CHAPTER 5

LONG-TERM BENEFITS ANALYSIS OF EERE'S PROGRAMS

Introduction

This chapter provides an overview of the modeling approach used in MARKAL-GPRA05 to evaluate the benefits of EERE R&D programs and technologies. The program benefits reported in this section result from comparisons of each Program Case to the Baseline Case, as modeled in MARKAL-GPRA05.

The Baseline Case used to evaluate the impact of the EERE portfolio was benchmarked to EIA's *Annual Energy Outlook 2003* (*AEO2003*) for the period between 2000 and 2025. To the extent possible, the same input data and assumptions were used in MARKAL-GPRA05 as were used to generate the *AEO2003* Reference Case. For example, the macroeconomic projections for GDP, housing stock, commercial square footage, industrial output, and vehicle miles traveled were taken from the *AEO2003*. At the sector level, both supply-side and demand-side technologies were characterized to reflect the *AEO2003* assumptions, in cases where the representation of technologies is similar between MARKAL (MARKet ALlocation) and the National Energy Modeling System (NEMS). The resulting projections track closely with the *AEO2003* at the aggregate level, although they do not match exactly at the end-use level. For the period after 2025, various sources were used to compile a set of economic and technical assumptions. For instance, the primary economic drivers of GDP and population were based on the real GDP growth rate from the Congressional Budget Office's *Long-Term Budget Outlook* and population growth rates from the Social Security Administration's 2002 *Annual Report* to the Board of Trustees. **Appendix A** provides a more complete discussion of the MARKAL-GPRA05 Baseline Case.

For each EERE R&D program, analysts make modifications to the characteristics of the technologies involved to generate a Program Case. Program Cases also may include technologies not available in the Baseline Case. The modifications made to the model parameters and attributes of a technology depend on the nature of the program. They directly affect the technology's competitiveness and market deployment presented in the model.

Table 5.1 provides a breakdown by program of the two types of analytical methods employed in EERE's long-term benefits analyses—specialized "off-line" tools and MARKAL-GPRA05. The activities listed are groupings of activities within each program that share either technology or market features. They do not represent actual program-management categories. A description of the MARKAL model is provided in **Box 5.1** at the end of this chapter. Descriptions of the off-line models are provided in the related program appendix. It is important to note that the offline analysis served to feed appropriate parameters and other factors into MARKAL-GPRA05, which was then run for all the programs. The indication that the Industrial Technologies Program (or other program areas) was modeled using off-line tools should not be interpreted to mean that the Industrial Technologies Program was not included in the MARKAL-GPRA05 modeling, or that the results of the Industrial Technologies Program analysis are not impacted by the MARKAL-GPRA05 modeling.

Table 5.1. Long-Term Benefits Modeling by Primary Type of Model Used and Activity Area

Program	Activities	Off-Line Tools	MARKAL-GPRA05
Biomass	Bio-based Products	✓	
	Cellulosic Ethanol	✓	✓
Buildings Technologies	Residential Sector	✓	
	Commercial Sector	✓	
DER	DER / CHP		✓
FEMP	FEMP	✓	
Geothermal	Geothermal		✓
Hydrogen, Fuel Cells, and Infrastructure Technologies	Fuel Cells		✓
	Production		✓
Industrial Technologies	R&D	✓	
	Deployment	✓	
Solar Energy Technologies	Solar Water Heaters		✓
	Photovoltaics	✓	✓
Vehicle Technologies	Light-Vehicle Hybrid and Diesel		✓
	Heavy Trucks		✓
Weatherization and Intergovernmental	Weatherization	✓	
	Domestic Intergovernmental	✓	
Wind and Hydropower Technologies	Wind		✓
	Hydropower	✓	

The following sections summarize how each EERE R&D program is formulated in MARKAL-GPRA05. In many cases, analysts convert the technological data and their projected market potentials in each program directly to MARKAL-GPRA05 input. When this is not feasible, the quantitative analyses undertaken in **Step 2** are used, in part, to generate the Program Cases.

Biomass Program

The goal of the Biomass Program is the development of biomass refineries, which produce a range of products including ethanol and biochemical feedstocks. This refinery approach reduces the cost of these biomass products compared to the earlier approach of individually producing each product. Unfortunately, it is currently not possible to directly model a biorefinery. Instead, analysts model individual biorefinery products (bio-based products and cellulosic ethanol) for the benefits analysis. This most likely results in an underestimation of the size of future markets and resulting benefits.

Bio-based products: In the Baseline Case, the supply/demand of petrochemical feedstocks is explicitly represented as nonenergy use of petroleum products and natural gas. At this early stage of biorefinery R&D, the output and cost of biorefineries are not yet well defined. Off-line projections of the use of petroleum and natural gas as chemical feedstock are represented in a highly aggregated manner. Program goals are estimated off-line and represented in MARKAL-GPRA05 as reductions in petroleum and natural gas demand for feedstocks. Off-line estimates include changes in fuel requirements for process heat. The off-line energy savings for displaced feedstocks and changes in process heat are represented in the MARKAL-GPRA05 model as upper bounds in the amounts shown in **Table 5.2**.

Table 5.2. Bio-based Products Energy Savings by Year

	2010	2020	2030	2040	2050
Natural Gas (TBtu/yr)	7.49	12.20	21.85	39.13	70.08
Coal (TBtu/yr)	-0.82	-1.34	-2.40	-4.31	-7.71
Electricity (Billion kWh/yr)	-0.66	-1.07	-1.92	-3.45	-6.17
Distillate (TBtu/yr)	7.88	12.84	22.99	41.16	73.72
Oil Feedstock (TBtu/yr)	18.27	29.74	53.26	95.38	170.82
Total (TBtu/yr)	**26.87**	**44.96**	**80.51**	**144.18**	**258.20**

Cellulosic ethanol: In the Biomass Program Case, a cellulosic ethanol production process is introduced, which is capable of producing ethanol beginning in 2007 at an initial cost comparable to current corn ethanol.[1] The enzyme-based technology for converting the cellulose and hemi-cellulose from the fiber contained in corn kernels will be available sooner than the related (but more complex) enzyme-based technology for converting agricultural residues to ethanol. Beginning in 2019, biorefineries producing ethanol as a major product, along with high-value coproducts, from biomass wastes and residues, will begin operation. However, as ethanol volumes increase, the total cost may increase as the process competes with other biomass-based technologies for the supply of biomass it uses as feedstocks. Currently, the MARKAL-GPRA05 model lacks sufficient technical detail to properly capture beneficial qualities of ethanol, such as octane enhancement; or the regional detail to model niche markets in agricultural states where ethanol/gasoline blends may compete on an even basis with traditional gasoline. Therefore, estimates of future ethanol demand from biomass-specific models are used for both the Baseline and Program Cases. In MARKAL-GPRA05, a portion of the total gasoline supply is blended with ethanol to produce blended ethanol for use in road vehicles. A single blending level (5.6 percent ethanol) is used in the model to match estimated demand. Actual blend levels vary across the country due to regulations and cost competitiveness. For instance, in some agricultural regions of the country, higher ethanol blends may be cost-competitive. **Table 5.3** depicts the upper bound of cellulosic and corn ethanol production set in MARKAL-GPRA05, which reflects cellulosic ethanol's penetration if program cost goals are met.

Table 5.3. Projected Ethanol Demand (million gallons/year)

	2000	2010	2020	2030	2040	2050
Corn	1,600	3,000	3,140	2,920	2,680	2,380
Cellulosic	0	90	710	3,010	6,400	10,200
Total	**1,600**	**3,090**	**3,850**	**5,930**	**9,080**	**12,580**

The benefits of the Biomass Program derived in MARKAL-GPRA05 (**Table 5.4**) are the results of direct substitution of biomass-based energy for fossil fuels. Bio-based products reduce the demand for petroleum feedstocks. Cellulosic ethanol displaces an increasing fraction of the gasoline used in light-duty vehicles (LDVs) in later periods. The reduction in fossil fuel consumption at high marginal cost generates savings both in carbon emissions and energy-system costs.

[1] Cellulose and hemi-cellulose that can be converted to ethanol (and other chemicals, materials, and biofuels) are found in biomass such as agricultural residues (corn stover, wheat, and rice straw), mill residues, organic constituents of municipal solid wastes, wood wastes from forests, future grass, and tree crops dedicated to bio-energy production.

Table 5.4. FY05 Benefits Estimates for Biomass Program (MARKAL-GPRA05)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Nonrenewable Energy Savings (quadrillion Btu/yr)	0.11	0.38	0.73	1.20
Economic				
Energy-System Cost Savings (billion 2001 dollars/yr)	2	3	2	0
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	1	4	11	23
Security				
Oil Savings (mbpd)	0.0	0.0	0.2	0.4
Natural Gas Savings (quadrillion Btu/yr)	0.07	0.32	0.34	0.36

Buildings Technologies Program

MARKAL-GPRA05 models technologies and activities in the Buildings Program based on two general types of activities: technology R&D and regulatory actions.

Technology R&D: New and improved technologies are introduced into MARKAL-GPRA05 by modifying the technology slates that are available in the Baseline Case. These modifications are accomplished by changing any (or all) of the following three parameters to reflect program goals: the date of commercialization, capital cost, and efficiency. Building technologies for which these parameters can be characterized to meet specific building service demands include end-use devices such as heating burners, air conditioners, and water heaters (**Figure 5.1**). In instances where the market potentials of a technology were estimated off-line, a maximum initial market penetration rate was imposed, combined with an annual growth rate limit to replicate these potentials in MARKAL-GPRA05. For example, in the Buildings Program Case, an improved electric heat-pump water heater was modeled in the residential sector with an initial maximum market penetration of 400 TBtu and a potential growth rate of 5 percent per year. In the commercial sector, solid-state lighting technologies for 2010, 2015, and 2020 are modeled with their technological characteristic shown in **Table 5.5**.

Table 5.5. New Commercial Lighting Technologies

	Maximum Initial Penetration*	Annual Growth Rate	Investment Cost**
Solid-State Lighting 2010	1000	5.0%	4.3079
Solid-State Lighting 2015	2000	5.0%	3.8437
Solid-State Lighting 2020	5000	10.0%	3.8437
Lighting Controls	500	5%-10%	2.6795

* Maximum initial investment is in 10^12 lumens-second
** Lighting investment cost in million $ per 10^12 lumen-second capacity

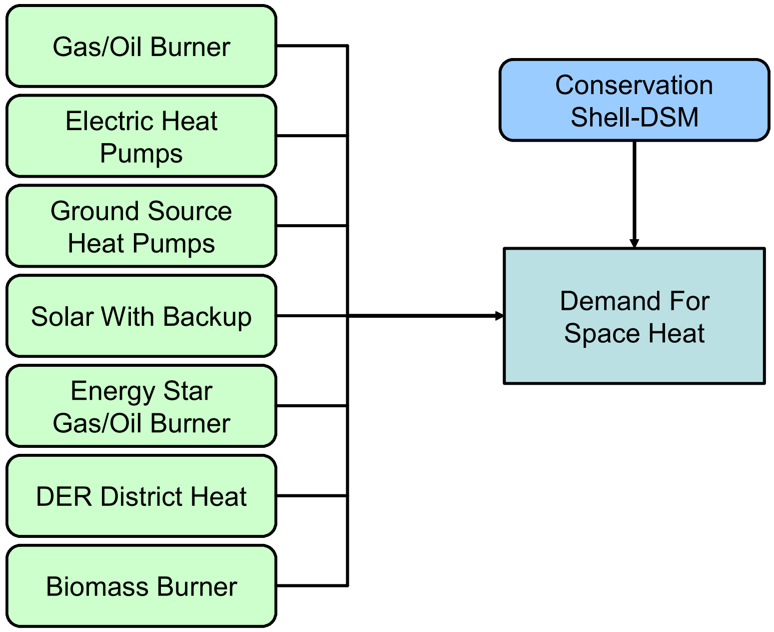

Figure 5.1. Demand-Side Linkages for End-Use Technologies and Energy Services

Technologies that lower service demand (*e.g.*, building shell technologies, lighting controls) are modeled in MARKAL-GPRA05 as conservation supply steps. Each supply step is characterized by capital cost, load-reduction potentials expressed as upper bounds of market penetration, consumer's hurdle rate, and technology lifetime. These conservation steps reduce the market size or load demand for end-use devices (**Figure 5.1**). In the Buildings Program Case, these newly introduced technologies compete with the baseline technologies for market share. For example, in future time periods, the size of the market for commercial air conditioning is the projected total heat in trillion Btus to be removed from the service areas. The new investment opportunity in that time period is the difference between the projected service demands in that period and the vintage capacities carried over from the previous period.

Technologies such as solid-state lighting in commercial buildings, although available in the Baseline Case, do not have a market share initially because of their high consumer hurdle rate (44 percent). These hurdle rates are lowered to 18 percent when running the Buildings Technology Case to reflect consumer acceptance of these products with improved performance.[2] The 18 percent is an empirical value based on observed consumer responses, but is much higher than would be observed if consumers were minimizing life cycle costs. Although the future market potential of new lighting technologies is great due to the relatively short life of the equipment, the penetration of these technologies modeled in MARKAL-GPRA05 is limited to a sustainable growth path that generates a potential market penetration path consistent with the program goals.

[2] The hurdle rates in MARKAL-GPRA05 include factors to reflect both the interest rate available to consumers, as well as behavioral and risk premiums that are implicit in consumer decisions. Behavioral premiums would reflect a documented consumer bias towards choosing reduced up-front investment costs over longer-term operating cost savings. The behavioral premium also incorporates agency issues where the decision maker would not benefit from long-term operating costs and, thus, would make decisions based primarily on initial capital costs. Risk premiums would apply to new, unfamiliar products that are presumed to be less desirable to consumers due to the lack of familiarity or a track record of successful application. Also, risk premiums would be appropriate for modeling situations where technologies may appear to be cost effective on paper, but are not chosen by consumers for reasons such as convenience, styling or lack of availability.

Regulatory Activities: Analysts represent new appliance standards and building codes in MARKAL-GPRA05 as either new technologies or energy-conservation supply steps. In the time period that a new standard becomes effective, the model removes technologies with efficiency below the set standard from the market. Regulatory activities primarily affect the performance of new energy products for a specific end-use product purchased by consumers in future markets. The overall impact of the Buildings Program, therefore, depends on the size of these markets. MARKAL-GPRA05 determines the size of these markets by dynamically keeping track of the turnover of capital equipment and deriving the new investment needed to meet projected energy service demands. Because some end-use devices (*e.g.*, heating equipments) have a long service lifetime, the stock turnover constraints modeled in MARKAL-GPRA05 limit near-term energy savings. **Table 5.6** depicts the size of the future markets for the major end-use categories defined in MARKAL-GPRA05 for buildings.

Table 5.6. Projected Annual Investment in Energy Capital Stock Used in Buildings

	2010	2020	2030	2040	2050
Residential Sector					
Space Heating (Million Units/yr)[1]	3.86	4.25	4.39	4.63	5.02
Air Conditioning (Million Ton/yr)	9.30	10.22	10.47	11.34	12.79
Water Heating (Million Units/yr)[2]	2.87	2.94	3.10	3.20	3.43
Refrigeration (Million Units/yr)[3]	2.99	2.80	3.32	3.34	3.44
Lighting (Million Units/yr)[4]	207.78	246.90	258.48	268.84	275.62
Commercial Sector					
Space Heating (Billion Btu per Hour/yr)	65.89	70.46	85.08	96.40	98.53
Air Conditioning (Million Ton/yr)	7.20	8.21	8.70	9.87	10.65
Water Heating (Billion Btu per Hour/yr)	9.90	11.22	12.91	14.30	14.94
Lighting (Million Units/yr)[5]	144.54	166.54	179.45	208.80	232.02

[1] Units with equivalent capacity of 150,000 Btu/hour.
[2] Units with equivalent capacity of 30,000 Btu/hour.
[3] Units with equivalent capacity of 1500 W.
[4] In terms of a 75W incandescent light or equivalent.
[5] In terms of a 40W standard fluorescent light or equivalent.

In MARKAL-GPRA05, energy savings are achieved when a more efficient and economic (on a life-cycle basis) end-use device is selected to substitute for a conventional device competing in the same market. For example, a 20 Watt (W) CFL can replace a 75W incandescent lightbulb and provide the same level of lighting service, but uses much less electricity. The total market potential for this substitution in a future time period, however, is constrained by the investment opportunity established in MARKAL-GPRA05 (*e.g.*, 275.62 million units for residential lighting in 2050, as shown in **Table 5.6**).

For building codes, analysts estimated unit load reductions in heating, cooling, and lighting demands—resulting from the implementation of more stringent building codes—within NEMS and implemented in MARKAL-GPRA05 as a set of conservation curves. **Table 5.7** depicts these potentials used in formulating the Buildings Program Case. The reduced loads or energy service demands lead to less electricity and fuels used in buildings.

Table 5.7: Building Conservation/Load-Reduction Potentials: Building Code and Envelop Improvement (% of total load)

	2010	2020	2030	2040	2050
Residential Sector					
Heating	0.5%	2.4%	3.1%	3.1%	3.1%
Cooling	1.8%	1.6%	3.0%	3.0%	3.0%
Commercial Sector					
Heating	1.5%	5.0%	5.8%	5.8%	5.8%
Cooling	2.2%	5.2%	5.2%	5.2%	5.2%

Tables 5.8 and 5.9 depict the projected delivered energy savings by demand and fuel generated from the use of more efficient end-use devices and cost-effective conservation measures covered under the Buildings Program.

Table 5.8. Residential Delivered Energy Savings by Demand and Fuel (trillion Btu/year)

	2010	2020	2030	2040	2050
Reduction by Service Demand					
Space Heating	24	142	207	348	497
Space Cooling	12	12	24	21	15
Water Heating	55	136	298	369	351
Lighting	60	0	0	0	0
Other	0	0	0	0	0
Total	**151**	**290**	**528**	**737**	**863**
Reduction by Fuel					
Petroleum	0	-2	105	246	323
Natural Gas	44	170	318	638	741
Coal	0	0	0	4	4
Electricity	107	122	106	-151	-204
Total	**151**	**290**	**528**	**737**	**863**

Table 5.9. Commercial Delivered Energy Savings by Demand and Fuel (trillion Btu/year)

	2010	2020	2030	2040	2050
Reduction by Service Demand					
Space Heating	27	104	142	132	149
Space Cooling	10	30	27	21	22
Water Heating	0	0	0	0	0
Lighting	20	149	423	716	755
Other	0	0	0	0	0
Total	**57**	**283**	**592**	**869**	**926**
Reduction by Fuel					
Petroleum	10	0	22	0	1
Natural Gas	5	82	102	4	17
Coal	0	0	0	0	0
Electricity	41	201	467	865	905
Total	**57**	**283**	**592**	**869**	**923**

In addition to the reduction in delivered primary energy, the reduction in electricity demand in buildings also leads to the reduction in gas-fired generation capacity, as well as fuel used for generation. Furthermore, building code and envelop improvements reduce both the demand for delivered energy and the required output capacity of end-use devices, such as furnaces or air conditioners. Thus, consumers see both a reduction in their energy bills, as well as reduced capital costs for end-use appliances. This is another factor attributable to the overall reduction in energy-system cost in addition to direct energy savings.

Table 5.10. FY05 Benefits Estimates for Building Technologies Program (MARKAL-GPRA05)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Nonrenewable Energy Savings (quadrillion Btu/yr)	1.2	2.3	2.3	2.8
Economic				
Energy-System Cost Savings (billion 2001 dollars/yr)	15	23	34	45
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	25	43	43	50
Security				
Oil Savings (mbpd)	0.0	0.1	0.2	0.2
Natural Gas Savings (quadrillion Btu/yr)	0.56	1.12	1.54	1.82
Electricity Capacity Avoided (gigawatts)	46	46	48	53

Distributed Energy Resources Program

The Distributed Energy Resources (DER) Program covers distributed generation technologies (DG) and combined heat and power (CHP). The program focuses on the improvement of these technologies (higher efficiency, lower cost, and lower emissions) and removal of market barriers for consumer acceptance.

The DER Program Case in MARKAL-GPRA05 is formulated by the introduction and performance improvements in several combined heat and power technologies. Two of these are for industrial applications: A relatively large gas-fired turbine (10 MW) and a smaller internal combustion engine (3 MW). Both produce electricity and heat for industrial-process steam. The third technology is a micro-turbine (100 KW)-based CHP serving commercial building electricity demand, and space and water heat. The heat generated from CHP is utilized through heat exchangers, displacing the conventional heating devices and the fuel they use. The fourth technology is a 1 MW-distributed generator to meet local peaking demands. The overall efficiencies and capital costs used to characterize these technologies are assumed to become more favorable due to R&D achievements expected from the DER Program (**Table 5.11**).

All of these technologies are modeled explicitly as decentralized systems in MARKAL-GPRA05 and do not require transmission and distribution for their electricity or heat output; and, therefore, avoid the associated costs and electricity losses. Implicitly, this improves the electric reliability at the end-use locations—although this value to consumers is not reflected in the model representation of consumer choices. In addition to the improvements in technological attributes, the discount (hurdle) rate of DG technologies are lowered by one percentage point to reflect DER's activities in enhancing the technologies' consumer acceptance. As currently modeled, distributed generation technologies do not directly contribute to the overall system peak in electric power demand.[3]

Under the DER Program, MARKAL-GPRA05 results in accelerated market penetration of DER technologies, as shown in **Table 5.12**.

Table 5.11. Distributed Generation Technology Assumptions

	2000	2005	2010	2015	2020
10MW Industrial Turbine					
Cost (2001$/kW)	950	914	879	843	807
Electric Efficiency	29%	30%	32%	33%	34%
Combined Efficiency	69%	70%	70%	71%	71%
3MW Industrial Gas Engine					
Cost (2001$/kW)	843	677	511	511	511
Electric Efficiency	34%	42%	50%	50%	50%
Combined Efficiency	65%	66%	67%	67%	67%
100kW Commercial Microturbine					
Cost (2001$/kW)	2000	1400	601	601	601
Electric Efficiency	26%	33%	40%	40%	40%
Combined Efficiency	65%	68%	70%	71%	72%
1MW Distributed Peaking Units					
Cost (2001$/kW)	766	613	460	460	460
Electric Efficiency	31%	36%	40%	40%	40%

Table 5.12. Installed Distributed Generation Capacity by Sector and Case (gigawatts)

	Commercial Sector	Industrial Sector	Distributed Peakers	Total
Baseline Case				
2015	0	62	6	68
2025	1	73	16	90
2050	8	131	171	310
DER Program Case				
2015	0	64	7	71
2025	12	78	20	110
2050	51	146	212	409
Increase				
2015	0	2	1	3
2025	11	5	4	20
2050	44	15	41	99

With the increase in distributed generation capacity, MARKAL-GPRA05 directly reduces the investment in centralized gas and coal-fired generators. On the demand side, the heat generated

[3] This will be addressed in the GPRA06 benefits analysis.

from CHP further reduces fuel use for space and water heat in buildings, and for process steam in industrial applications. The higher overall efficiency (combined heat and power with no transmission loss) of these technologies results in long-term benefits in energy savings, energy-system costs, and carbon emission reductions (**Table 5.13**).

Table 5.13. FY05 Benefits Estimates for DER Program (MARKAL-GPRA05)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Nonrenewable Energy Savings (quadrillion Btu/yr)	0.3	0.4	1.4	1.2
Economic				
Energy-System Cost Savings (billion 2001 dollars/yr)	4	4	3	6
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	9	8	23	30
Security				
Oil Savings (mbpd)	ns	ns	ns	ns
Natural Gas Savings (quadrillion Btu/yr)	-0.14	0.11	1.04	0.27
Capacity (gigawatts)	6	36	70	99
Total Displaced Need for New Electric Capacity (gigawatts)	26	26	30	63

Federal Energy Management Program

The Federal Energy Management Program (FEMP) aims to improve the overall energy efficiency in Federal Government buildings. As a deployment program, FEMP utilizes a broad spectrum of existing technologies and practices for achieving its goal. Therefore, it does not provide specific technological information in relating costs and energy savings under its activities. The program has a well-documented track record and provided estimates of future savings based on past results and current budgets. The savings by specific energy type projected by the program through the year 2030 are depicted in **Table 5.14**. For the period after 2030, the amount of energy displaced continues at a 2.7% annual growth rate.

Table 5.14. FEMP Annual Energy Savings Projections

Year	Total Primary Energy Displaced (TBtu/yr)	Direct Electricity Displaced (billion kWh/yr)	Direct Natural Gas Displaced (billion CF/yr)	Direct Petroleum Displaced (million barrels/yr)	Direct Coal Displaced (million short tons/yr)
2005	6.444	0.434	1.089	0.070	0.012
2006	12.364	0.860	2.158	0.138	0.023
2007	18.341	1.278	3.207	0.205	0.034
2008	23.346	1.689	4.237	0.271	0.045
2010	32.974	2.486	6.240	0.399	0.067
2015	44.437	3.549	8.942	0.565	0.096
2020	55.408	4.560	11.511	0.723	0.125
2025	67.108	5.521	13.955	0.874	0.151
2030	78.233	6.435	16.279	1.017	0.177

In order to quantify the broader benefits of these savings in MARKAL-GPRA05, a single energy-conservation supply curve was modeled in the FEMP Case to reduce the energy service demands in "miscellaneous" commercial energy demand. The conservation curve was set to reflect the program's estimated delivered energy savings as shown in **Table 5.14**. Further adjustments were made to the case to roughly match the level of delivered energy savings for each fuel type.

The reduction in commercial energy demand effectively leads to lower investment in the future capacity of demand devices servicing the Federal buildings, resulting in lower energy use in these devices. The reduction in electricity demand also leads to a slight drop in the electric generation by gas-fired power plants. FEMP also directly reduces fossil fuels used in commercial (government) buildings. The long-term systemwide benefits are provided in **Table 5.15**.

Table 5.15. FY05 Benefits Estimates for FEMP (MARKAL-GPRA05)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Nonrenewable Energy Savings (quadrillion Btu/yr)	0.08	0.10	0.17	0.17
Economic				
Energy-System Cost Savings (billion 2001 dollars/yr)	1	1	3	3
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	1.3	1.5	3.3	4.0
Security				
Oil Savings (mbpd)	ns	ns	ns	ns
Natural Gas Savings (quadrillion Btu/yr)	0.07	0.09	0.16	0.23

Geothermal Technologies Program

The main goals of the Geothermal Technologies Program are to reduce the cost of conventional geothermal technologies and to develop Enhanced Geothermal Systems (EGS) as a new source of electricity generation.

The Geothermal Technologies Program Case formulated in MARKAL-GPRA05 reflects the program goals for both conventional systems and EGS. For conventional geothermal systems, analysts changed the capital and operating and maintenance (O&M) costs to reflect program goals. However, EGS represents a new geothermal resource not previously represented in the MARKAL-GPRA05 model. The program identified three types of potential geothermal reservoirs:

- Type I. Improvement prospects in existing commercial reservoirs
- Type II. Identified reservoirs with suboptimal characteristics
- Type III. Prospective sites that are not currently identified as hydrothermal prospects

Due to program activities, the capital and O&M costs of EGS systems are projected to decline. **Table 5.16** shows the estimated capital and O&M costs for the three types of EGS systems for 2000 and 2050.

The EGS sites projected under the program are grouped into a set of supply steps, and the discount rate of these technologies is set at 8 percent (instead of 10 percent for the power generation-sector average) to reflect the accelerated depreciation schedule permitted by the Internal Revenue Service for renewable-generation technologies. The EGS systems are modeled as centralized base-load generation.

Table 5.16. EGS Generation Assumptions

EGS Type	Projected Resource MWe	2000 Cost		2050 Cost	
		Capital Cost 2001$/kW	O&M 2001$/kW/yr	Capital Cost 2001$/kW	O&M 2001$/kW/yr
I	3,400	2,448	153	934	50
II	25,000	2,815	176	1,074	58
III	60,000	3,182	199	1,214	66

Geothermal plants compete directly with fossil fuel-based plants for both electricity generation and meeting peak power requirements. In MARKAL-GPRA05, EGS becomes more competitive, as its higher capital cost is offset by increased fossil fuel costs for gas and coal-fired generators, which increase during the projection period as overall fuel demand increases.

The improvements in capital and O&M costs lead to increased market penetration for conventional geothermal-generation capacity. Furthermore, EGS capacity, which was not available in the Baseline Case, shows significant market penetration between 2020 and 2050. **Table 5.17** shows both Baseline Case and Geothermal Technologies Program Case capacity, while **Table 5.18** shows geothermal power generation for both cases.

The projected market penetration of geothermal generation technologies in MARKAL-GPRA05's Geothermal Technologies Program Case directly displaces both natural gas and coal-fired generation beginning in 2010. The long-term benefits are shown in **Table 5.19**.

Table 5.17. Total Geothermal Capacity by Type (gigawatts)

	2000	2010	2020	2030	2040	2050
Baseline Case						
Conventional	2.9	3.3	4.6	6.2	9.4	8.7
EGS	0.0	0.0	0.0	0.0	0.0	0.0
Total	**2.9**	**3.3**	**4.6**	**6.2**	**9.4**	**8.7**
Geothermal Program Case						
Conventional	2.9	5.4	6.4	7.1	11.8	10.4
EGS	0.0	0.0	0.2	6.0	20.0	34.4
Total	**2.9**	**5.4**	**6.6**	**13.0**	**31.7**	**44.8**
Increase						
Conventional	0.0	2.1	1.8	0.9	2.4	1.7
EGS	0.0	0.0	0.2	6.0	20.0	34.4
Total	**0.0**	**2.1**	**2.0**	**6.9**	**22.3**	**36.1**

Table 5.18. Total Geothermal Power Generation by Type (billion kilowatt hours/year)

	2000	2010	2020	2030	2040	2050
Baseline Case						
Conventional	15.0	19.6	30.5	42.2	64.4	59.9
EGS	0.0	0.0	0.0	0.0	0.0	0.0
Total	**15.0**	**19.6**	**30.5**	**42.2**	**64.4**	**59.9**
Geothermal Program GPRA Case						
Conventional	15.0	35.4	44.2	49.3	82.6	72.9
EGS	0.0	0.0	1.7	50.6	169.5	292.3
Total	**15.0**	**35.4**	**45.9**	**99.9**	**252.1**	**365.3**
Increase						
Conventional	0.0	15.8	13.6	7.1	18.1	13.0
EGS	0.0	0.0	1.7	50.6	169.5	292.3
Total	**0.0**	**15.8**	**15.3**	**57.7**	**187.7**	**305.4**

Table 5.19. FY05 Benefits Estimates for Geothermal Technologies Program (MARKAL-GPRA05)

Annual Benefits	**2020**	**2030**	**2040**	**2050**
Energy Displaced				
Nonrenewable Energy Savings (quadrillion Btu/yr)	0.17	0.42	1.47	2.13
Economic				
Energy-System Cost Savings (billion 2001 dollars/yr)	2	4	5	9
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	5	9	27	50
Security				
Oil Savings (mbpd)	ns	ns	ns	ns
Natural Gas Savings (quadrillion Btu/yr)	-0.03	0.16	0.92	0.40
Capacity (gigawatts)	2	7	22	36

Hydrogen, Fuel Cells, and Infrastructure Technologies Program

The Hydrogen, Fuel Cells, and Infrastructure Technologies (HFCIT) Program conducts research and development activities in hydrogen production, storage, and delivery, and transportation and stationary fuel cells. On the demand side, the program's activities focus on the introduction of fuel cells for both stationary and mobile applications. On the supply side, the program goal is to lower the production cost of hydrogen to a competitive level against petroleum products.

The representation of the Hydrogen, Fuel Cells, and Infrastructure Technologies Program in MARKAL-GPRA05 requires representation of fuel cell vehicles and transportation markets, hydrogen production and distribution infrastructure, and stationary fuel cell applications.

Fuel Cell Vehicles and Transportation Markets: Fuel cell vehicles are projected to compete with traditional petroleum and hybrid-electric vehicles for market share in the light-duty vehicle and commercial light truck markets. In MARKAL-GPRA05, analysts measure energy service demands for road transportation in vehicle miles traveled (VMT). Projected VMTs are taken directly from the *Annual Energy Outlook 2003* and extended past 2025, based on historical relationships between passenger and commercial VMTs and population and economic growth. Projected VMTs for cars, light trucks, and commercial light trucks are shown in **Table 5.20**.

Table 5.20. LDV and Commercial Light Truck Vehicle Miles Traveled (billion VMTs/year)

	2000	2010	2020	2030	2040	2050
Total Light-Duty Vehicles	2,355	3,004	3,753	4,417	4,868	5,241
Cars	1,498	1,649	1,992	2,325	2,382	2,288
Light Trucks	857	1,355	1,761	2,092	2,485	2,953
Commercial Light Trucks	69	84	107	134	157	177

For each time period, these demands are met by a mix of vehicle types selected by the model on the basis of total life-cycle costs. The vehicle type is characterized for each model year it is available for purchase. The Baseline Case cost and efficiencies of these vehicles were derived from the *AEO2003* assumptions, with cost and efficiency improvements extrapolated after 2025.

For the Hydrogen Program Case, capital costs, operation and maintenance costs, and fuel efficiency goals were provided by the HFCIT Program for gasoline fuel cell and hydrogen fuel cell vehicles. Assumptions were provided for gasoline fuel cell vehicles for 2010 and 2020, and for hydrogen fuel cell vehicles from 2012 to 2050. As with the Vehicle Technologies Program, these were provided as ratios to conventional gasoline-powered vehicles of the same vintage. For example, a 2020 gasoline-fuel cell passenger car with a cost ratio of 1.20 and an efficiency ratio of 1.8 would cost 20 percent more than the average 2020 traditional gasoline passenger car and have 80 percent higher fuel economy. The cost and efficiency assumptions for passenger cars, sport utility vehicles (SUVs), and commercial light trucks are shown in **Table 5.21**.

Table 5.21. Cost and Efficiency Assumptions for Fuel Cell Vehicles

	2010	2020	2030	2040	2050
Passenger Cars					
Cost Ratio to Conventional					
Fuel Cell (Gasoline)	1.30	1.20			
Fuel Cell (H2)		1.05	1.05	1.05	1.05
Efficiency Ratio to Conventional					
Fuel Cell (Gasoline)	1.50	1.80			
Fuel Cell (H2)		2.50	3.20	3.40	3.40
SUVs & Commercial Light Trucks					
Cost Ratio to Conventional					
Fuel Cell (Gasoline)	1.30	1.20			
Fuel Cell (H2)	1.25	1.05	1.05	1.05	1.05
Efficiency Ratio to Conventional					
Fuel Cell (Gasoline)	1.40	1.80			
Fuel Cell (H2)	2.00	2.50	3.20	3.40	3.40

Hydrogen Production and Distribution Infrastructure: The HFCIT Program conducts research on developing cost-effective hydrogen production technologies from distributed natural gas reformers, as well as a variety of renewable sources, including biomass. For the Hydrogen Case, analysts modeled five hydrogen production technologies: distributed natural gas reformers, central natural gas reformers, central coal gasification, central biomass gasification, and central electrolytic production. Other renewable hydrogen-production technologies were not modeled, due to a greater degree of uncertainty in their costs. Nuclear hydrogen production technologies were also not represented in the MARKAL-GPRA05 model. Carbon sequestration pathways were available for central coal and natural gas hydrogen production. However, because no carbon policies were assumed, producers would not have an economic incentive to incur the incremental cost to sequester carbon generated from hydrogen production activities and, thus, no carbon was sequestered in this Program Case.

HFCIT Program goals were used to estimate capital and O&M costs and production efficiencies for distributed natural gas reformers and central biomass gasifiers and electrolytic production technologies. Assumptions for central coal and natural gas production technologies were adapted from *Hydrogen Production Facilities Plant Performance and Cost Comparisons, Final Report*.[4] The infrastructure requirements and operating costs for the widespread distribution of hydrogen vary widely by distance and method. As a simplifying assumption, a flat cost of $5.28 per MMBtu—or $0.65 per gallon of gasoline equivalent (gge)—was assumed for hydrogen distribution costs based on published data from NREL.[5] (Please note that one kilogram of hydrogen is roughly equivalent in energy content to one gallon of gasoline, and is often referred to as a gallon of gasoline equivalent (gge).) **Table 5.22** shows projected hydrogen costs by cost component for the Hydrogen Program Case.

(Please note that due to market factors affecting feedstock costs, the projected costs may not match HFCIT Program goals.)

Stationary Fuel Cell Applications: In addition to use in vehicles, fuel cells also may be used for distributed electric generation. The HFCIT Program provided cost and performance goals for a 5kW CHP residential fuel cell system and a 200kW CHP commercial fuel cell system. The cost and performance parameters are shown in **Tables 5.23 and 5.24**.

Unlike other program cases, analysts ran the Hydrogen Program Case with both HFCIT and Vehicle Technologies Program assumptions. The rationale for this change is that the hydrogen fuel cell vehicle assumptions provided by the HFCIT Program assume that the Vehicle Technologies Program's hybrid systems and materials technologies R&D activities are successful. The market penetration of hydrogen fuel vehicles is somewhat limited by the increased competition from more-advanced hybrid vehicles. The market shares for LDVs are shown in **Table 5.25**.

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4 *Hydrogen Production Facilities Plant Performance and Cost Comparisons, Final Report*, March 2002, prepared for NETL by Parsons Infrastructure and Technology Group.

5 Amos W.A., Lane J.M., Mann M.K., and Spath P.L. *Update of hydrogen from biomass – determination of the delivered cost of hydrogen*, NREL, 2000.

Table 5.22. Hydrogen Production Costs by Technology and Component (2001 $/gge)

Central Coal								
Unit Costs	2015	2020	2025	2030	2035	2040	2045	2050
Capital Costs			$0.48	$0.48	$0.48	$0.48	$0.48	$0.48
O&M			$0.27	$0.27	$0.27	$0.27	$0.27	$0.27
Feedstock Costs			$0.22	$0.24	$0.25	$0.27	$0.27	$0.28
Plant Gate			**$0.97**	**$0.99**	**$0.99**	**$1.01**	**$1.02**	**$1.02**
Distribution, Storage & Tax			$1.03	$1.03	$1.03	$1.03	$1.03	$1.03
Total			**$2.00**	**$2.02**	**$2.03**	**$2.04**	**$2.05**	**$2.06**
Distributed Natural Gas Reformer								
Unit Costs	2015	2020	2025	2030	2035	2040	2045	2050
Capital Costs	$0.73	$0.42	$0.42	$0.42	$0.42			
O&M	$0.53	$0.54	$0.53	$0.54	$0.54			
Feedstock Costs	$0.79	$0.83	$0.84	$0.90	$0.93			
Plant Gate	**$2.05**	**$1.79**	**$1.80**	**$1.86**	**$1.89**			
Tax	$0.38	$0.38	$0.38	$0.38	$0.38			
Total	**$2.43**	**$2.17**	**$2.17**	**$2.24**	**$2.27**			
Central Natural Gas Reformer								
Unit Costs	2015	2020	2025	2030	2035	2040	2045	2050
Capital Costs			$0.15	$0.15	$0.15	$0.15	$0.15	
O&M			$0.08	$0.08	$0.08	$0.08	$0.08	
Feedstock Costs			$0.80	$0.86	$0.89	$0.93	$0.97	
Plant Gate			**$1.04**	**$1.10**	**$1.13**	**$1.17**	**$1.21**	
Distribution, Storage & Tax			$1.03	$1.03	$1.03	$1.03	$1.03	
Total			**$2.07**	**$2.13**	**$2.16**	**$2.20**	**$2.24**	
Central Biomass								
Unit Costs	2015	2020	2025	2030	2035	2040	2045	2050
Capital Costs		$1.16	$1.02	$0.98	$0.96	$0.95	$0.95	$0.95
O&M		$0.34	$0.31	$0.31	$0.31	$0.31	$0.31	$0.31
Feedstock Costs		$0.35	$0.32	$0.32	$0.32	$0.32	$0.32	$0.32
Plant Gate		**$1.85**	**$1.65**	**$1.61**	**$1.59**	**$1.58**	**$1.58**	**$1.58**
Distribution & Storage*		$0.65	$0.65	$0.65	$0.65	$0.65	$0.65	$0.65
Total		**$2.50**	**$2.31**	**$2.26**	**$2.25**	**$2.24**	**$2.23**	**$2.23**
Central Electrolytic Production**								
Unit Costs	2015	2020	2025	2030	2035	2040	2045	2050
Capital Costs		$0.12	$0.12	$0.12	$0.12	$0.12	$0.12	$0.11
O&M		$0.19	$0.19	$0.19	$0.19	$0.19	$0.19	$0.19
Feedstock Costs		$2.06	$2.02	$1.99	$2.31	$2.30	$2.21	$1.87
Plant Gate		**$2.37**	**$2.32**	**$2.30**	**$2.61**	**$2.60**	**$2.52**	**$2.17**
Distribution, Storage & Tax		$1.03	$1.03	$1.03	$1.03	$1.03	$1.03	$1.03
Total		**$3.41**	**$3.36**	**$3.33**	**$3.64**	**$3.64**	**$3.55**	**$3.20**

* Note: Hydrogen produced from biomass was assumed to receive preferential tax treatment.
** Central electrolytic production technologies did not penetrate in the Hydrogen Case. The above costs are based on a separate model run where this technology was required to produce.

Table 5.23. 5 kW Residential Combined Heat and Power System Assumptions

First Year	Last Year	CHP System Efficiency	Electrical Efficiency	Thermal Recovery Efficiency	Equip. Cost (2001 $/kW)	Maint. Cost (2001$/kW-yr)
2002	2004	0.70	0.30	0.571	$3,000	84.5
2005	2009	0.75	0.32	0.632	$1,500	81.6
2010	2014	0.80	0.35	0.692	$1,000	78.3
2015	2025	0.80	0.35	0.692	$1,000	74.3

Table 5.24. 200 kW Commercial Combined Heat and Power System Assumptions

First Year	Last Year	CHP System Efficiency	Electrical Efficiency	Thermal Recovery Efficiency	Equip. Cost (2001 $/kW)	Maint. Cost (2001$/kW-yr)
2002	2004	0.70	0.30	0.571	$2,500	84.5
2005	2009	0.75	0.32	0.632	$1,250	81.6
2010	2014	0.80	0.40	0.667	$750	78.3
2015	2019	0.80	0.40	0.667	$750	74.3
2020	2025	0.80	0.40	0.667	$750	72.5

Table 5.25. Light-Duty Vehicle Market Shares for the Hydrogen Case (% of VMT)

	2000	2010	2020	2030	2040	2050
Gasoline	100%	94%	81%	51%	21%	8%
Hybrid	0%	2%	17%	32%	51%	54%
Hydrogen	0%	0%	1%	13%	27%	38%
Other	0%	4%	1%	4%	1%	0%

Because the Hydrogen Program Case was run with both Hydrogen and Vehicle Technologies Programs' assumptions, analysts could not perform the calculation of benefits through the direct comparison of the Hydrogen Program Case and the Baseline Case. Instead, analysts based the calculation of oil and carbon benefits for the Hydrogen Program on the relative fuel/carbon intensities per vehicle miles traveled (VMTs) of gasoline and hydrogen fuel cell vehicles.

To determine petroleum savings, analysts calculated the average consumption of petroleum products per billion vehicle miles traveled (oil intensity) for light-duty vehicles and commercial light trucks in the Baseline Case. Analysts then multiplied the Baseline Case oil intensity by the VMTs traveled by gasoline fuel cell and hydrogen vehicles in the Hydrogen Program Case to estimate how much oil would be consumed if these VMTs were traveled by traditional gasoline vehicles. Finally, the gasoline consumed by gasoline fuel cell vehicles was subtracted to arrive at the total petroleum savings. These calculations are shown in **Table 5.26**.

Table 5.26. Calculation of Petroleum Savings

	2010	2020	2030	2040	2050
Baseline Case Oil Intensities (TBtu/billion VMT)					
Light-Duty Vehicles	6.59	6.37	6.22	6.12	5.98
Light Trucks	10.90	9.99	9.56	9.37	8.82
Gasoline Fuel Cell Vehicle (VMTs/yr)					
Light-Duty Vehicles	20.00	10.00	135.35	0.00	0.00
Light Trucks	0.00	0.00	0.00	0.00	0.00
Hydrogen Vehicle (VMTs/yr)					
Light-Duty Vehicles	0	45	582	1369	2037
Light Trucks	0	7	15	80	115
Petroleum Savings (TBtu/yr)					
Light-Duty Vehicles	10	290	4,053	8,376	12,186
Light Trucks	0	70	143	749	1,018
Total	**10**	**359**	**4,197**	**9,126**	**13,204**
Total (million barrels per day)	**0.00**	**0.17**	**1.98**	**4.31**	**6.24**

Carbon emission reductions accounted for both the reduced carbon emissions from burning gasoline, as well as increases in carbon emissions from the production of hydrogen, assuming no sequestration. If the hydrogen is produced at central facilities and the resulting carbon is sequestered, then the carbon savings will be accordingly larger in the projections below. These calculations are shown in **Table 5.27**.

Table 5.27. Calculation of Carbon Emission Reduction

	2010	2020	2030	2040	2050
Decreased CO2 Emissions from Decline in Gasoline Consumption					
Decrease in Gasoline Consumption (TBtu/yr)	10	359	4,197	9,126	13,204
Carbon Intensity of Gasoline (MT of Carbon per MMBtu)	19.3	19.3	19.3	19.3	19.3
Decline in Carbon (MMT/yr)	**0.2**	**7.0**	**81.2**	**176.5**	**255.3**
CO2 Emissions from Hydrogen Production					
Production of Hydrogen (TBtu/yr)	n.a.	134	1,196	2,825	4,010
Carbon Intensity of Hydrogen (MT of Carbon per MMBtu)	n.a.	12.2	22.5	25.3	29.2
Increase in Carbon (MMT/yr)	**n.a.**	**1.6**	**27.0**	**71.5**	**117.1**
Net decrease in Carbon Emissions (MMT/yr)	**0.2**	**5.4**	**54.2**	**105.0**	**138.2**

The carbon intensity of hydrogen varies significantly, because of the varying carbon content and market shares of the feedstocks used to produce hydrogen. Hydrogen production by feedstock is shown in **Table 5.28**. It should be noted that this analysis was conducted with a single-region MARKAL-GPRA05 model, and that the price of feedstocks and distribution costs are based on national averages. There is significant variation in regional fuel costs in the United States, and it is likely that during the development of a hydrogen infrastructure, these differences would lead to a greater diversity of hydrogen-production technologies than shown below. Furthermore, this analysis was conducted with only a subset of the full range of hydrogen-production technologies. Thus, this analysis may be biased toward hydrogen production from coal. Future efforts are planned to correct for these modeling limitations.

Table 5.28. Hydrogen Production by Feedstock
(% of total hydrogen production)

	2015	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Central Coal	0%	0%	46%	55%	60%	75%	84%	91%
Remote Natural Gas	100%	84%	33%	22%	12%	0%	0%	0%
Central Natural Gas	0%	0%	6%	7%	8%	6%	4%	0%
Central Biomass	0%	16%	14%	15%	20%	19%	12%	9%

Overall, the Hydrogen, Fuel Cells, and Infrastructure Technologies Program reduces gasoline consumption in the transportation sector through more efficient gasoline fuel cell vehicles and the deployment of hydrogen fuel cell LDVs and commercial light trucks (**Table 5.29**). Furthermore, the reduction in petroleum consumption leads to reduced carbon emissions. However, as noted above, these reductions in carbon emissions are partly offset due to carbon emissions from the production of hydrogen. The reductions in total energy-system costs arise from both the reduction in petroleum imports, as well as associated refining and distribution capacity. However, this is offset somewhat by the cost of establishing the hydrogen-production and -distribution infrastructure.

Table 5.29. FY05 Benefits Estimates for Hydrogen, Fuel Cells, and Infrastructure Technologies Program (MARKAL-GPRA05)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Nonrenewable Energy Savings (quadrillion Btu/yr)	0.2	2.8	6.4	9.2
Economic				
Energy-System Cost Savings (billion 2001 dollars/yr)	-6	16	51	79
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	5	54	105	138
Security				
Oil Savings (mbpd)	0.2	2.0	4.3	6.2
Natural Gas Savings (quadrillion Btu/yr)	-0.19	-0.56	-0.09	0.40

Industrial Technologies Program

The Industrial Technologies Program (ITP) covers a wide range of technologies, industries, and end-use applications. The overall goal of this program is to increase energy efficiency through R&D, as well as the deployment of new and improved technologies. The heterogeneity of the program's R&D activities makes it difficult to represent program activities explicitly in the MARKAL-GPRA05 framework. Instead, the projected ITP goals by various industries were aggregated into MARKAL-GPRA05 industrial energy-use demand categories as a set of conservation supply curves. Because this approach does not reflect economic competition nor interaction among program technologies, analysts reduced the off-line energy savings by an "integration factor" before these supply curves were constructed and input into the model (**Table 5.30**). The amount of the integration factor is based on how much program overlap or "integration" was captured by the off-line tools. The reduction is based on the expert judgment of the benefits analysis team.

Table 5.30. Industrial Program Integration Factors

Subprogram	Integration Factor
Industries of the Future	15%
Crosscutting R&D	30%
Industrial Assessment Centers	15%
Best Practices[6]	35%

The potential savings represented in these conservation measures are depicted in **Table 5.31**.

The implementation of the conservation curves characterized in the previous section yields an overall reduction in delivered energy consumption, as shown in **Table 5.32**.

The reduction in electricity demand also leads to the reduction in gas-based generation. Both conservation and reduction in electricity demand result in less investment in end-use devices and electric-generation capacity on the supply side (**Table 5.33**).

[6] The Best Practices activity was initially reduced by 50 percent. However, the program revised the Best Practices savings estimate, and the equivalent final reduction is roughly 35 percent.

Table 5.31. Industrial-Sector Conservation Curves (trillion Btu/year)

	2005	2010	2015	2020	2025	2030
Aluminum	0.0	3.9	20.0	43.6	39.1	31.2
Machine Drive						
Step 1	0.0	8.6	41.2	92.2	132.0	187.2
Step 2	0.0	1.2	7.9	26.3	35.5	31.9
Step 3	0.0	4.4	9.6	13.9	14.8	14.8
Step 4	0.0	49.5	70.0	73.4	71.7	71.7
Industrial Steam Heat						
Step 1	0.0	16.7	82.1	187.3	214.5	204.4
Step 2	0.0	7.8	48.2	158.6	205.4	129.0
Step 3	0.0	10.5	21.1	29.6	31.7	32.2
Step 4	0.0	119.4	152.3	153.7	155.6	157.7
Other Industrial Heat						
Step 1	0.0	13.8	64.7	143.4	161.2	149.0
Step 2	0.0	5.3	30.8	98.4	125.0	76.2
Step 3	0.0	7.1	13.5	18.4	19.3	19.0
Step 4	0.0	80.2	97.2	95.3	94.7	93.1
Petrochemicals and Nonenergy Use	0.0	2.9	15.4	43.3	62.0	78.8

Table 5.32. Delivered Energy Savings in the Industrial Sector (trillion Btu/year)

	2010	2015	2020	2025	2030	2040	2050
Petroleum	55	111	164	176	79	100	179
Natural Gas	229	459	854	997	919	919	919
Coal	38	59	74	71	65	61	6
Electricity	68	149	249	293	337	366	398
Heat	0	0	0	0	0	0	0
Renewable	0	0	0	0	0	0	9
Subtotal	**390**	**778**	**1,341**	**1,537**	**1,399**	**1,446**	**1,493**
Petrochemicals	3	15	43	62	79	83	88
Total	**392**	**794**	**1,385**	**1,599**	**1,478**	**1,529**	**1,581**

Table 5.33. FY05 Benefits Estimates for Industrial Technologies Program (MARKAL-GPRA05)

Annual Benefits	**2020**	**2030**	**2040**	**2050**
Energy Displaced				
Nonrenewable Energy Savings (quadrillion Btu/yr)	1.9	2.1	2.1	2.2
Economic				
Energy-System Cost Savings (billion 2001 dollars/yr)	14	13	15	15
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	35	38	34	41
Security				
Oil Savings (mbpd)	0.1	0.1	0.1	0.1
Natural Gas Savings (quadrillion Btu/yr)	1.16	1.12	1.57	1.26
Displaced Capacity (gigawatts)	19	19	18	23

Solar Energy Technologies Program

The Solar Energy Technologies Program covers solar water-heating technologies and photovoltaic (PV)-based electricity generation. The program goal is to lower the cost and improve performance of these technologies.

The Solar Energy Technologies Program Case includes characterization of several solar water heaters with backup systems and PV systems for electricity generation. Analysts base the characterization of solar water heaters for households on the capital cost reductions and reduced reliance on backup fuels as projected in the program objectives. The use of backup fuels is modeled as the percentage of total use. Thus, a 2020 solar water heater would rely on its backup fuel for 45 percent of the time. Analysts assume the efficiency of the backup system to be the efficiency of the least-expensive traditional water heater of the same vintage. Because the MARKAL-GPRA05 model assumes that homes will utilize the same fuel for water heat that is used for space heat, it was assumed that solar water heaters could use natural gas, electricity, and heating oil as the backup fuel.

Analysts modeled both centralized and decentralized PV power systems. The capital cost and O&M costs for both units are reduced to meet program goals. In addition, analysts set the discount rates of these technologies at 8 percent (instead of the industrial average of 10 percent) to reflect the accelerated depreciation schedule available for renewable-generation technologies. The total installed capacity of the decentralized units reflects the Million Solar Roofs installation goals for reducing end-use electricity demand from the central grid. Analysts model the centralized PV-generating systems to compete with conventional fossil fuel-based power plants. To reflect uncertainty in the availability of the solar resource, the potential contribution from these systems to meeting peak power demand is limited to 50 percent of installed capacity for central systems and 30 percent for distributed systems. This disadvantages PV in competing with fossil fuel-based plants, because additional reserve capacity is needed for PV systems. The cost and performance characteristics of the Solar Energy Technologies Program Case for water heaters and PV systems are shown in **Table 5.34**.

Likewise, solar photovoltaic capacity increases dramatically over the Baseline Case (**Table 5.36**). By 2050, the Solar Energy Technologies Program Case shows an additional 25.3 GW of photovoltaic capacity over the Baseline Case. However, potential improvements in central solar-thermal generation were not included in this analysis. Consequently, photovoltaics displace two GW of central solar-thermal capacity.

Central PV-generation technologies in the Solar Energy Technologies Program Case directly displace central gas-fired generation capacity. However, because of the solar technologies' lower availability factor and reduced contribution to peak power supply, the total gas capacity replaced is less than the installed solar capacity. Solar water heaters and rooftop PV reduce fuel use in residential water heating and end-use electricity demand from the central grid, reducing fossil fuel use, carbon emissions, and overall energy system cost. Benefits estimates for the Solar Energy Technologies Program are shown in **Table 5.37**

Table 5.34. Solar Program Technology Assumptions

Photovoltaics

Year	Central Generation Installed Price (2001$/kW)	Central Generation O&M (2001$/kW)	Residential Buildings Installed Price (2000$/kW)	Residential Buildings O&M (2000$/kW)	Commercial Buildings Installed Price (2000$/kW)	Commercial Buildings O&M (2000$/kW)
2003	5,300	60	9,450	160	6,250	160.0
2007	3,600	40	6,250	40	4,500	40.0
2020	2,000	10	2,800	10	2,800	10.0
2025	1,700	9	2,380	9	2,380	8.5
2030	1,445	7	2,023	7	2,023	7.2
2035	1,228	6	1,720	6	1,720	6.1
2040	1,105	6	1,548	6	1,548	5.5
2050	1,050	5	1,470	5	1,470	5.3

Solar Water Heaters

Vintage	Installed Cost	Backup Fuel Use
2000	2,300	50%
2010	2,000	48%
2020	1,000	45%
2030	680	36%
2040	680	33%

Table 5.35. Solar Water-Heater Market Share by Backup Fuel (% of total market)

	2000	2010	2020	2030	2040	2050
Electric	0%	0%	0%	8%	22%	21%
Natural Gas	0%	0%	0%	0%	11%	19%
Oil	0%	0%	0%	2%	13%	10%
Total	**0%**	**0%**	**0%**	**10%**	**46%**	**51%**

Table 5.36. Solar-Generation Capacity by Case and Type (gigawatts)

	2000	2010	2020	2030	2040	2050
Baseline Case						
Central Thermal	0.3	0.4	0.5	0.6	2.1	2.0
Central PV	0.0	0.1	0.3	2.9	8.8	8.7
Distributed PV	0.0	0.1	0.1	0.0	0.0	0.0
Total	**0.3**	**0.6**	**0.9**	**3.5**	**10.9**	**10.6**
Solar Program Case						
Central Thermal	0.3	0.4	0.5	0.4	0.2	0.0
Central PV	0.0	0.5	1.8	5.5	11.1	13.0
Distributed PV	0.0	0.8	4.0	9.1	21.5	21.0
Total	**0.3**	**1.8**	**6.2**	**15.0**	**32.7**	**34.0**
Increase						
Central Thermal	0.0	0.0	0.0	-0.1	-2.0	-2.0
Central PV	0.0	0.4	1.5	2.5	2.3	4.3
Distributed PV	0.0	0.7	3.9	9.1	21.5	21.0
Total	**0.0**	**1.1**	**5.4**	**11.5**	**21.8**	**23.4**

Table 5.37. FY05 Benefits Estimates for Solar Energy Technologies Program (MARKAL-GPRA05)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Nonrenewable Energy Savings (quadrillion Btu/yr)	0.11	0.41	1.51	1.61
Economic				
Energy-System Cost Savings (billion 2001 dollars/yr)	0.2	0.1	0.3	0.3
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	1	5	22	29
Security				
Oil Savings (mbpd)	ns	ns	ns	ns
Natural Gas Savings (quadrillion Btu/yr)	0.22	0.33	1.41	1.16
Capacity (gigawatts)	5	11	22	23

Vehicle Technologies Program

The Vehicle Technologies Program[7] consists of Hybrid Systems R&D, Advanced Combustion R&D, Heavy Systems R&D, and Materials Technologies R&D. The general goal of these R&D activities is to improve the efficiency and lower the cost of road vehicles.

Energy service demands for road transportation are measured in vehicle miles traveled (VMT). Projected VMTs are taken directly from the *Annual Energy Outlook 2003 (AEO 2003)* and extended past 2025 based on historical relationships between passenger and commercial VMTs, and population and economic growth. Projected VMTs for cars, light trucks[8], commercial light trucks,[9] and heavy trucks are shown in **Table 5.38**.

Table 5.38. Projected Vehicle Miles Traveled by Vehicle Class (billion VMTs/year)

Vehicle Class	2000	2010	2020	2030	2040	2050
Light-Duty Vehicles	2,355	3,004	3,753	4,417	4,868	5,241
Cars	1,498	1,649	1,992	2,325	2,382	2,288
Light Trucks	857	1,355	1,761	2,092	2,485	2,953
Commercial Light Trucks	69	84	107	134	157	177
Heavy Trucks	207	263	338	422	493	544

For each time period, these demands are met by a mix of vehicle types, selected by the model on the basis of total life-cycle costs. The vehicle type is characterized for each model year that it is available for purchase. The Baseline Case cost and efficiencies of these vehicles were derived from the *AEO2003* assumptions, with cost and efficiency improvements extrapolated for periods after 2025.

For the Vehicle Technologies Program Case, the costs and efficiencies for hybrid (HEV) and advanced diesel vehicles were changed for passenger cars, sport utility vehicles (SUVs),

[7] The Vehicle Technologies Program is run by the Office of FreedomCAR and Vehicle Technologies.

[8] Light trucks include trucks with a gross vehicle weight under 8,500 pounds and may include pickups, vans, or sport utility vehicles (SUVs).

[9] Commercial light trucks are light trucks with a gross vehicle weight between 8,500 and 10,000 pounds and may include pickups, vans, or SUVs.

commercial light trucks, and commercial heavy trucks. These changes reflect the results of the fuel combustion, hybrid systems, and materials R&D activities. Alternate cost and efficiency assumptions were provided for gasoline and diesel hybrid vehicles, as well as advanced diesel engines for use in passenger cars, SUVs, and commercial light trucks for the period 2010 to 2050. Cost and efficiency assumptions for diesel hybrid Class 3-6 trucks and advanced diesel Class 7-8 trucks also were provided for the period 2010 to 2040. The cost and efficiency assumptions were provided from the off-line analysis as ratios to conventional gasoline or diesel internal combustion engine-powered vehicles of that vintage. For example, a 2020 gasoline-hybrid passenger car with a cost ratio of 1.05 and an efficiency ratio of 1.7 would cost 5 percent more than the average 2020 traditional gasoline passenger car and have 70 percent better fuel economy. The cost and efficiency assumptions for passenger cars, SUVs, and commercial light trucks are shown in **Table 5.39**, while **Table 5.40** shows these assumptions for heavy trucks.

Table 5.39. Cost and Efficiency Assumptions for Light Duty Vehicles

	2010	2020	2030	2040	2050
Passenger Cars					
Cost Ratio to Conventional in Same Year					
Gasoline HEV	1.09	1.05	1.03	1.02	1.01
Advanced Diesel	1.07	1.04	1.02	1.02	1.02
Diesel HEV	1.12	1.07	1.05	1.04	1.04
Efficiency Ratio to Conventional in Same Year					
Gasoline HEV	1.50	1.70	1.90	2.00	2.00
Advanced. Diesel	1.40	1.50	1.50	1.60	1.60
Diesel HEV	1.70	1.90	2.10	2.19	2.27
Light Trucks and SUVs					
Cost Ratio to Conventional in Same Year					
Gasoline HEV	1.10	1.06	1.04	1.03	1.02
Advanced Diesel	1.08	1.05	1.03	1.02	1.02
Diesel HEV	1.13	1.09	1.07	1.06	1.05
Efficiency Ratio to Conventional in Same Year					
Gasoline HEV	1.35	1.50	1.60	1.62	1.64
Advanced Diesel	1.40	1.45	1.50	1.60	1.60
Diesel HEV	1.50	1.75	1.80	1.81	1.82

Table 5.40. Cost and Efficiency Assumptions for Heavy Trucks*

	2010	2020	2030	2040
Class 7-8 - Diesel				
Efficiency Ratio	1.03	1.18	1.31	1.33
Cost Ratio	1.05	1.02	1.01	1.01
Class 3-6 - Diesel Hybrid				
Efficiency Ratio	1.09	1.34	1.62	1.67
Cost Ratio	1.04	1.01	1.01	1.01

* Note: Ratios are compared to conventional vehicles in the same year.

The oil savings generated from the Vehicle Technologies Program are attributable to the market penetration of more efficient LDVs and heavy trucks. **Table 5.41** shows the market shares for traditional gasoline and alternative light-duty vehicles for the Vehicle Technologies Program Case, while **Table 5.42** shows transportation-sector petroleum consumption for the Baseline and Vehicles Technologies Program Case.

The reduction in transportation-sector petroleum consumption (**Table 5.43**) is due to both increased market share and fuel efficiency of alternative vehicles, particularly hybrid-electric vehicles. The reductions in total energy-system costs arise from both the reduction in petroleum imports, as well as associated refining and distribution capacity.

Table 5.41. Light-Duty Vehicle Market Shares for the Vehicles Technologies Program Case (% of total fleet)

	2000	2010	2020	2030	2040	2050
Gasoline	100%	93%	84%	63%	22%	0%
Hybrid	0%	3%	15%	36%	77%	100%
Advanced Diesel and Other	0%	3%	1%	0%	0%	0%

Table 5.42. Petroleum Consumption by Vehicle Class and Case (trillion Btu/year)

	2000	2010	2020	2030	2040	2050
Baseline Case						
Light-Duty Vehicles	14,826	19,801	23,911	27,469	29,789	31,350
Commercial Light Trucks	654	916	1,069	1,279	1,468	1,559
Heavy Trucks	4,215	5,549	7,065	8,002	9,255	10,014
Vehicle Technologies Program Case						
Light-Duty Vehicles	14,826	19,540	22,802	23,512	20,141	18,339
Commercial Light Trucks	654	977	1,012	1,214	1,070	1,110
Heavy Trucks	4,215	5,549	6,905	6,303	7,006	7,500
Savings						
Light-Duty Vehicles	0	261	1,108	3,957	9,648	13,011
Commercial Light Trucks	0	-62	57	64	397	449
Heavy Trucks	0	0	159	1,699	2,249	2,514
Total Transportation Sector	0	199	1,325	5,720	12,295	15,974

Table 5.43. FY05 Benefits Estimates for Vehicle Technologies Program (MARKAL-GPRA05)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Nonrenewable Energy Savings (quadrillion Btu/yr)	1.31	5.88	12.36	16.24
Economic				
Energy-System Cost Savings (billion 2001 dollars/yr)	18	25	83	150
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	25	117	241	317
Security				
Oil Savings (mbpd)	0.6	2.8	5.8	7.6
Natural Gas Savings (quadrillion Btu/yr)	-0.03	-0.30	-0.03	0.03

The Weatherization and Intergovernmental Program

The Weatherization and Intergovernmental Program (WIP) Case formulated in MARKAL-GPRA05 focuses on deployment programs that have impact on the energy consumption in the residential sector and vehicle fuel use. Projected program goals of the Weatherization Assistance

Program, Rebuild America, and Code Training and Assistance are transformed into conservation-supply curves that reduce the heating and cooling loads in households benefiting from these programs. **Table 5.44** depicts the projected funds and program goals of the Weatherization Assistance Program used to develop the MARKAL-GPRA05 input.

The aggregated conservation supply curves estimated for MARKAL-GPRA05 (**Table 5.45**) are consistent with the potential savings projected in NEMS. Analysts distributed the aggregated market potentials in proportion to household savings in the four MARKAL-GPRA05 residential regions: Northeast, Midwest, South, and West.

Table 5.44. Weatherization Assistance Program Projected Budget and Goals[10]

Year	Funds for Houses	Cost per House	No. Houses Weatherized	Annual Total Houses Weatherized	SITE Energy Savings (TBtu/yr)	Single-Family Home Savings (TBtu/yr)	Mobile Home Savings (TBtu/yr)	Multi-family Home Savings (TBtu/yr)
2005	$ 531,640,642	$ 2,391	222,395	222,395	6.97	4.46	1.39	1.12
2010	$ 569,455,081	$ 2,463	231,243	1,360,565	42.68	27.31	8.54	6.83
2015	$ 577,584,873	$ 2,478	233,119	2,526,161	79.28	50.74	15.86	12.68
2020	$ 577,584,873	$ 2,478	233,119	3,469,363	108.91	69.7	21.78	17.43
2025	$ 577,584,873	$ 2,478	233,119	3,496,788	109.81	70.28	21.96	17.57
2030	$ 577,584,873	$ 2,478	233,119	3,496,788	109.81	70.28	21.96	17.57

Table 5.45. Residential-Sector Conservation Curves (trillion Btu/year)

	2010	2020	2030	2040	2050
Heating	40.6	97.5	129.9	136.0	140.4
Cooling	0.0	0.0	27.0	28.6	29.6

In addition to the heating and cooling supply curves, the compact fluorescent light (CFL) technology included in these programs is specifically modeled in MARKAL-GPRA05 to compete with the conventional incandescent light in households. The deployment of CFL is achieved by lowering the Baseline Case hurdle rate of 44 percent to the normal rate of 18 percent. An upper bound of CFL's market penetration is imposed to reflect the program goals of increasing the market share of lighting service demand met by CFL. This increasing trend of CFL's market share is projected to continue in the long run (**Table 5.46**).

Table 5.46. Compact Florescent Market Penetration (10^{12} lumen-second)

	2010	2020	2030	2040	2050
Penetration	2,456	9,045	14,726	18,395	20,828

Analysts modeled the Clean Cities Program based on program estimates of alternative-fueled vehicle market penetration, as shown in **Table 5.47**. These vehicles were then allocated to different vehicle classes and fuel types by the breakdown of the 2002 fleet (**Table 5.48**).

[10] See Appendix K for additional documentation on these goals.

Table 5.47. Projection of Baseline Case and Clean Cities Program Case Alternative-Fueled Vehicles (number of vehicles on the road)

	Baseline Case	Program Case	Additional Vehicles due to Program
2000	321,495	432,344	n.a.
2005	337,894	566,709	228,815
2010	355,130	723,431	368,301
2015	373,245	936,661	563,415
2020	392,284	1,230,259	811,353
2025	412,295	1,638,871	1,194,843

Table 5.48. Alternative-Fueled Vehicles by Type and Class, 2002

	Total	LDV	% of LDV	HDV	% of HDV
CNG	66,197	55,923	45%	10,274	38%
LNG	2,158	88	0%	2,070	8%
Propane	29,203	24,027	19%	5,176	19%
Ethanol	29,229	29,173	24%	56	0%
Electric	4,244	3,935	3%	309	1%
Biodiesel	16,970	7,806	6%	9,164	34%
Methanol	787	771	1%	16	0%
Neighborhood Electric	1,955	1,955	2%	0	0%
Other	485	430	0%	55	0%
Total	**151,228**	**124,108**	**100%**	**27,120**	**100%**

The program goals of Inventions and Innovations and the State Energy Program were not modeled in the WIP Program Case, because of insufficient data to develop the input required in MARKAL-GPRA05. **Tables 5.49 and 5.50** depict the energy savings by end-use demand and fuel type in the residential sector mainly due to the Weatherization Assistance Program and CFL modeled in MARKAL-GPRA05.

Table 5.51 reports the change of fuel mix in transportation fuel generated from the use of Clean Cities Vehicles. It is highlighted by the penetration of natural gas (CNG) as a transportation to replace gasoline and diesel fuels.

Table 5.49. Delivered Energy Demand Reductions in the Residential Sector (trillion Btu/year)

	2010	2020	2030	2040	2050
Reductions by Demand Service					
Space Heating	38	85	182	157	172
Space Cooling	-1	-2	10	8	8
Water Heating	4	15	23	2	3
Lighting	100	191	184	160	106
Other	0	0	0	0	0
Total	**140**	**290**	**400**	**328**	**288**
Reduction by Fuel					
Petroleum	-6	-1	38	55	85
Natural Gas	19	71	189	103	99
Coal	19	3	2	0	2
Electricity	109	216	170	170	104
Total	**140**	**290**	**400**	**328**	**289**

Table 5.50. Delivered Energy Demand Reductions in the Commercial Sector (trillion Btu/year)

	2010	2020	2030	2040	2050
Reductions by Demand Service					
Space Heating	-3	-1	3	0	-9
Space Cooling	0	0	1	0	1
Water Heating	0	0	0	0	0
Lighting	1	2	2	2	2
Other	0	0	0	0	0
Total	**-3**	**1**	**6**	**2**	**-7**
Reduction by Fuel					
Petroleum	0	1	0	0	0
Natural Gas	-15	-7	-10	0	8
Coal	0	0	0	0	0
Electricity	12	7	15	2	-15
Total	**-3**	**1**	**6**	**2**	**-7**

Table 5.51. Reduction in Fuel Consumption in the Transportation Sector (trillion Btu/year)

	2010	2020	2030	2040	2050
Petroleum	-32	17	84	249	581
Gasoline	-32	-40	-17	75	330
Distillate	0	64	114	190	291
Jet Fuel	0	0	0	0	0
LPG	0	-6	-12	-16	-40
Residual Fuel	0	0	0	0	0
Natural Gas	28	-38	-113	-262	-569
Ethanol	-2	-4	-9	-20	-45
Total	**-6**	**-26**	**-38**	**-36**	**-33**

The reduction in electricity demand in residential space conditioning and lighting also leads to the reduction in gas-based generation in the long run. Both conservation and reduction in electricity demand result in fewer investments in end-use devices and electric-generation capacity on the supply side. This is another factor attributable to the overall reduction in energy-system cost and carbon emissions, in addition to direct energy savings (**Table 5.52**).

Table 5.52. FY05 Benefits Estimates for Weatherization and Intergovernmental Program (MARKAL-GPRA05)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Nonrenewable Energy Savings (quadrillion Btu/yr)	0.8	0.6	0.5	0.5
Economic				
Energy System Cost Savings (billion 2001 dollars/yr)	4	5	6	5
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	16	9	10	12
Security				
Oil Savings (mbpd)	0.0	0.1	0.1	0.3
Natural Gas Savings (quadrillion Btu/yr)	0.37	0.43	0.20	-0.45
Displaced Capacity (gigawatts)	6	6	6	2

Wind and Hydropower Technologies Program

The goal of the wind component under the Wind and Hydropower Technologies Program is to reduce the cost and improve the performance of wind generators. The Hydropower Program seeks to reduce the environmental impact of hydroelectric facilities through improved turbine design and operating practices. Reducing the environmental impact of these facilities ensures that they will be relicensed, maintaining overall hydroelectric-generating capacity.

The Wind Program R&D aims to reduce capital and O&M costs and improve capacity factors for wind turbines. 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 coincide with the program goals as represented in **Table 5.53**.

Table 5.53. 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%

The discount rate for wind generators is set at 8 percent (instead of the utility average of 10 percent) 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 percent, 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 are very competitive with fossil fuel-based power plants.

For the Hydropower Program, the projected capacity and electricity output represented in the MARKAL-GPRA05 Baseline Case was reduced from the *AEO2003* reference projection levels to account for the reduction in capacity and generation resulting from environmental concerns during the relicensing process. These reductions were taken from program estimates and indicate that a total of 4.7 GW of hydro capacity and 19.7 billion kWh of hydro generation would be lost between 2000 and 2010. For the Hydropower Technologies Program Case, it was assumed that, due to improved turbines, no hydro capacity would be lost through the relicensing process; and that improved operations would result in an additional 1.1 billion kWh of hydrogenation in 2010 and 5.3 billion kWh in 2020 to *AEO2003* levels.

The improvements in wind turbines result in a significant increase in installed wind generation capacity over the Baseline Case. Total wind generation increases due to both the increase in total installed capacity and the increase in capacity factors. The change in wind capacity and generation is shown in **Table 5.54**.

For the Hydopower Program, total hydropower capacity returns to *AEO2003* levels, while improved operations result in additional hydropower generation. These results are shown in **Table 5.55**.

In the Wind and Hydropower Technologies Program Case, wind and hydropower generation directly displaces gas-fired and coal-based generation. However, because of wind's lower availability and reduced contribution to peak, the total gas and coal generation capacity replaced is less than the wind capacity installed.

Table 5.54. Total Wind Capacity and Generation

	2000	2010	2020	2030	2040	2050
Wind Capacity (GW)						
Baseline Case	4.0	7.1	10.3	23.0	53.6	66.1
GPRA Case	4.0	12.1	37.4	73.0	114.5	186.7
Increase	**0.0**	**5.0**	**27.1**	**50.1**	**60.9**	**120.6**
Wind Generation (Billion kWh/year)						
Baseline Case	11.2	22.4	35.9	83.1	193.2	240.2
GPRA Case	11.2	40.4	149.9	296.6	467.1	763.0
Increase	**0.0**	**18.0**	**114.0**	**213.5**	**273.9**	**522.8**
Wind % of Total Capacity						
Baseline Case	0.5%	0.7%	0.9%	1.6%	3.5%	3.8%
GPRA Case	0.5%	1.3%	3.2%	5.1%	7.4%	10.2%
Wind % of Total Generation						
Baseline Case	0.3%	0.5%	0.7%	1.3%	2.7%	2.9%
GPRA Case	0.3%	0.9%	2.7%	4.7%	6.5%	9.3%

Table 5.55. Total Hydropower Capacity and Generation

	2000	2010	2020	2030	2040	2050
Total Capacity (GW)						
Baseline Case	79.0	74.3	74.3	74.3	74.3	74.3
GPRA Case	79.0	79.0	79.0	79.0	79.0	79.0
Increase	**0.0**	**4.7**	**4.7**	**4.7**	**4.7**	**4.7**
Total Generation (Billion kWh/year)						
Baseline Case	301.7	282.0	280.7	280.7	280.7	280.7
GPRA Case	301.7	302.9	307.0	307.0	307.0	307.0
Increase	**0.0**	**20.8**	**26.3**	**26.3**	**26.3**	**26.3**

The estimated benefits of for the Wind and Hydropower Programs are shown in **Tables 5.56 and 5.57**, respectively.

Table 5.56. FY05 Benefits Estimates for Wind Program (MARKAL-GPRA05)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Nonrenewable Energy Savings (quadrillion Btu/yr)	1.21	1.81	2.34	4.01
Economic				
Energy-System Cost Savings (billion 2001 dollars/yr)	3	4	6	6
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	26	35	46	85
Security				
Oil Savings (mbpd)	ns	ns	0.1	ns
Natural Gas Savings (quadrillion Btu/yr)	0.49	0.84	1.31	1.56
Capacity (gigawatts)	27	50	61	121

Table 5.57. FY05 Benefits Estimates for Hydropower Program (MARKAL-GPRA05)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Nonrenewable Energy Savings (quadrillion Btu/yr)	0.27	0.22	0.23	0.24
Economic				
Energy-System Cost Savings (billion 2001 dollars/yr)	2	2	2	2
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	4	3	3	3
Security				
Oil Savings (mbpd)	ns	ns	ns	ns
Natural Gas Savings (quadrillion Btu/yr)	0.26	0.20	0.23	0.25
Capacity (gigawatts)	5	5	5	5

Box 5.1—The MARKAL Model

The U.S. MARKAL model is a technology-driven linear optimization model of the U.S. energy system that runs in five-year intervals over a 50-year projection period. MARKAL provides a framework to evaluate all resource and technology options within the context of the entire energy/materials system, and captures the market interaction among fuels to meet demands (*i.e.*, competition between gas and coal for electric generation). The model explicitly tracks the vintage structure of all capital stock in the economy that produces, transports, transforms, or uses energy.

In MARKAL, the entire energy system is represented as a network, based on the reference energy system (RES) concept. The RES depicts all possible flows of energy from resource extraction, through energy transformation, distribution, and transportation; to end-use devices that satisfy the demands of useful energy services (e.g., vehicle miles traveled, lumen-second in lighting). **Figure 5.2** illustrates a simplified RES in graphical form. The U.S. MARKAL has detailed technical representations of four end-use sectors (residential, commercial, industrial, and transportation), as well as fossil fuel and renewable resources, petroleum refining, power generation, hydrogen production, and other intermediate conversion sectors. Cross comparisons of MARKAL outputs provide detailed technical and economic information to use in estimating the programs' benefits.

Technology choice in the MARKAL framework is based on the present value of the marginal costs of competing technologies in the same market sector. On the demand side, the marginal cost of demand devices is a function of levelized capital cost, O&M cost, efficiency, and the imputed price of the fuel used by these devices. For a specific energy-service demand and time period, the sum of the energy-service output of competing technologies has to meet the projected demand in that period. The relative size of the energy-service output (market share) of these technologies depends not only on their individual characteristics (technical, economic, and environmental), but also on the availability and cost of the fuels (from the supply side) they use. The actual market size of a demand sector in a future time period depends on the growth rate of the demand services and the stock turnover rate of vintage capacities. MARKAL dynamically tracks these changes and defines future market potentials. Another factor considered in MARKAL, which affects the market penetration of a specific demand device, is the sustainability of the expansion in the implied manufacturing capacity to produce these devices. For EERE R&D programs that have independently projected the market potentials of their technologies, an initial market penetration (combined with an annual growth rate limit) was imposed in MARKAL to replicate these potentials for assessing the benefits of these technologies.

On the supply side, technology choice made in MARKAL is based on the imputed price of the energy products and the marginal cost of using these products downstream in the demand sectors. The cost of resource input for production (exogenously projected in MARKAL) such as imported oil prices and cost of biomass feedstock, together with the characteristics of supply technologies (including electricity generation) determine the market share of a particular fuel type (including renewables) and the technology that produces it. The supply-demand balance achieved for all fuels under the least energy-system cost represents a partial equilibrium in the energy market.

Figure 5.2. An Illustrative Reference Energy System