Appendix L – GPRA06 Wind Technologies Program Documentation

1 Introduction

The Wind Technologies Program seeks to reduce the cost and improve the performance of wind technology, and to reduce barriers to its use. The GPRA benefits are estimated primarily from model projections of the market share for wind technologies, based on their economic characteristics. Several models are utilized for this purpose. This document describes the inputs and assumptions that are used by the models to calculate those benefits. The most significant change from the GPRA05 benefits methodology in assumed program direction and activities for the current GPRA06 estimates is the inclusion of offshore wind energy technology development.

1.1 Target Markets (the Baseline Case)

Large-scale wind energy is expected to penetrate in two market segments: the least cost (competitive bulk power) power market and the green power market.

In the competitive power markets, wind technology is projected to improve significantly during the next decade, in part because of program-sponsored research. This improvement is represented in the GPRA06 modeling effort by a declining capital cost trajectory, lower O&M costs, and increased performance. The values used for the wind technology cost and performance projections are consistent with the program's 2012 cost of energy goals for low wind-speed technology, both onshore and offshore.

In addition to competing on an economic basis with other electricity-generation technologies, wind capacity may be partially valued for its environmental attributes. Princeton Energy Resources International (PERI)—using its Green Power Market Model—provided an estimate of wind capacity additions in response to the expanding green power markets in many places throughout the country. The projections for green power wind installations were incorporated exogenously into the OnLocation-modified NEMS (NEMS-GPRA06), and Brookhaven National Laboratory-modified MARKAL (MARKAL-GPRA06) models as planned capacity additions.

Description of Key Elements of the 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-GPRA06 characterizes wind by three wind classes, each with its own capital costs and resource cost multipliers. The regional resource cost multipliers increase capital costs as increasing portions of a wind class is 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 a particular region increases with greater development, at some point it may become 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. These multiplier assumptions are viewed as very conservative, and may overestimate the effects of actual market dynamics.

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. NEMS-GPRA06, as in the *AEO2004*, 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 *AEO2004* assumption that a cost premium is imposed when new orders in a year are 20% higher than in the highest of the previous 10 years was maintained in the Program Case (the same as applied to all electricity generation technologies)

Further detail on the representation of wind power in NEMS may be found in **Chapter 4** and **Appendix A.**

Description of Key Elements of the MARKAL Approach to Modeling Wind

Wind generators are modeled as centralized plants to compete with fossil fuel-based plants. As in NEMS, resource cost multipliers were applied to the capital cost of wind generators as additional capacity is developed. The resource cost multipliers are based on the assumptions used in the AEO2004. However, since MARKAL-GPRA06 is a single region model, these multipliers were applied on a national basis.

To account for the intermittent nature of wind resources, the potential contribution of wind systems to meeting peak power demand is limited to a fraction of total wind capacity. This factor ranges between 30% and 40% depending on wind class, year, and maximum assumed capacity factor. This disadvantages wind generators, compared to fossil fuel generators, as additional reserve capacity is required to meet peak power requirements. However, this disadvantage is offset by fossil fuel cost savings, as well as 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. The green power capacity additions are added as a lower bound in the MARKAL-GPRA06 model.

Developing the GPRA06 Baseline for Wind

The Baseline, which is used as the benchmark against which to measure the Wind Program’s benefits, is developed using NEMS-GPRA06 and some of the technology assumptions in the Energy Information Administration’s (EIA) *Annual Energy Outlook 2004 (AEO2004)* Reference Case. The AEO2004 baseline treats wind as a mature technology that experiences, in the future, only a limited amount of cost reduction through learning (only 1% reduction in costs is assumed for every doubling of capacity). As a result, in the EIA projections, the projected capital costs decline only slightly over time.

Three changes from the AEO2004 Reference Case were made regarding wind. The AEO2004 uses short-term (national growth) and longer-term (regional resource) multipliers. These factors account for various resource and market phenomena that are intended to reflect increases in the cost of deploying technology as cumulative installed capacity increases). In NEMS-GPRA06, the resource multipliers are applied by wind class rather than across the entire wind resource in each region. This is a more restrictive assumption in that it tends to increase the assumed cost of wind technology, and, therefore, to lower projections of installed capacity.

A second modification is to the capital cost and capacity factor assumptions for current (2005) wind technology. The EIA and program assumptions about the expected performance (capacity factor) of new wind capacity additions are significantly different. They needed to be reconciled, so that the same assumptions would be used for the year 2005 in both the Baseline and Program cases. For example, EIA assumes that the capacity factor of wind turbines in Class 6 winds, in 2005, is 38%, while the program believes it is 49%. A compromise between the two was made such that the capacity factor assumptions for 2005 are midway between the two views (e.g., 44% for Class 6). The Baseline wind capacity factors then improve over time at the same rate as assumed in the AEO2004. The capital costs estimates for 2005 were more similar, and the program's view for 2005 was adopted for the 2005 Baseline, followed by a small decline in cost over time at the same rate as in the AEO2004.

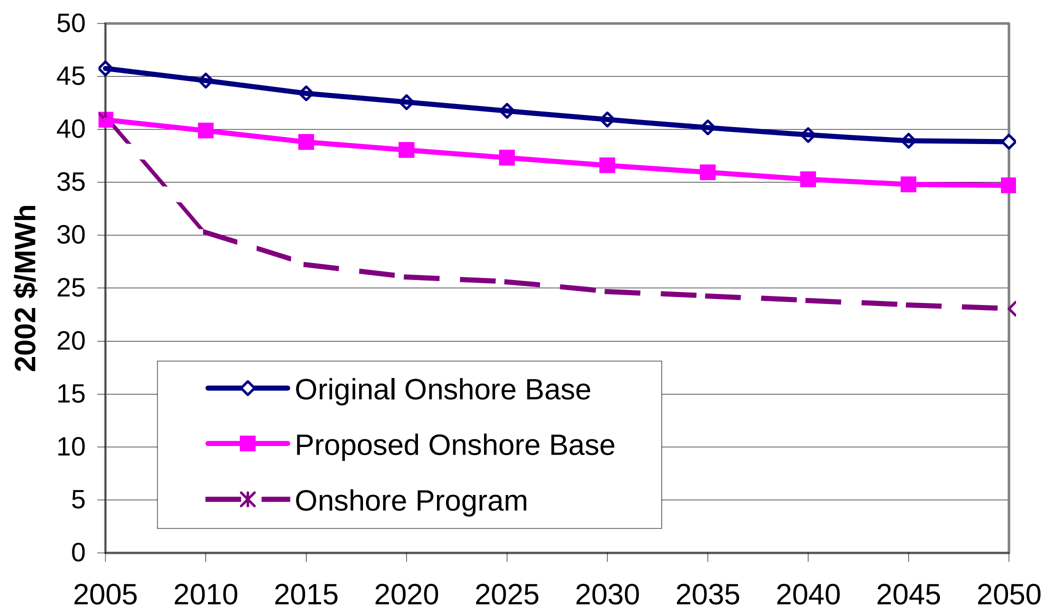

Figure 1. Onshore Wind Class 6 COE

The third change from the AEO2004 to the Baseline is the addition of offshore wind as a separate technology. The offshore wind is represented as a distinct technology that competes with all other generation technologies. It is characterized in a similar manner as onshore wind, with three wind classes, but also has a distinction between shallow and deep water sites. The constraints on intermittent generation and rapid growth apply similarly to offshore as to onshore wind development. The offshore wind does not have the regional resource cost multipliers because there is insufficient data on how they might apply.

Table 1 provides the complete set of technology assumptions used in developing the Baseline estimate for GPRA06.

Table 1. Baseline Projections for Capital Costs, Capacity Factors, and O&M Costs for Onshore and Offshore Wind Systems

		2005	2010	2015	2020	2025	2030	2040	2050
Capital Costs									
Onshore	Class 5 & 6	1050	1048	1045	1042	1039	1036	1031	1025
	Class 4	1103	1087	1084	1076	1053	1050	1045	1039
Offshore	Shallow Water	1243	1241	1234	1225	1212	1196	1155	1102
	Deep Water	1787	1767	1743	1707	1636	1604	1497	1383
O&M Costs									
Onshore	All Classes	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Offshore	Shallow Water	55.0	49.3	45.0	41.0	40.0	39.0	37.0	35.0
	Deep Water	55.0	51.3	47.0	43.0	42.0	41.0	39.0	37.0
Capacity Factors									
Onshore	Class 6	0.436	0.446	0.458	0.466	0.474	0.482	0.498	0.504
	Class 5	0.398	0.407	0.417	0.426	0.433	0.440	0.453	0.459
	Class 4	0.338	0.345	0.354	0.361	0.366	0.374	0.390	0.395
Offshore	Class 7	0.532	0.537	0.563	0.569	0.569	0.569	0.569	0.569
	Class 6	0.442	0.446	0.468	0.474	0.474	0.474	0.474	0.474
	Class 4	0.351	0.356	0.373	0.380	0.380	0.380	0.380	0.380

*Includes 1.05 contingency factor for onshore systems and 1.07 for offshore systems.
Sources: [1] [2]

1.2 Key factors in shaping market adoption of EERE technologies

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. The United States has an estimated 60 gigawatts (GW) of shallow water resource and 141 GW of deep water resources within 5-20 nautical miles (nm) of the coast, and a further 38 GW of shallow water resources and 668 GW of deep water resources located 20-50 nm out. Early offshore wind development in Europe, at shallow depths of 5-12m, has relied on the marinisation of land-based turbines anchored to the seabed. It is expected, however, that the growth of offshore wind technology in the United States will also require new technologies that allow deep water development (e.g., floating platforms and power distribution and transmission systems). [2]

1.3 Methodology and calculations

Technical Characteristics of the Program Case for Wind

The assumptions about capital costs, capacity factors, and O&M costs, which are used as inputs into the Program Case, are provided in **Table 2.** These projections match the program's performance goals, as described in the *Wind Energy Multi Year Program Plan For 2005-2010,* November 2004, available for downloading in PDF format at: http://www.nrel.gov/wind_meetings/2003_imp_meeting/pdfs/wind_prog_mypp_15Nov2004.pdf

So far, the program has only completed preliminary analyses of the costs and performance of deep water wind turbines. For this reason, their estimated cost and performance should be regarded as tentative, reflecting the best program judgment available at the time of this analysis, but being almost certain to change as more knowledge is gained and more comprehensive studies are completed. A more detailed examination of cost-reduction potential is being undertaken in 2005, and will be structured using the wind program's Technology Improvement Opportunity (TIO) pathways framework.

Table 2. Program Projections for Capital Costs, Capacity Factors, and O&M Costs for Onshore and Offshore Wind Systems

		2005	2010	2015	2020	2025	2030	2040	2050
Capital Costs									
Onshore	Class 5 & 6	1050	893	840	819	814	788	767	746
	Class 4	1103	982	919	893	866	866	856	840
Offshore	Shallow Water	1243	1129	1070	1070	1050	1016	989	962
	Deep Water	1787	1723	1370	1177	1050	1024	977	945
O&M Costs									
Onshore	All Classes	25.0	20.0	16.0	15.0	14.2	13.8	13.2	12.8
Offshore	Shallow Water	55.0	47.0	41.0	38.0	37.3	36.0	34.0	32.0
	Deep Water	55.0	49.3	44.0	41.0	40.0	39.0	37.0	36.0
Capacity Factors									
Onshore	Class 6	0.436	0.495	0.507	0.514	0.517	0.519	0.522	0.525
	Class 5	0.398	0.442	0.453	0.457	0.460	0.460	0.462	0.462
	Class 4	0.338	0.404	0.463	0.469	0.472	0.480	0.482	0.483
Offshore	Class 7	0.535	0.546	0.604	0.604	0.604	0.604	0.604	0.604
	Class 6	0.442	0.450	0.501	0.501	0.501	0.501	0.501	0.501
	Class 4	0.352	0.359	0.401	0.401	0.401	0.401	0.401	0.401

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

Green Power Market Penetration Projections

Green power additions (estimated by the PERI Green Power Market Model) were provided by region and are included as planned capacity additions. (For more details on the Green Power Market Model, see **Appendix M**). Estimates of the Green Power additions were provided to

2035. After 2035, they remain flat as most of the renewable capacity will likely be introduced competitively by then. The same general technology assumptions were made for the green power additions as for the economic builds predicted by NEMS or MARKAL. However, none of the Green Power additions was modeled as coming from offshore installations, due to their generally higher cost in the near term when green power markets are assumed to be most important. **Table 3** summarizes the green power capacity additions. The green power additions do not necessarily lead to greater total wind capacity than those projected for pure economic reasons, because development costs are assumed to increase as wind resources are developed.

Table 3. Green Power Wind-Capacity Additions (MW) for Program Case

Wind	2006-2010	2011-2015	2016-2020	2021-2025	2026-2030	2031-2035	Total
1. ECAR	160	164	69	39	27	28	487
2. ERCT	142	179	91	46	36	38	532
3. MAAC	316	204	16	18	19	20	592
4. MAIN	99	101	43	24	16	17	300
5. MAPP	13	27	21	11	4	4	79
6. NY	210	136	11	12	13	13	395
7. NE	231	139	22	20	19	19	450
8. FL	0	0	0	0	0	0	0
9. STV	0	0	0	0	0	0	0
10. SPP	146	192	104	52	38	41	573
11. NWPP	18	33	23	14	9	10	107
12. RA	28	47	32	20	14	15	156
13. CNV	7	18	17	8	3	3	57
Total	1,372	1,239	448	262	198	210	3,729

1.4 Sources

1. Cohen, Joseph M., "Assessment Of Potential Improvements In Large-Scale Low Wind Speed Technology," proceedings of Global Windpower 2004, March 29, 2004, American Wind Energy Association, Washington, DC.
2. Musial, W., and Butterfield, S., *Future For Offshore Wind Energy in the United States*, June 2004, NREL.CP-500-46413 http://www.nrel.gov/docs/fy04osti/36313.pdf
3. Milborrow, D., Offshore Wind Rises to the Challenge, *Windpower Monthly*, April 2003.