of this technology. Key wind resource areas, such as the northern Great Plains and western Texas are separated from major load centers by limited transmission capacity. The development of new clean energy highways to move larger amounts of low-cost wind power to areas of high load concentration will be required to enable full uptake of these resources.

Environmental / Acceptance

Wind energy is viewed by many segments of society as having a positive impact on the environment. It uses no fuel, produces electricity without producing greenhouse gases, and uses no fresh water for cooling or processing. But, as with any manmade technology, it does have an effect on the environment in which it operates. Wind developments have the potential to reduce, fragment, or degrade habitat for wildlife, fish, and plants, as well as to directly and indirectly cause harm to biotic communities.

Noise impacts resulting from construction, turbine operations, substation operations, and transmission lines in addition to visual impacts in less-developed areas are leading to increased acceptance pressures for wind technologies. Proper siting and equipment design and the use of setbacks from residential areas can help minimize these impacts. While the visual impact of wind turbines on the landscape is quite subjective, it poses a challenge to the continued growth of wind energy, particularly on ridgelines and mountaintops (this objection often being referred to as NIMBY – “not in my backyard”). As with noise and ecological impacts, visual aesthetics must be considered in the context of other types of development that affect the visual landscape.

Immediate Outcomes

Justification for Wind Program Case estimates of both current and future technology characteristics for land-based turbines are contained in a report to be published by NREL in FY 2007. This report, *Low Wind Speed Technology Pathways Analysis Methodology and Baseline*, will update earlier, preliminary documentation (Cohen 2004). The methodology described in that report was discussed earlier in this appendix on **Page E-22**. In addition, by using information obtained through R&D conducted since the path analysis was completed, program researchers are currently updating the technical rationale, description, and potential for improvements in technology cost and performance that can reasonably contribute toward achieving the projected trajectory of those characteristics. The technology characteristics presented in this section reflect preliminary results from that update. The Wind Program plans to incorporate these new technical insights into an updated pathways analysis/risk analysis during FY 2007, which will be included in the FY 2009 GPRA report.

As a starting point for the Program Case cost and performance trajectory, the program splits the difference between the program capacity factor and the AEO capacity factor in 2005, as has been done in past years, and then adjusts to the program capacity factor for 2010 and beyond. The AEO capital cost for 2005 is used, but program costs decrease after that, aligning with the program’s projections from 2010 onward. **Table E-8** shows the turbine characteristics used for the capacity factor calculations in NREL’s spreadsheet model.

Table E-8: Land-Based Turbine Characteristics for Calculating Capacity Factors

	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050
Turbine Rating (kW)	1500	2500	3000	3000	3000	3000	3000	3000	3000	3000
Diameter (m) (Classes 3 & 4)	77	93	107	108	108	108	108	108	108	108
Diameter (m) (Classes 5–7)	77	90	96	97	97	99	99	99	99	99
Hub Height (m) (Classes 3 & 4)	80	100	120	120	130	120	120	120	120	120
Hub Height (m) (Class 5–7)	80	100	110	110	110	110	110	110	110	110
Peak Power Coefficient (Cp)	0.47	0.50	0.51	0.51	0.51	0.52	0.52	0.52	0.52	0.52
Peak Conversion Efficiency	0.95	0.96	0.97	0.97	0.98	0.98	0.98	0.98	0.98	0.98
Net Losses	0.12	0.06	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Availability	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98

By averaging the program’s estimated capacity factor and the AEO capacity factor for wind plant performance in 2005, the differences in methodology are mitigated. The transmission constraints that can cause curtailment in some cases are not related to the technology performance, nor are

other interannual variations in wind resource levels that can cause energy production reported to EIA to be lower than calculated estimates would predict. It is assumed that these issues will be resolved or mitigated in the future. While still too early in the project, current analysis of wind plant performance and associated wind resource level for commercial several sites may help resolve some of these issues. Thus, the program's projected capacity factors based on technology improvement assumptions are used for future technology. One of the key barriers to the widespread implementation of wind technologies relates to the acceptance and integration of wind technologies into the national electric system. Increased funding in this area supports the President's Advanced Energy Initiative by opening up more of the Nation's vast wind resources to development and productive use. An expansion of these activities will include further collaboration between the Wind Program and the Office of Electricity Delivery Energy Reliability, who will work together to address the near-term to midterm risks of transmission-based limitations being imposed on wind development. Increased funding will be directed to expanding the number of wind plant characterization, integration, and interconnection studies supported by the program, the addition of laboratory staff to provide analytical support, and establishment of regional wind integration teams to allow participation in regional forums as decisions about wind energy are made.

As discussed in the baseline case section, a spreadsheet model was used in conjunction with the turbine characteristics in **Table E-8** to calculate capacity factors. In forming the values in **Table E-8**, assumptions were made regarding the physical dimensions of the technology, e.g., rotor diameter and hub height, with respect to progress toward the Technical Improvement Opportunities (TIOs) that were defined to achieve the cost of energy goals. The primary R&D drivers of improved cost and performance are extended rotors and taller towers, which can be achieved through the use of sophisticated control designs, new materials, and innovative tower concepts. In addition, continued improvement of drivetrain technology and reliability also contribute to future improvements. There are a large number of potential combinations of components with such advancements that could result in turbine system designs with overall cost and performance improvements on the projected level.

Program analysis and documentation for offshore technology projections is an evolving process. The current and planned program-sponsored SeaCon studies will provide a much more detailed technical foundation for making such projections. To develop preliminary offshore cost and performance inputs, program analysts scaled capital costs over six periods from 2006 to 2025, using cost-reduction rates (i.e., capital cost reductions for each period corresponding to a doubling of installed capacity) typical of wind industry experience. The rates were assumed to include improvements in technology, increases in production volume, and "learning" improvements in manufacturing and wind plant installation. The doubling periods and cost-reduction rate used in the cost calculations were derived from IEA and European reports (Milborrow 2003). The rate was augmented by a one-time additional 10% reduction in capital cost based on 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 E-9** are all within the bounds established by the cost-scaling exercise.

Interim Outcomes

Market penetration was estimated using NEMS (to 2030) and MARKAL (to 2050). The implementation of wind energy in NEMS and MARKAL is discussed in the appendices covering those models.

The program characterized the offshore resource potential by wind class, water depth, and region. For GPRA 07, costs were based on a wind plant distance of 20 miles from the substation, which is expected to be located at shoreline. This approach is not entirely accurate because it does not reflect the true costs based on distance from shore, and makes all of the shallow and transitional resources in each wind class available at the same price. Initial studies indicate that there is a moderate cost multiplier based on the costs of transmission (see **Figure E-4**) (University of Massachusetts 2006). Including these costs allows a more rational application of wind technology within the GPRA models. For this GPRA08 analysis, the program further split the resource data into two groups, the resource that is available at a distance of 5 to 20 miles and at 20 to 50 miles. Cost values were applied to these two groups as if all of the resources were located at 12.5 and 35 miles, respectively.

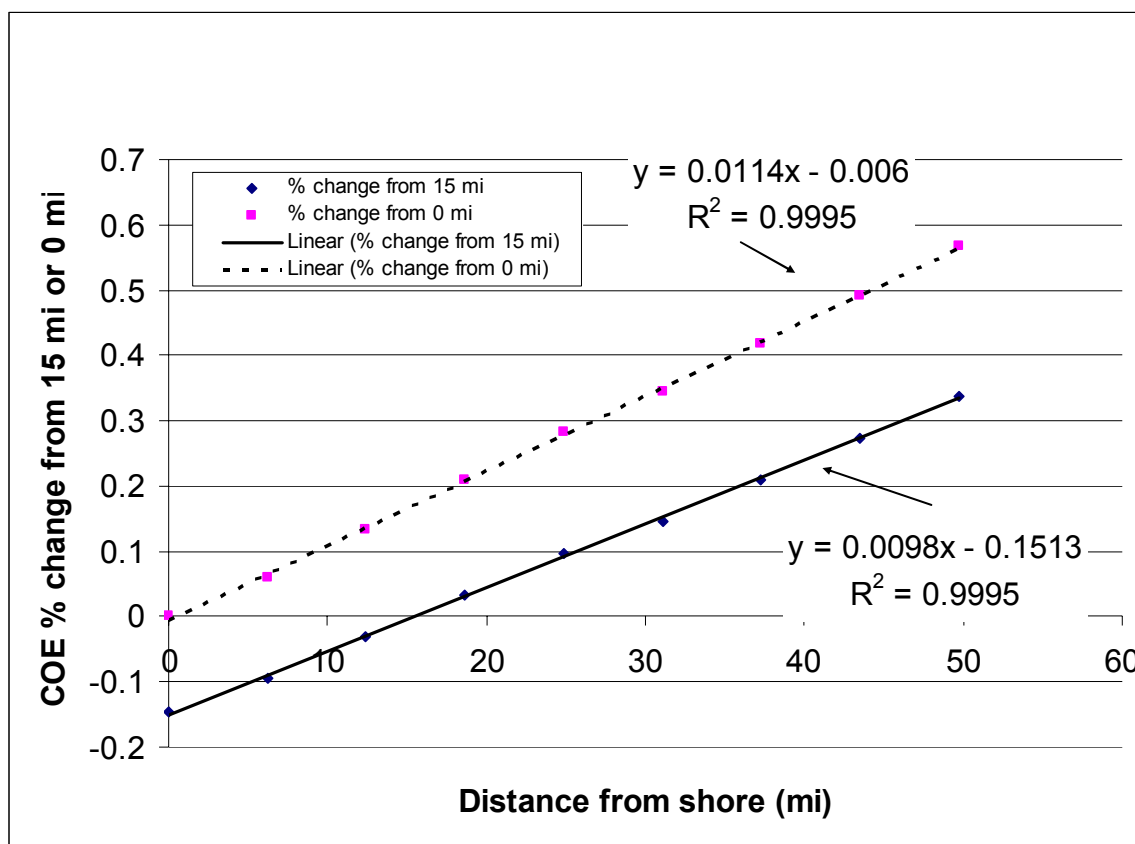


Figure E-4. Cost of Offshore Wind Plants Vs. Distance from Shore

It was necessary to make one other modification to the offshore wind resource inputs for the NEMS model. The current NEMS-GPRA 08 projections produce extremely high offshore wind penetration in the Southeastern Electric Reliability Council (SERC) region. To address this issue within the current GPRA cycle, a short-term solution was developed: the SERC offshore wind

resource was reduced by the ratio of new electric generating capacity in Virginia, North Carolina, and South Carolina to the new capacity in the entire SERC region. The trend toward overestimation of the reduction factor, because not all new capacity will be met by wind generation, was assumed to cancel (on a first-order level) the trend toward underestimation, because there will be some wind generation that will be transmitted to other states in the SERC region. The original wind resource data set was scaled by maintaining the same proportion of resources for each wind power class, by distance from shore and depth of water. This, again, was estimated to result in an accurate estimate, to the first-order, and was assumed because more detailed analysis has not been performed.

Final Outcomes (Benefits)

The program does not calculate benefits outside of, or exogenous to, the integrated energy market models discussed in this report. The benefits reported in the primary part of this document represent the program's best estimate of the results of its technology development activities associated with large wind systems. The program does not currently assess the long-term benefits of its Technology Application or Distributed Wind Technology efforts, though may attempt to do this in the future.

Summary of Inputs

Capital costs, capacity factors, and O&M costs, which are used as inputs to the NEMS-GPRA 08 model for the Program Case, are provided in **Table E-9**. The projections match the program's performance goals, as described above. Projections for land-based wind plants are consistent with the analysis described in the MYPP (U.S. Department of Energy 2007). The capital costs do *not* include a contingency factor of 5% for land-based wind and 7% for offshore wind, which is applied, as is done with other electric generating technology cost inputs, before being input to NEMS. Capital costs are overnight costs, i.e., they do not include financing during construction.

Table E-9: Summary of Inputs to Models (“Immediate Outcomes” of Program R&D)

2004 Dollars		2005	2010	2015	2020	2025	2030	2040	2050
Capital Costs*									
Land Based	Classes 5&6	1167	893	841	818	814	789	765	747
	Class 4	1167	999	992	946	868	868	856	839
Offshore	Shallow	2118	2037	1601	1125	941	922	873	844
	Transitional	2803	2765	2134	1251	1140	1004	951	892
O&M Costs									
Land Based	All Classes	27.6	24.4	22.6	20.9	19.3	18.0	15.4	13.2
Offshore	Shallow	81	81	63	50	44	44	39	34
	Transitional	81	81	63	50	44	44	39	34
Capacity Factors									
Land Based	Class 6	0.432	0.482	0.494	0.503	0.505	0.520	0.522	0.522
	Class 5	0.399	0.446	0.459	0.468	0.470	0.484	0.487	0.487
	Class 4	0.350	0.410	0.461	0.469	0.471	0.478	0.480	0.480
Offshore <i>Shallow</i>	Class 6	0.384	0.384	0.422	0.431	0.436	0.442	0.450	0.458
	Class 5	0.337	0.337	0.375	0.385	0.389	0.395	0.403	0.410
	Class 4	0.298	0.298	0.336	0.346	0.349	0.355	0.363	0.370
Offshore <i>Transitional</i>	Class 7	0.423	0.423	0.472	0.464	0.484	0.491	0.509	0.514
	Class 6	0.384	0.384	0.433	0.422	0.442	0.449	0.466	0.471
	Class 5	0.337	0.337	0.386	0.373	0.390	0.397	0.414	0.418
*Does not include a 1.05 contingency factor applied to land-based systems and 1.07 to offshore systems (Cohen 2004, Musial 2004; U.S. Department of Energy 2007). Land-based costs were converted from 2002 dollars using a CPI Inflation of 1.05. Offshore costs were converted from 2005 dollars using a GDP deflator of 0.97									

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