Appendix L – GPRA05 Wind and Hydropower Technologies Program Documentation

Description of GPRA05 Benefits Methodology for Wind

The wind energy component of the Wind and Hydropower 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 based primarily on model projections of the market share for wind technologies, based on their economic characteristics. This document describes the assumptions that are used by the models to calculate those benefits.

Market Segments

Wind energy is expected to penetrate in two market segments: the least cost (competitive bulk power) power market and the green power market. Through program-sponsored research, wind technology is projected to improve significantly during the next decade. This improvement is represented in the GPRA05 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.

In addition to competing on an economic basis with other electricity generation technologies, wind capacity may be constructed 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 into the OnLocation-modified NEMS (NEMS-GPRA05), and Brookhaven National Laboratory-modified MARKAL (MARKAL-GPRA05) models as planned capacity additions.

Detailed Model Input Information

NEMS-GPRA05 Baseline

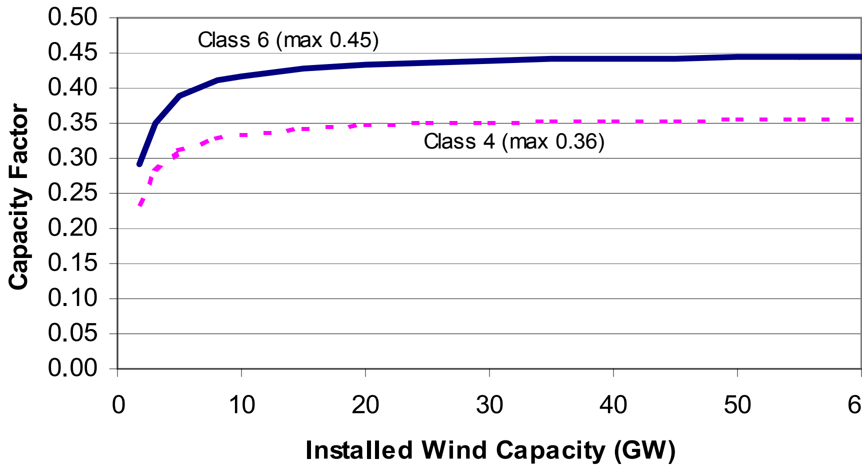
The baseline, which is used to measure the wind program's benefits, is developed using NEMS-GPRA05 and some of the assumptions in the Energy Information Administration's (EIA) *Annual Energy Outlook 2003* (*AEO2003*) Reference Case. In developing the baseline, the only change made to the model regarding wind energy is that certain assumptions about regional cost multipliers are altered, as described below. The *AEO2003* 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 for each doubling of capacity). As a result, the capital costs decline only slightly over time (**Table 1**).

Table 1. *AEO2003* Wind Costs

	Overnight Cost ($2001/kW)	Total Including Contingency ($2001/kW)
2002	938	1004
2005	932	997
2010	929	994
2015	927	992
2020	925	990
2025	924	989

Source: *Assumptions to the AEO2003*, p. 121, Table 73

The capacity factors for the three wind classes in the *AEO2003* are based on a learning function and a specified ultimate capacity factor for each class. The learning-induced improvements in capacity factors used by EIA asymptotically approach the specified capacity factor limits. The resulting factors for Class 4 and Class 6 wind resources, using the *AEO2003* parameters (see **Figure 1**).



Source: *AEO2003*

Figure 1. *AEO2003* Wind Performance

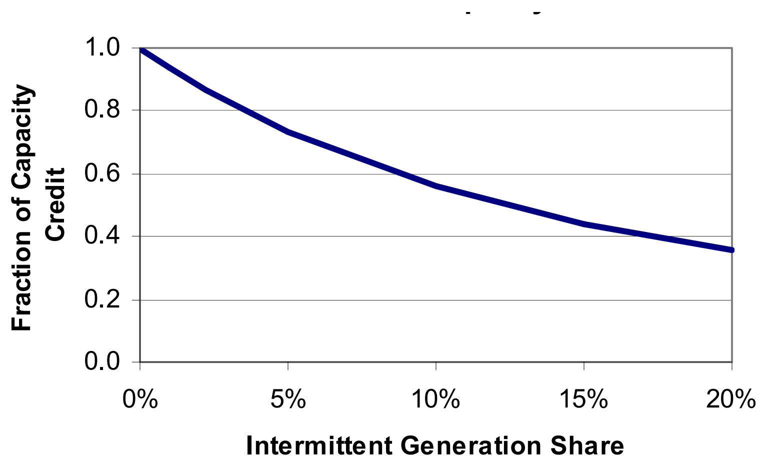
The resulting capacity factors by year are not very different from those of the *AEO2002.* The capacity factors can be specified by year instead of as a function of the learning parameters.

Table 2. *AEO2003* Resulting Wind-Capacity Factors

	Class 6	Class 5	Class 4
2005	0.406	0.370	0.325
2010	0.412	0.376	0.330
2015	0.418	0.381	0.335
2020	0.421	0.383	0.337
2025	0.423	0.385	0.338

Source: *AEO2003*

EIA set the limit on the share of generation in each region that can be met with intermittent technologies at 20% for the *AEO2003*, up from 12% in the *AEO2002*. However, the capacity credit toward meeting peak requirements declines with the increasing share of intermittent generation (wind, CSP, and PV). When the share of intermittent generation is very small, the capacity credit is equal to the capacity factor in the time period when the peak occurs. If the intermittent generation share rises to as high as 20%, the capacity credit would only be 35% of the capacity factor. (**Figure 2**).



Source: *AEO2003*

Figure 2. *AEO2003* Intermittent Capacity Credit

The *AEO2003* uses short-term (national growth) and long-term (regional resource) multipliers (factors to account for various resource and market phenomena that are postulated to increase the cost of deploying technology). In NEMS-GPRA05, the resource multipliers are applied by wind class rather than across the entire wind resource in each region.

Assumptions in Support of NEMS-GPRA05 Benefits Analysis

The NEMS-GPRA05 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. Unlike the *AEO2003* version of NEMS, NEMS-GPRA05 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 that region increases, it may be more cost-effective to consider installing wind turbines in areas of lesser wind resource, but with lower ancillary costs and less-costly access to the grid, as reflected in the model by the capital cost multipliers. 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. The *AEO2003* assumption that wind may provide only a maximum of 20% of a region's generation was maintained, even though the program disagrees with that characterization. NEMS-GPRA05, as in the *AEO2003*, 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 *AEO2003* assumption that a cost premium is imposed when new orders exceed 50% of installed capacity was maintained for the benefits analysis.

The following assumptions (**Table 3**) about capital costs, capacity factors, and O&M costs are used as inputs into the NEMS-GPRA05 model to match the program's performance goals.

Table 3. Capital Costs, Capacity Factors, and O&M Costs for Wind

Wind Technology Assumptions		2005	2010	2015	2020	2025
Class 6 Capital Cost*	2003 $/kW	1,113	910	856	835	829
Class 5 Capital Cost*	2003 $/kW	1,113	910	856	835	829
Class 4 Capital Cost*	2003 $/kW	1,231	1,017	963	936	910
Capacity Factor - Class 6	fraction	0.520	0.495	0.507	0.514	0.517
Capacity Factor - Class 5	fraction	0.462	0.442	0.453	0.457	0.460
Capacity Factor - Class 4	fraction	0.391	0.388	0.452	0.467	0.470
Total O&M Costs	2003 $/kW-year	13.4	8.0	7.6	7.6	7.6

*Includes 1.07 contingency factor.
Source: Wind Energy Program, as reflected in *Wind Energy Program Multi Year Technical Plan, 2004 – 2010 (November 2003),* http://www.nrel.gov/wind_meetings/2003_imp_meeting/pdfs/mytp_nov_2003.pdf

In addition to competing on an economic basis with other electricity generation technologies, wind capacity may be constructed for its environmental benefit. The PERI Green Power Market Model estimated that nearly 4,700 MW of wind would be installed by 2025, in response to the expanding green power markets in many places throughout the country. Analysts included the region-by-region breakout of projections for green power wind installations in NEMS-GPRA05 as planned capacity additions. Because these additions "use up" a part of the overall wind resource base, they may reduce the new construction estimated for the least-cost sector. As a result, the total incremental capacity may not equal the green power plus these additions.

MARKAL-GPRA05

The program goals are represented in the MARKAL-GPRA05 model by changing the capital and O&M costs and capacity factors for wind turbines to match the program goals as represented in **Table 1**.

The discount rate for wind generators is set at 8% (instead of the utility average of 10%) to reflect the accelerated depreciation schedule available for renewable generation technologies. Wind generators are modeled as centralized plants to compete with fossil fuel-based plants. The potential contribution of wind systems to meeting peak power demand is limited to 40%, reflecting the intermittent nature of the technology. As with PV systems, this disadvantages wind generators, as additional reserve capacity is needed to meet peak power requirements. However, this disadvantage is offset by the reduction in capital cost and performance improvements projected for wind technologies by the program. As a result, wind generators near the central grid can be competitive with fossil fuel-based power plants. The green power capacity additions are added as a lower bound in the MARKAL-GPRA05 model.

Green Power

Green power additions (from PERI) were provided by region and are included as planned capacity additions. 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.

Table 4. Wind-Power Assumptions

	2010	2020	2030	2040	2050
Capital Costs with Contingency Factor (2003 $/kW)					
Class 6	$910	$835	$803	$781	$760
Class 5	$910	$835	$803	$781	$760
Class 4	$1,017	$936	$899	$877	$856
Fixed O&M Cost ($/kW/year)	8.0	7.6	7.6	7.6	7.6
Capacity Factor					
Class 6	50%	51%	52%	52%	52%
Class 5	44%	46%	46%	46%	46%
Class 4	39%	47%	47%	47%	47%

Source: Wind Energy Program, as reflected in *Wind Energy Program Multi Year Technical Plan, 2004 – 2010 (November 2003)*, http://www.nrel.gov/wind_meetings/2003_imp_meeting/pdfs/mytp_nov_2003.pdf

Table 5. Incremental Green Power Wind-Capacity Additions (MW)

	2005	2006-2010	2011-2015	2016-2020	2021-2025	2005-2025
ECAR	31	267	299	126	67	791
ERCT	12	139	166	83	42	442
MAAC	59	300	221	16	17	613
MAIN	19	165	185	78	41	488
MAPP	2	38	99	77	35	251
NY	39	200	147	11	12	409
NE	32	185	134	22	21	394
FL	0	0	0	0	0	0
STV	0	0	0	0	0	0
SPP	12	157	229	137	66	601
NWPP	2	35	69	57	33	196
RA	4	33	58	38	26	159
CNV	0	50	108	107	55	319
Total	212	1,569	1,714	751	415	4,661

Hydropower Program Assumptions in Support of Benefits Estimates

The hydropower program benefits, as projected in response to GPRA05 (for the FY2005 budget request), were developed from data provided by the Wind and Hydropower Technologies Program. The program has identified five opportunities for increasing generation (and installed capacity) from U.S. hydropower resources:

1. Building new capacity at untapped or underutilized high-head sites
2. Preserving capacity and generation that might otherwise be lost to relicensing processes
3. Increasing energy production through new operational procedures and increased reservoir efficiency
4. Increasing energy production at existing facilities through the implementation of advanced turbine technology
5. Building capacity at new low-head/low-power sites

For GPRA05, the analysis of the hydropower program's impacts was limited to the first three items. The program plans to perform the necessary analysis during the coming year to estimate the outcomes from the latter two items.

The program's estimates of outcomes, which serve as inputs into NEMS-GPRA05 and MARKAL-GPRA05, are provided in **Table 6**, and their basis is described below.

Table 6. Hydropower Program Estimates of Capacity and Generation (used in NEMS-GPRA05 and MARKAL-GPRA05 Integrated Modeling)

	2010	2015	2020	2025
Impact 1: Capacity Not Lost to Relicensing and Operational Review Processes (GW)	3.4	3.5	3.7	3.8
Impact 2: Generation Not Lost to Relicensing and Operational Review Processes (billion kWh)	13.1	13.5	14.0	14.4
Impact 3: Generation Increase Due to Operational Efficiencies (billion kWh)	3	6	8	9
Total Increase in Generation (billion kWh)	16	19	22	24

Capacity Growth at High-Head Sites

The NEMS-GPRA05 model, used by EERE for GPRA analyses, allows new conventional hydroelectric capacity to be built in addition to reported plans. Drawing from Idaho National Engineering and Environmental Laboratory information on U.S. hydroelectric potential, the

NEMS Electricity Market Module (EMM) contains regional conventional hydroelectric supply estimates at increasing capital costs. All the capacity is assumed available at a uniform capacity factor of 45%, which is a good estimate of the national annual average capacity factor. Data maintained for hydropower include the available capacity, capacity factors, and costs (capital, and fixed and variable operating and maintenance). Because of hydroelectric power's priority position in the merit order of generation, it is assumed that all available installed hydroelectric capacity will be used within the constraints of available water supply and general operating requirements (including environmental regulations).

NEMS-GPRA05 does not estimate pumped storage hydroelectric capacity, which is considered a storage medium for coal and nuclear power and not a renewable energy supply.

NEMS does not project the construction of any new hydropower capacity in the Energy Information Administration's (EIA) *Annual Energy Outlook 2003* (*AEO2003*) cases, due to the high cost of building new sites relative to other generating options.

Capacity Not Lost to Relicensing and Operational Review Processes

The EIA *AEO2003* "Reference Case" currently projects that, in 2005, there will be 78.8 GW installed in the United States. That number increases to 78.92 GW in 2010, and stays level after that. The Hydroelectric Power Data File in the EMM represents reported plans for new conventional hydroelectric power capacity connected to the transmission grid and reported on Form EIA-860, Annual Electric Generator Report, and Form EIA-867, Annual Nonutility Power Producer Report.

Important to note, EIA's projections are level, despite the large quantity of hydropower under review for relicensing. The GPRA hydropower analysts assume that EIA's AEO projections reflect the projected success of R&D efforts sponsored by the Office of Wind and Hydropower Technologies. This success will allow hydro-facility owners/operators to overcome regulatory impetus for plant derating and/or decommissioning.

Because the purpose of the EERE GPRA analysis is to measure the benefit of EERE program activities, the EIA *AEO2003* projections are adjusted, where necessary, to allow for representation of the "program case." The baseline, which is used to measure the program case, therefore, is the level of hydropower that would happen if no DOE-sponsored programs existed. That baseline is used for the GPRA analysis and is summarized in **Table 7**.

The amount of capacity up for relicensing is sizeable. There are currently 2,200 non-Federal projects, representing about 37 GW. This is roughly one-half the total U.S. hydropower capacity. Of the 37 GW, some 15.5 GW are due to be relicensed by the end of 2010. In the following five years, an additional 4.6 GW are due, with 1.0 GW and 2.5 GW in the two five-year increments beyond that. The total due by 2010 is 23.2 GW, or about 30% of total U.S. capacity.

The GPRA hydropower analysis uses the assumption that, by 2010—without DOE efforts—6% of the capacity (and by assumption, an equivalent percentage of generation) of plants up for relicensing during that period would be lost. The 6% estimate of recovered generation is based on an inventory of all plants that will have their licenses renewed during the analysis period. By 2025, program efforts would save 6% of the generation from of an additional 7.8 GW, which is the amount subject to relicensing between 2011 and 2025. Values for intervening years are interpolated.

In addition, the 41 GW of Federal facilities, while not subject to FERC relicensing, are subject to continual review for the same issues. The 6% saving factor, therefore, is assumed to also apply to Federal facilities.

It should be noted that, although assumed to be true for this analysis, a 6% reduction in the 2010 capacity is not necessarily equated to a 6% loss in generation, because relicensing stipulations might require different water-flow management strategies. However, for simplicity, that assumption was made for GPRA05. As a further simplification, the GPRA05 model runs did not attempt to capture regional effects. For GPRA06, the program will attempt to capture regional variations, which, while having little or no effect on the hydropower projections for annual generation, could have some implications for the use of other renewables and conventional fuels.

Improved Operations

An additional effect of the program activities is expected to result from improved operation of reservoirs. Generation can be increased at a given plant by optimizing a number of different aspects of plant operations. These include settings of individual units, multiple-unit operations, and release patterns from multiple reservoirs. This is a new opportunity for the program that responds to requests from industry and environmental interests.

Table 7. Relicensing Data and Assumptions

Total U.S. Hydro Capacity (2004)	78 GW	AEO 2003 Data
Non-Federal U.S. Hydro Capacity (2004)	37 GW	FERC Data
Capacity up for relicensing 2004-2010	15.4 GW	Based on FERC data; ~20% of total U.S. hydro capacity
Capacity up for relicensing 2011-2015	4.6 GW	Based on FERC data
Capacity up for relicensing 2016-2020	1.0 GW	Based on FERC data
Capacity up for relicensing 2021-2025	2.2 GW	Based on FERC data
Capacity up for relicensing 2004-2025	23.2 GW	Based on FERC data
Federal Capacity Under Review	41 GW	All Federal capacity subject to environmental review
Program GPRA Assumption for capacity saved in 2010	6% of capacity up for relicensing and 6% of all Federal capacity, or 3.4 GW	Generation is assumed to be also increased by 6%.
Program GPRA Assumption for capacity saved in 2025	6%, of capacity up for relicensing and 6% of all Federal capacity, or 3.8 GW	Generation is assumed to be also increased by 6%.

FERC Source (November 2003): http://www.ferc.gov/industries/hydropower/gen-info/projlic.PDF

There are significant technical challenges that need to be addressed in this effort, including improved hydraulic measurements. Also, an integrated approach to energy and environment will be applied in this research, ensuring that the multiple objectives of environmental quality and energy production are achieved together. The need to improve the scientific basis for decisions concerning water management at hydropower dams and reservoirs is becoming increasingly acute as competition over limited water resources escalates throughout the United States.

Experience from TVA's hydropower improvement programs has demonstrated that energy production can be increased 30% or more through a combination of equipment upgrades and optimizing operations. Other expert opinions from the hydropower industry estimate average improvements of at least 10%. **Figure 3** shows hydropower operational data from TVA's hydropower system for the period 1956 to 1997, before and after implementation of a series of improvement programs that replaced older equipment with advanced technology, and optimized operations at levels ranging from individual units to series of reservoirs.

For the GPRA05 analysis, the program has chosen as its goal the modest improvement by 2010 of 3 billion kWh (or 1% of total U.S. hydropower generation). It should be noted that the overall program goal for increased generation at existing plants is 10% by 2010, of which operational improvements are 4% component, and the introduction of new turbine technology is another 6%. For GPRA05, the generation increase from operational improvements is assumed to grow to 3% of the U.S. total generation. This value of 3% is still short of the program goal—and, thus, is a conservative understatement of the program impact.

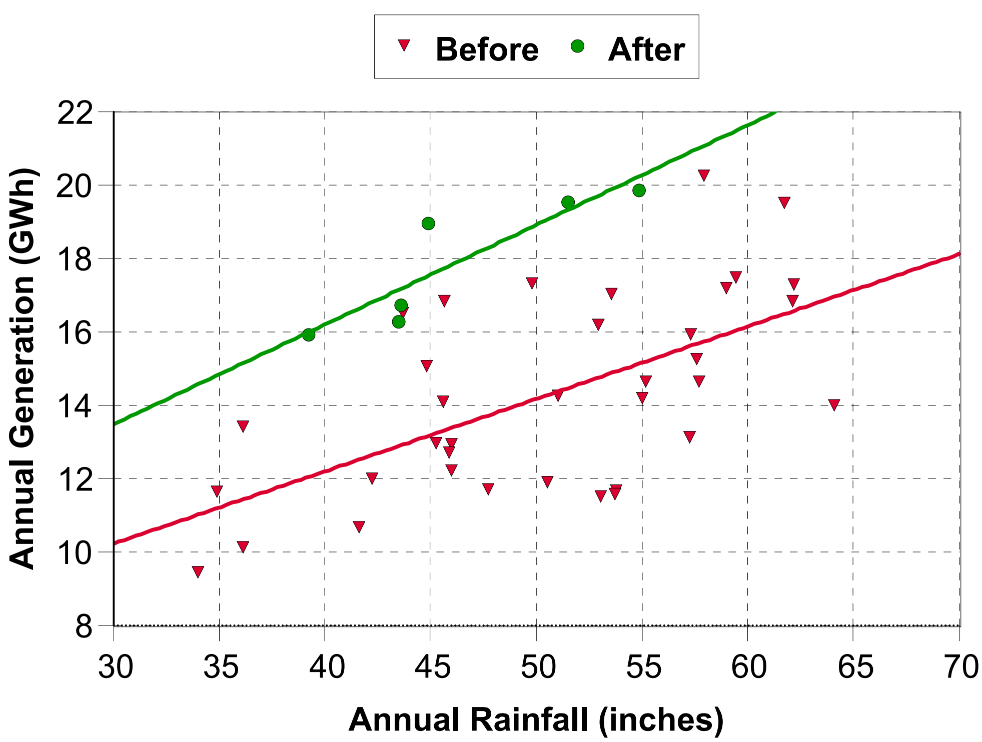


Figure 3. Data from TVA's Hydropower Improvement Program