Appendix D – GPRA05 Distributed Energy Program Documentation

Program Objective

The major programs modeled for DE include:

Industrial Gas Turbines
Advanced Microturbines
Gas-Fired Reciprocating Engines
Thermally Activated Technologies
Distributed Energy Systems Applications Integration
Cooling Heating and Power Integration
The Technology Base – (Advanced Materials and Sensors is not modeled directly because its benefits are represented in the other programs).

Methodology and Calculations

Because the time horizon of the *Annual Energy Outlook 2003* Reference Case (AEO-3 case) version of the National Energy Modeling System (NEMS) is 2025, and the goals of Distributed Energy (DE) programs are relatively short-term, the approach taken in this GPRA cycle is that most of the outputs are captured before that date. However, DE programs are part of a wider effort to transform the power system from its current highly centralized form to a more robust decentralized paradigm, a transformation with a longer time horizon than NEMS-GPRA provides.

Distributed generation (DG) appears in multiple modules (roughly corresponding to subsectors of the full energy sector, i.e. utility, commercial, etc.), which hinders the DE program's use of NEMS-GPRA. Further, only a limited number of technology slots are typically available to represent a broad array of equipment types, sizes, and configurations. For example, the reciprocating engines in the commercial sector all have combined heat and power (CHP) heating (but not cooling) capability, while those in the utility sector do not—in some instances, engines without CHP might be attractive in the commercial sector and vice-versa. Proper representation of DE program goals includes an accurate representation of DE's technology-advancement targets, as well as an accounting for the limitations in the structure of NEMS, which can hinder estimation of the benefits that can be realized from DG technologies. Therefore, in addition to changing input assumptions relative to the AEO-3 version of NEMS, other *fixes* to perceived limitations or omissions are also appropriate in both the base and program cases.

Inputs to Base Case

Expectations of improvements in technologies embedded in the AEO-3 reference case, which presuppose existence of DE programs, need to be eliminated from the base case (referred to as the baseline) for comparisons with achievement of program goals. Two full sets of forecast scenarios are actually needed, *with* and *without* DE programs in place; and the AEO-3 case is likely, although not certain, to fall between. In the FY 2005 GPRA (GPRA05), the baseline case generally corresponds to the AEO-3 reference case, though there are exceptions as described below. Estimation of the benefits of the programs is based on a comparison of the *baseline* and *program* scenarios. In this analysis, both scenarios were effectively estimated together, as two deviations from the AEO-3 case—therefore, they are presented together in the following section.

NEMS-GPRA Inputs

NEMS-GPRA input specifications follow by program, and all are summarized in **Table 3**. Inputs for each program are briefly described in the following sections.

The AEO-3 case and prior GPRA forecasts were compared with a draft of the National Renewable Energy Laboratory's (NREL) and Gas Technologies Institute's Technology Characterizations (TeChars) for three technologies: microturbines, gas engines, and industrial gas turbines. Further data from the subsequent revisions released at a July 2003 workshop in Washington was used, together with some responses to the TeChars draft. With a few noted exceptions, technology cost and *electrical* efficiency inputs are derived both from the TeChars and from DE program goals, while *combined* efficiency values are derived from other sources. The TeChars is now finalized and available.[1]

To simplify and clarify the graphs, not all generator capacity sizes are shown. The technology inputs for baseline and program cases generally correspond to the same-sized units as NEMS-GPRA uses—though, in some instances, the GPRA05 inputs correspond to larger systems, i.e. when the standard AEO-3 capacity is unrepresentative. For clarification, a summary table of technology type, module, and nameplate capacities represented in the AEO-3 case —and corresponding nameplate capacities for GPRA05 technology inputs—is included in **Table 1**.

Table 1. Summary of Technology Size Representation by Module

Technology Type	Module	Representative Size in NEMS	Corresponding Size in GPRA05
Gas Turbine	Commercial	1 MW	5 MW
	Industrial	1 MW, 5 MW, 10 MW	1 MW, 5 MW, 10 MW
	EMM	2 MW	5 MW
Microturbine	Commercial	100 kW	Baseline: 200 kW in 2015, 500 kW in 2025 Program: 200 kW in 2005, 500 kW in 2010
Gas Engine	Commercial	200 kW	800 kW
	Industrial	800 kW, 3 MW	800 kW, 3 MW
	EMM	1 MW	800 kW

[1] Goldstein, Larry, Bruce Hedman, Dave Knowles, Steven I. Freedman, Richard Woods, and Tom Schweizer, (November 2003). "Gas-Fired Distributed Energy Resource Technology Characterizations," NREL/TP-620-34783.

While many of the technology inputs reflect the achievement of DE program goals in 2010, the exact replication of this time frame is not always possible because of certain model constraints. For example, technological progress in the *commercial* module is limited to a step-function advance, and input values are updated on a five-year time step. These limitations are shown graphically below, where applicable.

Industrial Gas Turbines

Gas turbine sizes in NEMS-GPRA range from 1 to 40 MW, and explicitly appear in the commercial and industrial demand modules, and less definitively in the utility electricity market module (EMM), where the technology type is defined generically as either a base-load or peak system. The industrial-sector turbines cover a wide size range, but proposed inputs to the FY05 GPRA process focus on the 1 MW-, 5MW-, and 10 MW-size systems. The commercial sector contains a single representative turbine sized at 1 MW. The inputs for the commercial turbine were adjusted to reflect the range of sizes that will likely be adopted in that sector. The baseline and program case inputs for the commercial sector correspond to the 5 MW system shown in the graphs below. Also, the 2 MW base-load EMM generator is represented as a gas turbine.

The *baseline* input values for gas turbines reflect a 1% improvement in electrical efficiency for 1 MW, 5 MW, and 10 MW turbines, relative to the TeChars values. There is no cost difference between baseline and program cases. Finally, baseline combined efficiencies are derived from an unpublished source, and are below AEO-3 values.

The *program* input values are the TeChars values for cost and electrical efficiencies. The main objective of this program currently is NOx and CO emissions reduction; but, because these are not reported metrics, forecasts for these improvements are not included here.

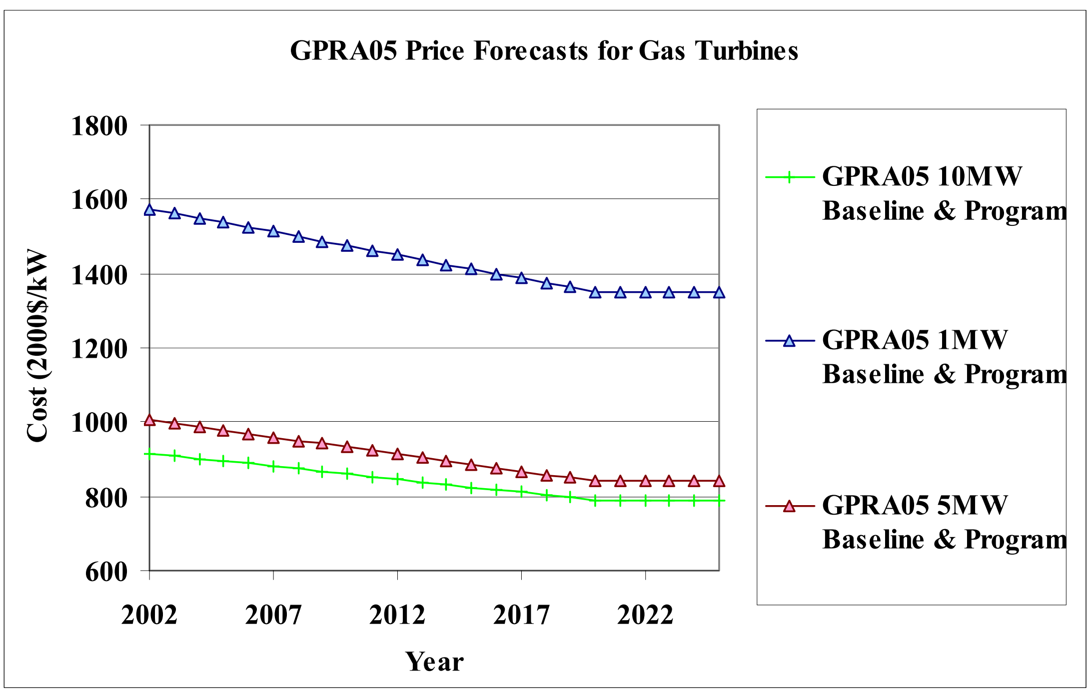

Figure 1. Industrial Gas Turbine Installed Cost (2000 $/kW)

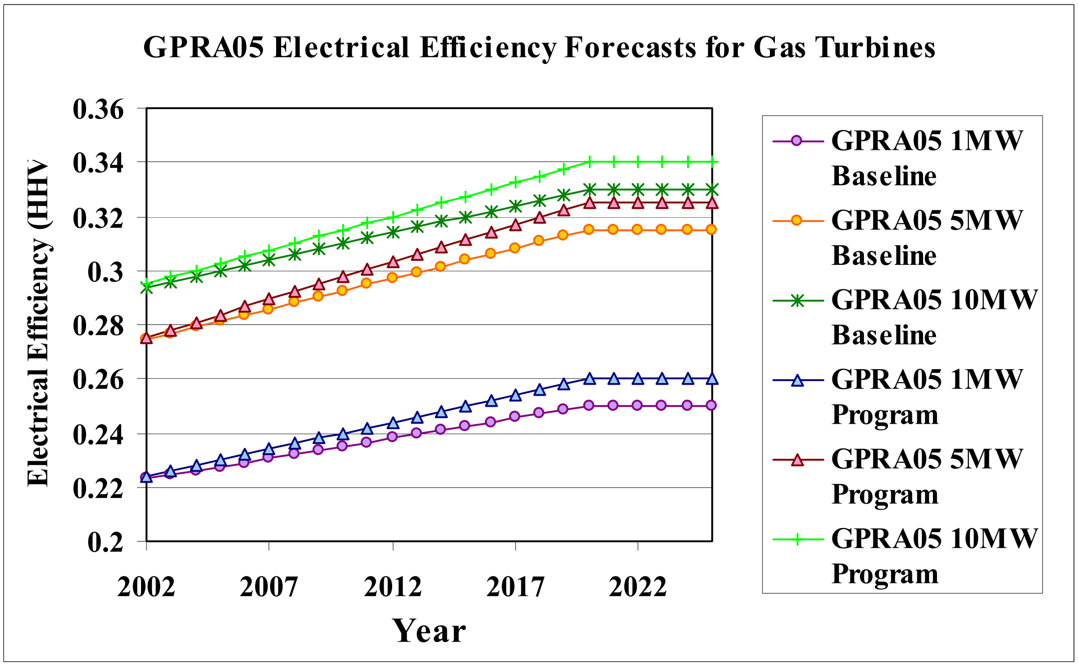

Figure 2. Industrial Gas Turbine Electric Efficiency

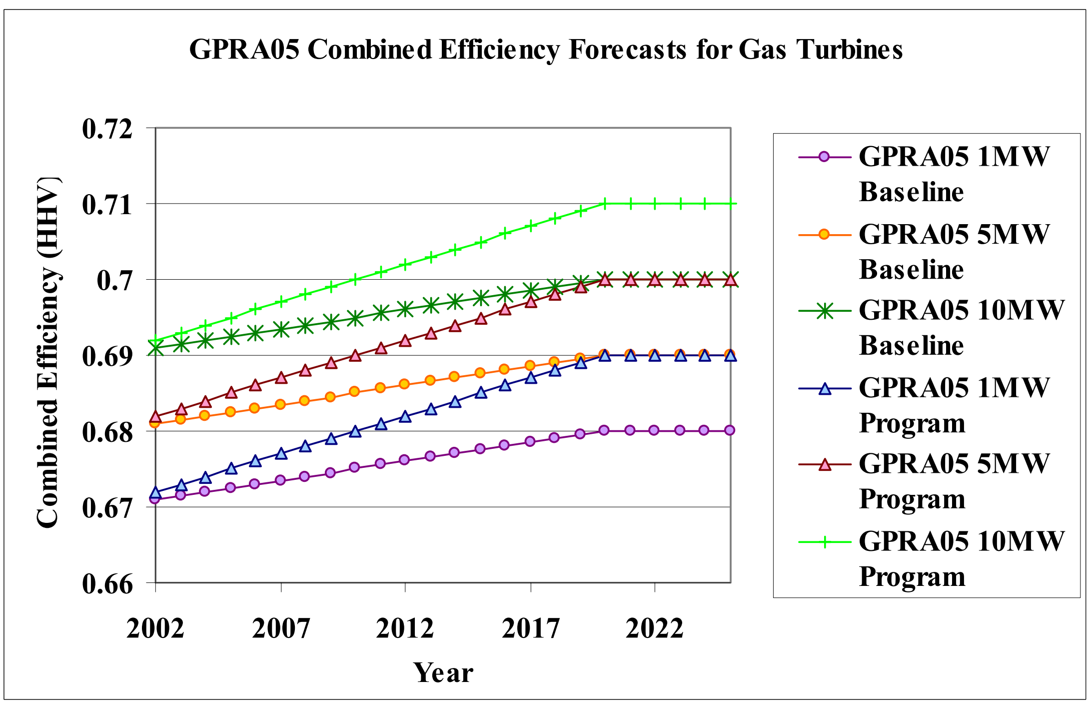

Figure 3. Industrial Gas Turbine Combined Efficiency

Advanced Microturbines

Microturbines occur only in the commercial module as a representative 100 kW system. Therefore, NEMS-GPRA is failing to capture two key aspects of this emerging technology. First, it is likely to be deployed in other sectors; for example, its tolerance to low-quality fuel makes it highly attractive for landfill and sewage-treatment gas applications. Second, larger-sized microturbines are emerging and promise higher efficiencies and lower costs than the NEMS-GPRA representative 100 kW unit. Little can be done directly to rectify the first problem in this GPRA cycle, but the future availability of larger sizes is represented by dramatically improved performance of the 100 kW unit after 2010.

The *baseline* input values for costs and electricity conversion efficiency are the AEO-3 assumptions. Combined efficiencies are higher than the AEO-3, hitting 70% by 2020.

The *program* input values are a 40% simple efficiency and a target $575/kW first cost by 2010, and then remain flat.[2] Combined efficiency values reach 72% by 2020.

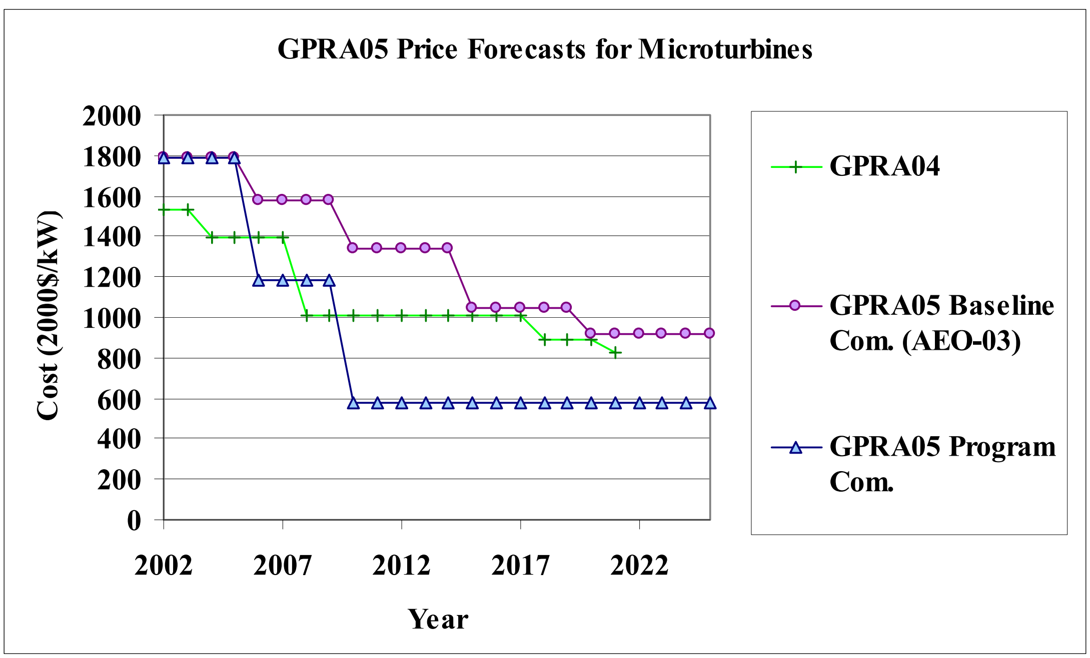

Figure 4. Microturbine Installed Cost (2000 $/kW)

[2] The Advanced Microturbines Program goal is $500/kW, and these inputs are based on an additional first cost for CHP-enabled systems.

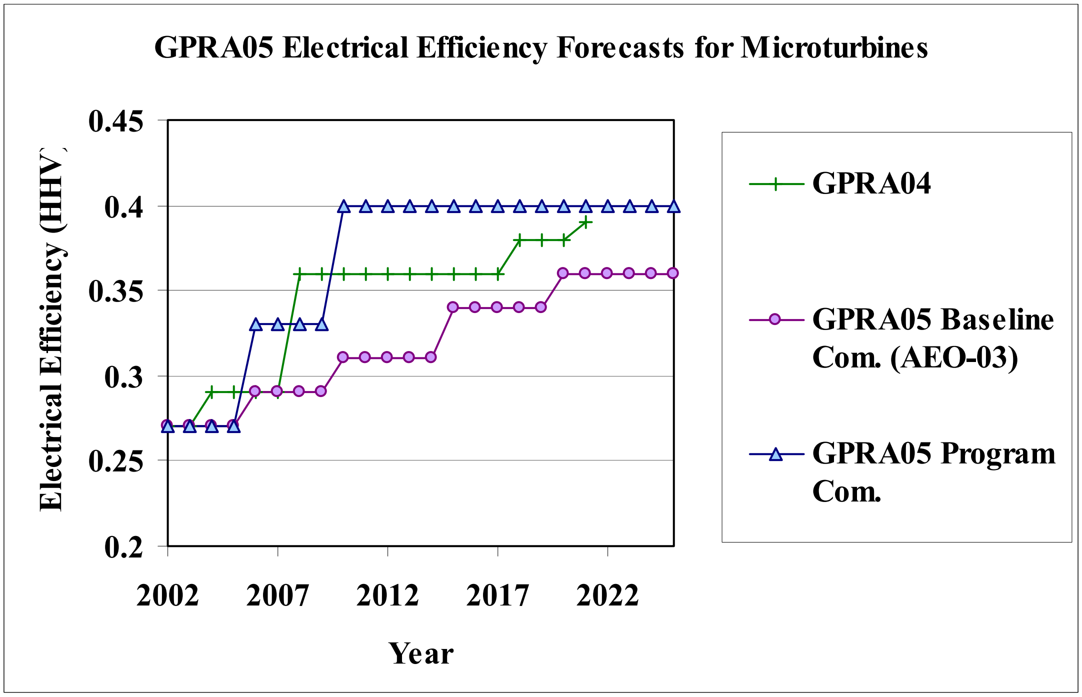

Figure 5. Microturbine Electric Efficiency

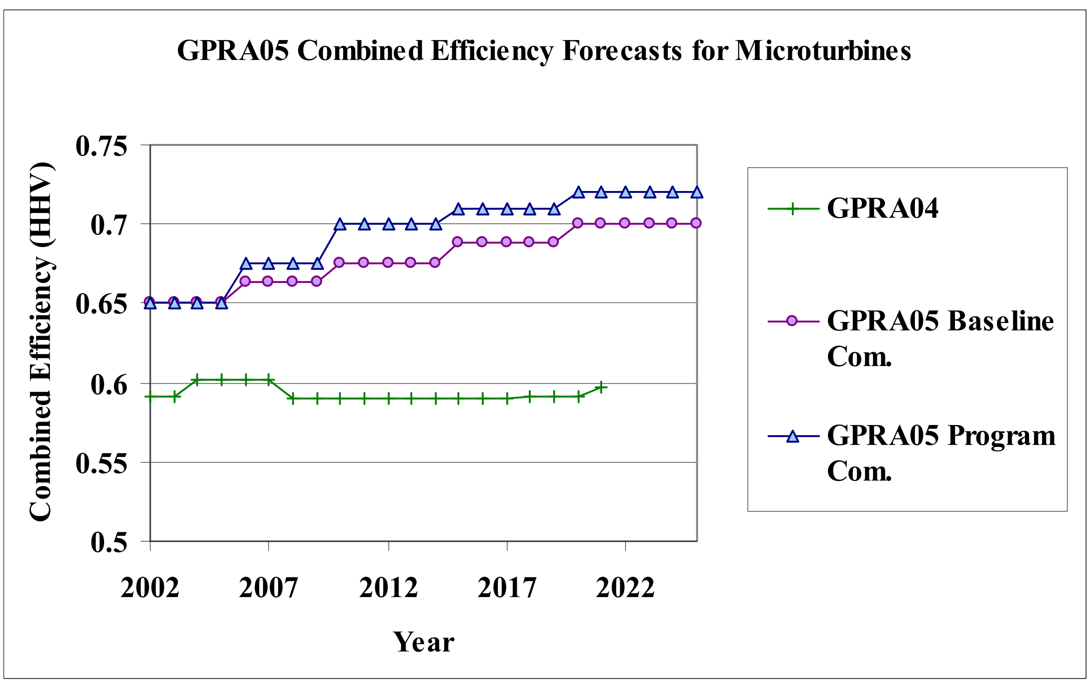

Figure 6. Microturbine Combined Efficiency

Gas-Fired Reciprocating Engines

Gas engines appear in several modules in NEMS, in both CHP and simple-cycle configurations—but only one or two marker models represent the wide range of available engines (see **Table 1**). The limited number of available technology slots—together with the maturity and clear attractiveness of gas engines in many configurations—makes the choice of inputs for this technology somewhat complex.[3] The commercial module has a marker 200 kW CHP-enabled unit, the industrial module has 800 kW and 3 MW CHP-enabled units, and the 1 MW unit that appears in the EMM is also taken to be a simple-cycle gas engine.

The *baseline* input values for costs and electricity conversion efficiency are the AEO-3 assumptions. Combined efficiencies deviate significantly from the AEO-3.

The *program* input values for both the commercial-sector engine and the 800 kW industrial-sector engine are a 40% simple efficiency and a target $570/kW first cost by 2010, combined with a 71% combined efficiency by 2020. Again, this target represents improvements resulting from the program, as well as the emergence of larger engines available in the commercial sector. The 3 MW system in the industrial module has equivalent 50% electric efficiency and $500/kW targets by 2010, and 69% combined efficiency values by 2020.

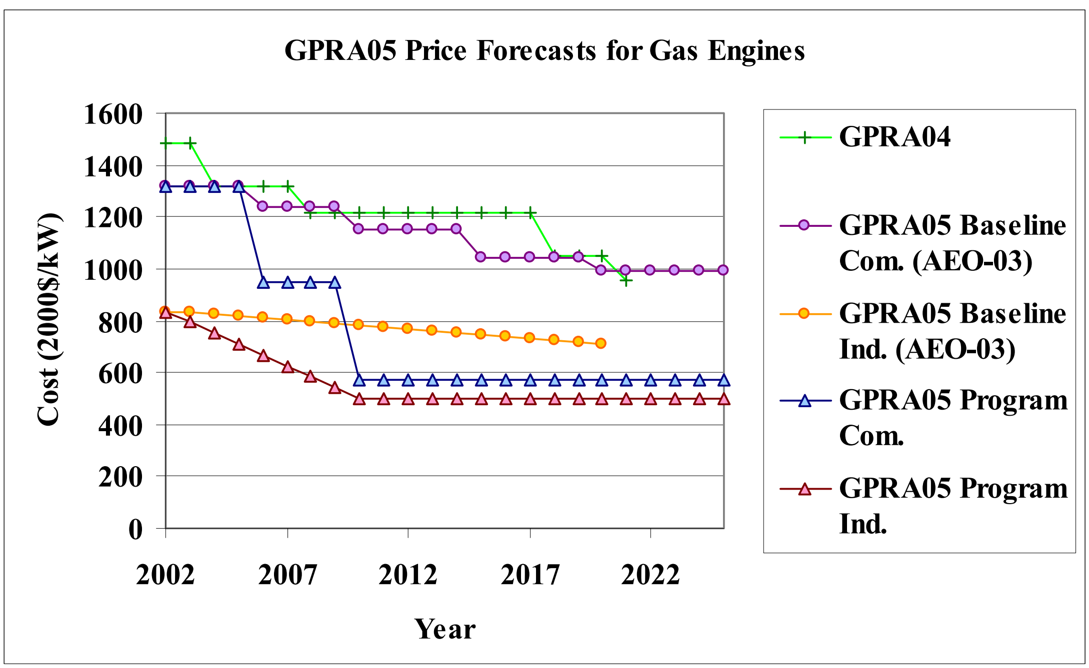

Figure 7. Gas Engine Installed Cost (2000 $/kW)

[3] Heat recovery can be from exhaust gas or jacket coolant, and a promising CHP application is absorption- cycle cooling, which is non-existent in NEMS-GPRA.

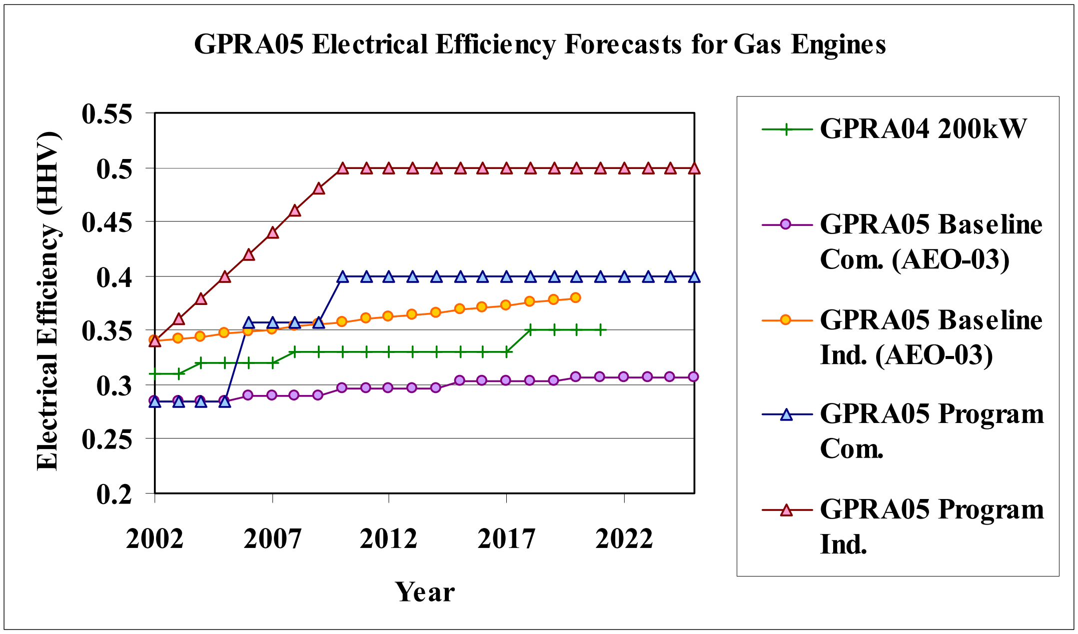

Figure 8. Gas Engine Electric Efficiency

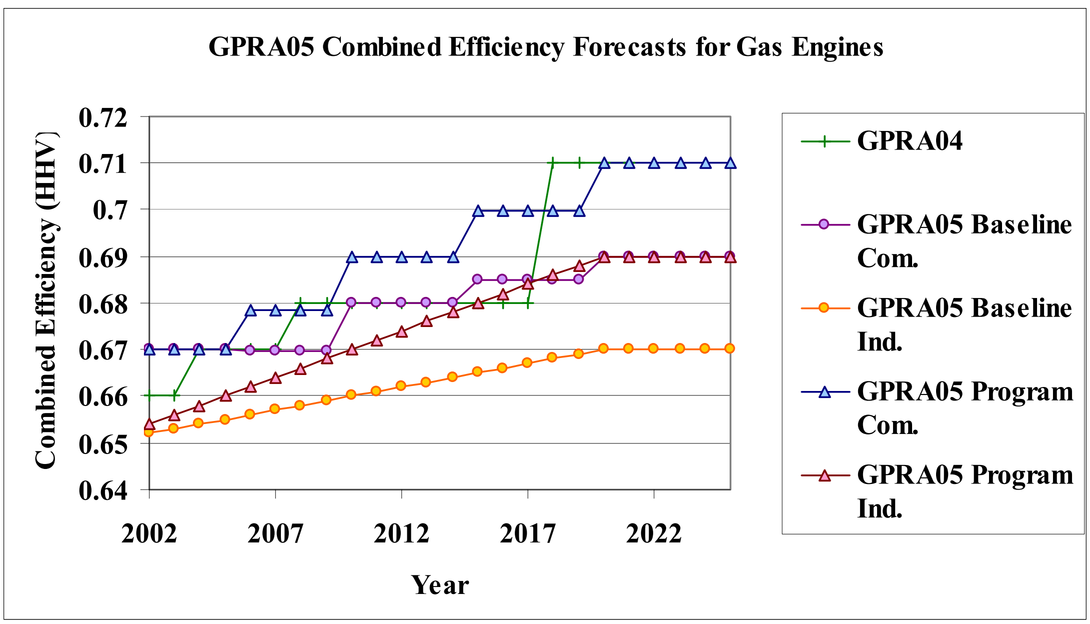

Figure 9. Gas Engine Combined Efficiency

Technology Representation in the Utility Sector (Electricity Market Module)

The EMM contains two generic DG technologies: a 2 MW base-load system and a 1 MW peak-load system, neither with CHP capability. Baseline and program representation of these technologies will correspond to a gas engine for the peak system (using the 800 kW system values stated above) and a gas turbine for the base system (using the 5 MW system values stated above). Although CHP applications may be attractive to utilities, DG systems in the EMM do not include heat-recovery components, and therefore projected technology costs are slightly lower.

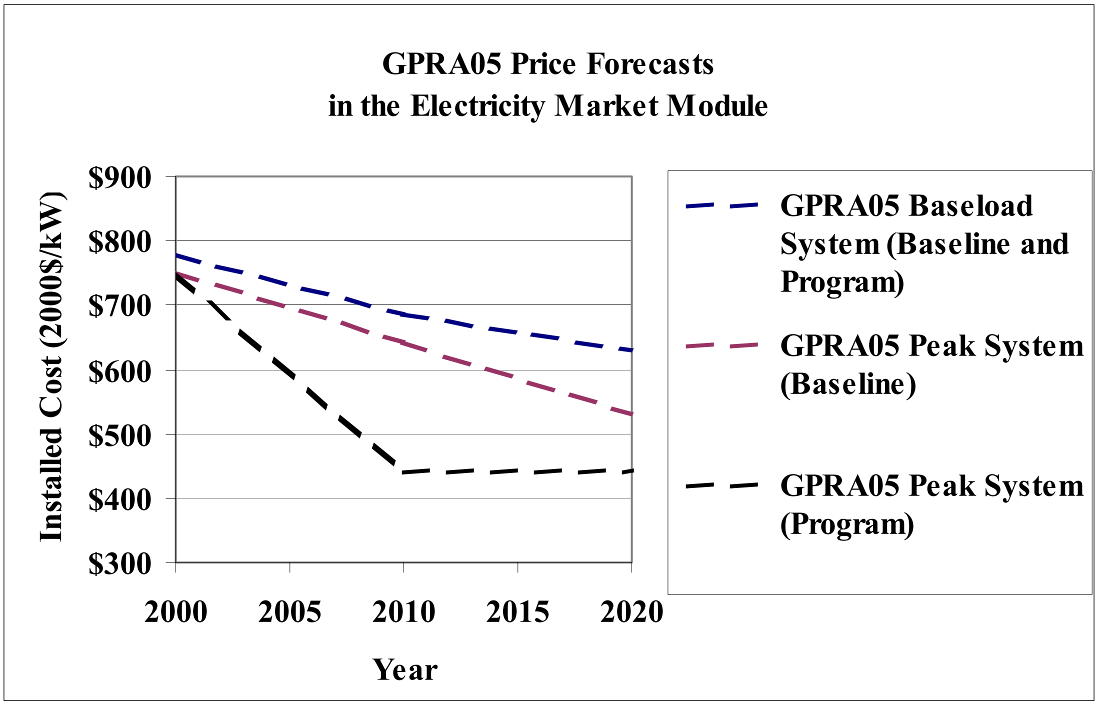

Figure 10. Electricity Market Module Installed Cost

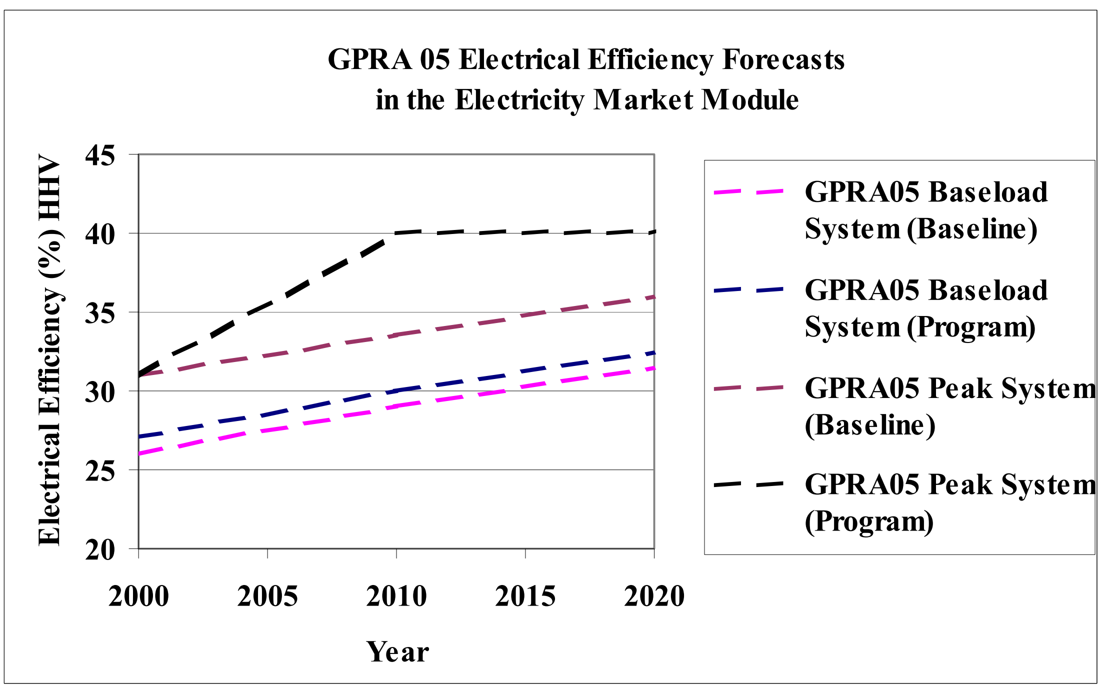

Figure 11. Electricity Market Module Electrical Efficiency

Advanced Materials

No separate inputs to represent this program are proposed. The benefits of this activity are represented in the preceding technology-development activities.

Thermally Activated Technologies

DE's thermally activated technologies program includes direct-fired absorption chiller technologies and desiccant dehumidification systems. Only the former are represented here as changes applied to gas-fired absorption chillers in the commercial technology input file.

The NEMS-GPRA commercial module represents the commercial building stock using 11 representative building types. Of these, the commercial technology input file restricts gas-fired absorption chillers from being installed in the following building types: food sales, food service, small office, warehouse, and other. These restrictions are removed for both the baseline and program cases to allow small commercial-sized systems to be installed in all buildings.

The assumptions for the program case inputs include: cost-improvement data taken from Resource Dynamics' study of integrated energy systems[4] with future cost values (2005+) available in 2010; double-effect chillers are approximately 1.5 times the cost of single-effect chillers; and technology costs correspond to 50–100 cooling ton[5] range.

The *baseline* case, based on a double-effect chiller introduced in 2020, uses cost assumptions from the AEO-3.

The *program* case is based on a double-effect chiller introduced in 2005.

Table 2. GPRA 05 Inputs for DE's Thermally Activated Technologies Program

	Baseline Case			Program Case		
Year	COP	Cost ($/kBtu/hr)	Cost ($/Ton)	COP	Cost ($/kBtu/hr)	Cost ($/ton)
2000	0.7	78.75	945	1	78.75	945
2005	1	78.75	945	1.2	59.08	709
2010	1	78.75	945	1.2	53.50	642
2020	1.2	78.75	945	1.4	42.50	510

[4] LeMar, P. (August 2002). "Integrated Energy Systems (IES) for Buildings: A Market Assessment," Resource Dynamics.

[5] *1 cooling ton is equal to 12,000 Btu/hr or approx 3.5 kW thermal.*

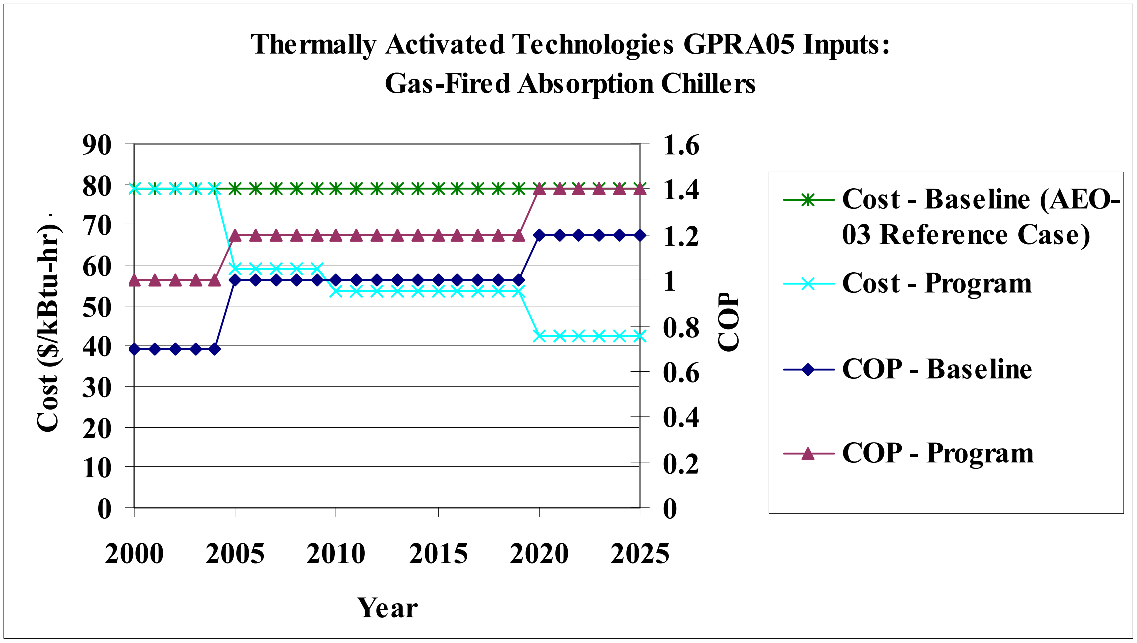

Figure 12. Thermally Activated Cooling Technology Inputs

Distributed Energy Systems Applications Integration

The Distributed Energy Systems Applications Integration (DESAI) Program' strives to accelerate adoption of DG technologies in certain sectors, especially among the existing building market (i.e. through retrofits). The NEMS model calculates DG adoption in *existing* buildings as a set share of the adoption in *new* buildings, and that share is set at 2% in the AEO-3 reference case. Because the retrofit market is the primary target of the DESAI Program, the outputs are represented by an increase in the cap on the share of existing commercial sites that can adopt DG.

The *baseline* input values are achievements of cost and efficiency targets by 2010, as described above in Sections 0–0. The existing building adoption rate is 2% of new buildings, equivalent to the AEO-3 value.

The *program* input values increase the share of existing buildings eligible to adopt DG from 2% to 10% of new buildings.

As part of the DG adoption logic fixes described in Section 9, additional changes to the new building adoption parameter were made in addition to the DESAI Program representation.

Cooling Heating and Power Integration

This program develops improved CHP packages and otherwise supports the market penetration of CHP technologies, including indirect-fired absorption chillers. Because NEMS-GPRA does not have a representation of indirect-fired absorption chillers, this program is represented by a proxy improvement in the payback period of the prime mover technology equivalent to the economic benefit of using 25% of the generator waste heat for a cooling end use.

The *baseline* input values are AEO-3.

The *program* input values are a reduction of one year of payback for the three prime movers. This payback reduction is calculated to be the effect on whole-system payback for an increase in absorption chiller COP from 0.7 to 1.2.

DG Adoption Logic Fixes

Two fixes were made to the DG adoption logic of new buildings in the commercial sector of NEMS-GPRA for both baseline and program cases. The adoption algorithm for DG in new buildings caps the maximum market adoption rate (the *penparm* parameter*)* at 30%for a one-year payback level. The cap on adoption rates for different paybacks (max *pen)* decays as an inverse function at a rate of 1/years to positive cash flow, and this decay is known as the payback acceptance function (shown as equation 1 below).

$$\max pen = \frac{penparm}{payback} \quad (1)$$

This approach severely disfavors technologies with paybacks that are moderate but still quite acceptable to many building owners—such as in the three- to six-year range—while it allows smaller adoption at very long paybacks, such as 15 years.

First, the cap for new buildings with a one-year payback (represented by the *penparm* parameter) is raised from 30% to 50%. A similar change was made in the GPRA04 analysis.

Second, the payback acceptance function is changed from an inverse decay function to one based on data of observed customer adoption of energy efficiency projects as a function of simple payback time[6]. These data are shown below for buildings in the institutional sector (n=768) and commercial buildings in the private sector (n=108).

[6] *Market Trends in the U.S. ESCO Industry: Results from the NAESCO Database Project*. Goldman, C., J. Osborn and N. Hopper, LBNL, and T. Singer, NAESCO, May 2002, LBNL-49601.

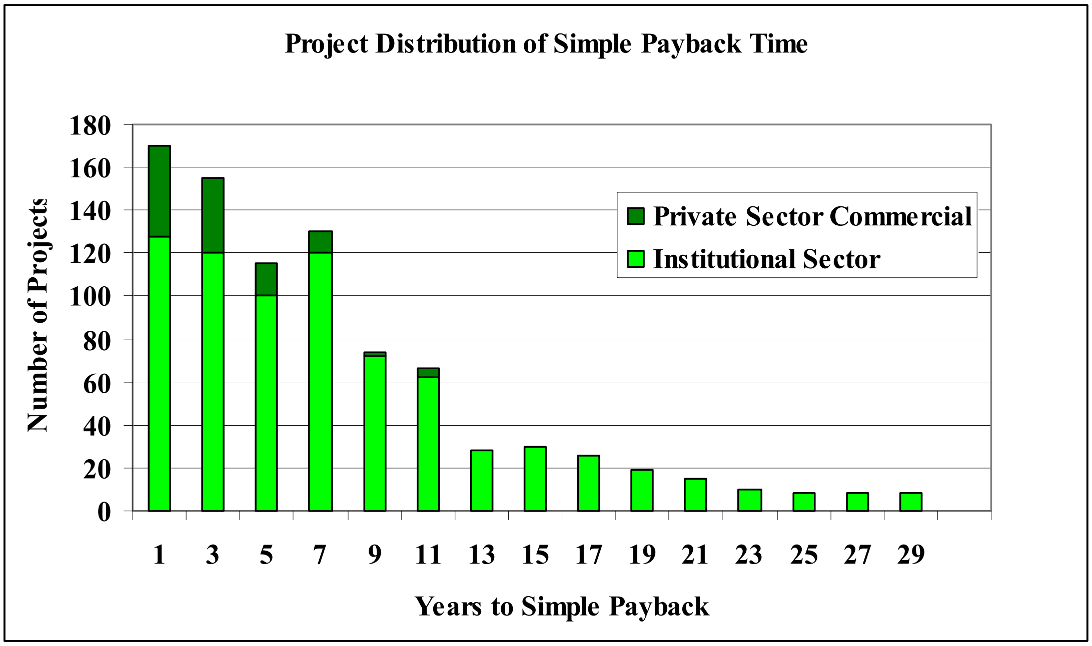

Figure 13. Distribution of Years to Simple Payback

To determine a decay function for the max *pen* based on this data set, the percentage of potential adopters from the total sample for each given payback year is calculated. It is assumed that for a given payback year, all of the adopters in that year and all adopters of projects with shorter payback periods would adopt, i.e. all columns are summed to the right in **Figure 13**. For example, all adopters of projects with 29-year paybacks also would adopt projects with 27-year paybacks, 25-year paybacks, etc. The resulting customer-acceptance curve is shown in **Figure 14**, along with the mathematical representation of the revised curve for input to NEMS-GPRA and the current equation used in the AEO-3. **Figure 14** shows that a maximum of 100% will adopt, and this represents 100% of the sample size; however, in NEMS-GPRA, the percentage of the total population that actually will adopt is scaled down using the *penparm* parameter (set at 50% for GPRA05), as discussed above.

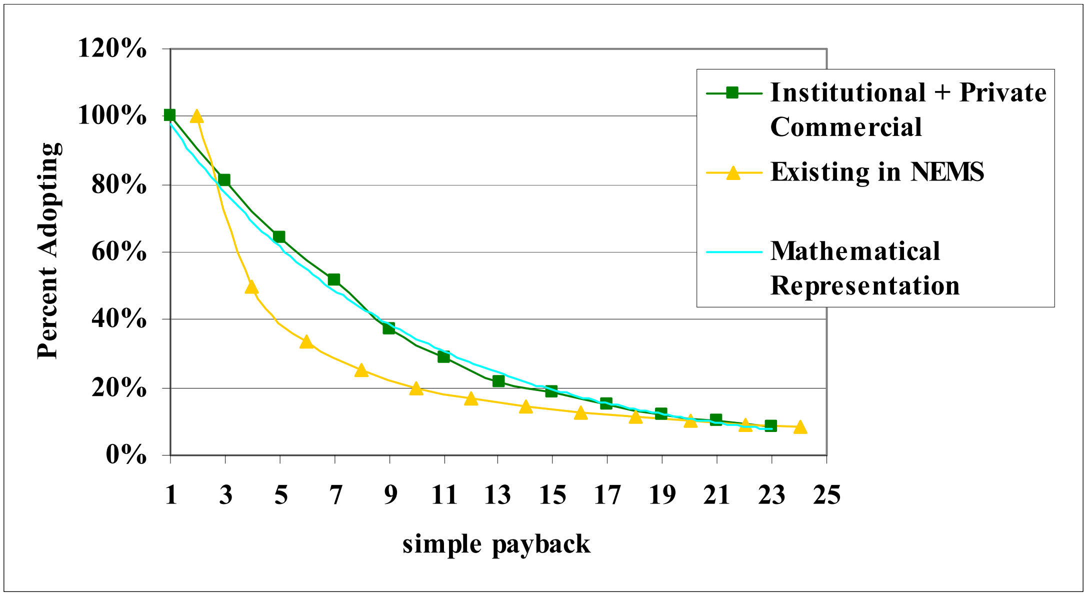

Figure 14. Decay Function of the Maxpen

Because NEMS-GPRA uses years to positive cash flow[7] (rather than payback period) as the primary metric of DER adoption, the data in Figure 14 has been converted to this metric by dividing the simple payback time in half. Justification for this conversion was determined by a simple spreadsheet analysis, using the financing assumptions that are used in NEMS-GPRA. Ultimately, the decay above is represented by equation 2 below as a function of the *payback* variable as defined in NEMS-GPRA:

$$\max pen = \frac{1.1 penparm}{e^{0.24\, payback}} \quad (2)$$

Two additional NEMS-GPRA fixes have been implemented in the base and program cases to ensure that the changes to the adoption logic described above do not result in an exaggerated number of DG adoptions. First, a fix to the model developed by OnLocation, Inc., subtracts the share of existing buildings that already have adopted DER systems from the pool of eligible existing buildings to prevent oversaturation of the market. Second, an internal check is included to ensure that the percentage of existing buildings that have DER systems installed will not exceed the cap imposed on new buildings. This will prevent a case where the installations in new buildings are not allowed to reach the rate of existing buildings.

The NEMS-GPRA fixes, along with additional minor changes, are summarized in **Table 4**.

[7] The NEMS *payback* (or *simple payback)* variable is defined as the first year in the cash-flow stream for which an investment has a positive cumulative net cash flow. *(EIA, NEMS Commercial Module Documentation Report 2003)*

Market Uptake

No wider market potential or penetration analyses were done exogenously to NEMS-GPRA for this work. The market definition and penetration rates for DG are those that are endogenous to NEMS-GPRA, and these are described briefly here for the EMM and the commercial-demand module.

In the EMM, the market is driven by the growing electricity-demand forecast and the deferred cost of transmission and distribution (T&D) expansion. The two available DER generators (the peak and base-load units) compete against the cost of central-station generation and T&D upgrades to supply growing demand and replace retiring generating capacity. The total capacity of DG is constrained to correspond to a specific level of avoided T&D costs, indicating that there is a maximum economic value of T&D deferrals that DG can provide.[8]

In the NEMS commercial sector, the market is represented by 11 building types and is disaggregated into the nine geographic census divisions. Annual penetration into the new-building market is determined by the economic attractiveness of on-site generation with heat recovery relative to the purchase of electricity and other fuels. The retrofit market is not characterized distinctly, and the market adoption is simply proportional to the new-building adoption. Distributed generation adoption in the commercial sector is dominated by a few building types. The education, lodging, and mercantile/service sectors account for the large majority of DG capacity additions from the DE program. Regional DG adoption is distributed more evenly among census divisions, though the Pacific and Middle Atlantic regions account for a larger share of DG adoption, partly because of the higher electricity demand and prices forecasted for those regions.

Because DG market segments are broadly characterized in NEMS, an accurate representation of niche market adoption is difficult to include exogenously in NEMS-GPRA. Several niche market segments that contribute to the total market for DG (such as markets for reliability, security, or environmental benefits) are not represented in NEMS-GPRA.

[8] Energy Information Administration (2003). “The Electricity Market Module of the National Energy Modeling System: Model Documentation Report,” U.S. Department of Energy, Washington, D.C. pg.91.

Table 3. Summary of DE Program and Baseline Representation in GPRA05

	DE Program	Program Goals	Representation in NEMS-GPRA	
			Baseline	Program
Technology Development	Industrial Gas Turbines	38% electric efficiency, <10% cost increase, <5 ppm NOx by 2007	Industrial module: 1% reduction in electrical efficiency for 1, 5, and 10 MW systems; combined efficiency values at 68%, 69%, and 70% respectively by 2020. Commercial module set to 5 MW values	Industrial module: NREL TeChars for 1, 5, and 10 MW system; combined efficiency values at 68%, 69%, and 70% respectively by 2010. EMM baseload unit considered a 5 MW turbine without CHO capability. Commercial module equivalent to 5 MW values.
	Advanced Microturbines	40% electric efficiency < $500/kW NOx < 7ppm	AEO-3; 70% combined efficiency by 2020	40% electric efficiency, $575/kW, 72% combined efficiency by 2010[9]
	Gas-Fired Reciprocating Engines	45% electric efficiency (HHV) $400-450/kW 0.13 g/kWh	AEO-3; 69% combined efficiency in commercial module by 2020, 67% combined efficiency in industrial module by 2020	200 kW commercial module and 800 kW industrial module units: 40% electric efficiency, $570/kW, 69% combined efficiency by 2010; Industrial module 3 MW unit: 50% electric efficiency, $500/kW, 67% combined efficiency by 2010[10]; EMM 1 MW peaker unit treated as an 800 kW engine.
	Technology Based-Advanced Materials and Sensors	Advanced material research to assist in other program goals	No additional changes	Included in acceleration cases represented by End-Use Integration programs
	Thermally Activated Technologies	Cost and efficiency improvements for direct-fired absorption chillers	COP of 1.2, $78.75/kBtu-hr by 2020; allow installations in all building types	COP of 1.4, $42.50/kBtu-hr by 2020; allow installations in all building types

[9] Cost and electrical efficiency values from program goals; combined efficiency values from NREL 200 kW system. (NREL Technology Characterizations Workshop of Analysts and Modelers, Washington DC, July 9, 2003)

[10] Cost and electrical efficiency values from program goals, scaled for different system sizes in different NEMS modules; combined efficiency values from NREL 300 kW system in the commercial module and NREL 3 MW system in the industrial module. (NREL Technology Characterizations Workshop of Analysts and Modelers, Washington DC, July 9, 2003)

	DE Program	Program Goals	Representation in NEMS-GPRA	
			Baseline	Program
End-Use Integration	Distributed Energy Systems Applications Integration	Demonstration and integration projects in industrial sector, high-tech industry, hospitals, and other commercial sectors.[11]	Percent of existing buildings that adopt DER set at 2% of new buildings (same as AEO-3)	Percent of existing buildings that adopt DER increased to 10% of new buildings.
	Cooling Heating and Power Integration	Added 8 GW electric capacity and 10 GW thermal capacity in buildings by 2010[12]; advance the use of indirect-fired absorption chillers in buildings	Chiller COP assumed to be 0.7	Chiller COP increase from 0.7 to 1.2, implemented as a 1-year payback reduction of prime mover coupled with electricity use reduction in commercial demand module that is yet to be determined.

[11] The National Accounts Energy Alliance focuses on “Fortune 1000, national chain end-users, including the retail, supermarket, food service, hotel, and healthcare industries.”
[12] http://www.eere.energy.gov/der/thermally_activated/related_programs.html

Table 4. Additional NEMS-GPRA Enhancements for both the Baseline and Program Cases

Change	Module	Program or Baseline	Implemented in NEMS-GPRA	Source/Rationale
Maximum Annual Penetration Caps for New Buildings	Commercial	Both	*Penparm* parameter currently set to 30%, change to 50%	Change made in GPRA 04
Maximum Annual Penetration Caps for Existing Buildings	Commercial	Both	Remove penetration cap of 0.25% new building penetration	Additional methods are implemented to prevent oversaturation in existing buildings
Falloff of Maximum Annual Penetration Caps as a Function of Payback Years	Commercial	Both	Currently set as an inverse function: $\max pen = \frac{penparm}{simplepayback}$ Change to: $\max pen = \frac{1.1 penparm}{e^{0.24 simplepayback}}$	*Market Trends in the U.S. ESCO Industry: Results from the NAESCO Database Project*. Goldman, C., J. Osborn and N. Hopper, LBNL, and T. Singer, NAESCO, May 2002, LBNL-49601.
Remove DG Adopters in Existing Buildings from Pool of Potential Adopters	Commercial	Both	Subtract out share of existing buildings that adopted DG in previous year from current year stock	Prevent oversaturation of existing building stock
Implement non-linear technology advancement trajectory	Industrial	Program	Allow for technology performance and cost targets to be hit in 2010 and flat thereafter	Accurate representation of program goals