CHAPTER 5

LONG-TERM BENEFITS ANALYSIS OF EERE'S PROGRAMS

Introduction

This chapter provides an overview of the modeling approach used in MARKAL-GPRA06 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-GPRA06.

The Baseline Case used to evaluate the impact of the EERE portfolio was benchmarked to EIA's *Annual Energy Outlook 2004* (*AEO2004*) for the period between 2000 and 2025. To the extent possible, the same input data and assumptions were used in MARKAL-GPRA06 as were used to generate the *AEO2004* Reference Case. For example, the macroeconomic projections for GDP, housing stock, commercial square footage, industrial output, and vehicle miles traveled were taken from the *AEO2004*. At the sector level, both supply-side and demand-side technologies were characterized to reflect the *AEO2004* 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 *AEO2004* 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 2003 *Annual Report* to the Board of Trustees. **Appendix A** provides a more complete discussion of the MARKAL-GPRA06 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-GPRA06. 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 off-line analysis served to feed appropriate parameters and other factors into MARKAL-GPRA06, 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-GPRA06 modeling, or that the results of the Industrial Technologies Program analysis are not impacted by the MARKAL-GPRA06 modeling.

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

Program	Activities	Off-Line Tools	MARKAL-GPRA06
Biomass	Bio-based Products	✓	
	Cellulosic Ethanol	✓	
Buildings Technologies	Residential Sector	✓	✓
	Commercial Sector	✓	✓
DE	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 Technologies	Wind		✓

The following sections summarize how each EERE R&D program is formulated in MARKAL-GPRA06. In many cases, analysts convert the technological data and their projected market potentials in each program directly to MARKAL-GPRA06 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-based refineries (biorefineries), which produce a range of products including cellulosic ethanol and/or other fuels, chemicals, materials, and/or electricity. The biorefinery concept allows the cost of production to be reduced through synergies associated with feedstock handling and processing, and the allocation of capital and fixed O&M costs across multiple products. For the current analysis, we modeled two types of biorefineries. The first type produces chemicals and materials, but not fuels, and the second type produces ethanol fuel as the major output. Future analyses may include additional fuels that the program identifies in the longer term.

Bio-based products: At this early stage of biorefinery R&D, the output and cost of the nonfuel biorefineries (producing only chemicals and materials) are not yet well defined. Program goals are estimated off-line and represented in MARKAL-GPRA06 as reductions in petroleum and natural gas demand for feedstocks. Off-line projections of the use of petroleum and natural gas as chemical feedstock are represented in a highly aggregated manner and 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-GPRA06 model as a conservation curve 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)	1.13	3.53	11.68	35.66	71.54
Coal (TBtu/yr)	-0.15	-0.47	-1.56	-4.75	-9.54
Electricity (Billion kWh/yr)	-0.15	-0.47	-1.56	-4.75	-9.54
Distillate (TBtu/yr)	1.13	3.53	11.68	35.66	71.54
Oil Feedstock (TBtu/yr)	2.75	8.62	28.54	87.17	174.86
Total (TBtu/yr)	**4.70**	**13.60**	**45.03**	**137.51**	**275.85**

Corn and cellulosic ethanol: EERE is sponsoring research aimed at reducing the cost of producing ethanol from cellulosic biomass.[1] The second type of biorefineries assumed in this analysis is one that focuses on the production of ethanol, lignin-derived electricity and a small quantity of chemical coproducts. In the Biomass Program Case, the conversion of corn fiber and residual starch to ethanol becomes available for dry mills beginning in 2012 and yields a 20 percent increase in a dry mill's ethanol output. Corn stover-to-ethanol technology becomes available in 2018, whereas sugar-based biorefineries producing ethanol as a major product, along with high-value coproducts, from corn stover and other cellulosic wastes and residues, become available in 2024. Currently, the MARKAL-GPRA06 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 (e.g., ELSAS Bioref) are used for both the Baseline and Program Cases. **Table 5.3** depicts the production of cellulosic and corn ethanol set in MARKAL-GPRA06, which reflects corn and 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	3,733	4,018	3,644	3,531	3,531
Corn Fiber & Residual Starch	0	0	340	474	459	459
Cellulosic	0	0	0	3,600	9,000	13,200
Total	**1,600**	**3,733**	**4,357**	**7,718**	**12,990**	**17,190**

The benefits of the Biomass Program derived in MARKAL-GPRA06 (**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. FY06 Benefits Estimates for Biomass Program (MARKAL-GPRA06)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	0.05	0.23	0.71	1.13
Economic				
Energy-System Cost Savings (billion 2002 dollars/yr)	0.0	0.2	0.5	0.6
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	1	4	12	19
Security				
Oil Savings (mbpd)	0.05	0.09	0.29	0.40
Natural Gas Savings (quadrillion Btu/yr)	-0.08	0.02	0.06	0.16

Building Technologies Program

MARKAL-GPRA06 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-GPRA06 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. 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-GPRA06.

Technologies that lower service demand (*e.g.*, building shell technologies, lighting controls) are modeled in MARKAL-GPRA06 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. 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, 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-GPRA06 is limited to a sustainable growth path that generates a potential market penetration path consistent with the program goals.

Regulatory activities: Analysts represent new appliance standards and building codes in MARKAL-GPRA06 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-GPRA06 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-GPRA06 limit near-term energy savings.

In MARKAL-GPRA06, 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 light bulb 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-GPRA06.

While the Building Technologies Program conducts research on a variety of technologies and applications, the three activities with the highest potential in the GPRA06 analysis are Solid State Lighting, Residential and Commercial Unitary DX System, and Building America. For solid-state lighting, the Building Technologies Program is conducting research to improve the efficiency and reduce the cost of the lamps. Unitary DX Systems research aims to double the efficiency of both residential and commercial space cooling and heat pump technologies with only a 10 percent increase in cost (by 2020).

The goal of the Build America Program is to improve efficiency of new and existing homes through research, development, demonstrations, and technology transfer strategies using the whole buildings approach. This program was modeled as a series of three conservation curves for residential space heating and cooling demands. The first conservation curve represents the incremental cost to reduce energy consumption by 20 percent, while the next two supply curves represent the incremental cost to reduce energy consumption by a further 20 percent and 10

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[2] The hurdle rates in MARKAL-GPRA06 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.

percent, respectively. The technology assumptions for these activities are shown in **Tables 5.5, 5.6**, and **5.7**.

Table 5.5. Solid-State Lighting Technologies

	2010	2020	2030	2040	2050
Efficacy (lumens/watt)	60	118	153	162	162
Price ($/kilolumen)	$126.93	$9.91	$4.09	$4.00	$4.00

Table 5.6. Residential and Commercial Unitary DX System Technologies

	2010	2015	2020	2025
Incremental Cost (percent)	100%	89%	64%	10%
Incremental Efficiency (percent)	100%	100%	100%	100%

Table 5.7. Building America Building Shell Cost Assumptions (2001$/MMBtu)

	2010	2015	2020
North			
Step 1	$21.2	$15.9	$10.7
Step 2	$196	$147	$98
Step 3	$258	$194	$129
Midwest			
Step 1	$29	$22	$15
Step 2	$240	$180	$120
Step 3	$240.7	$180.6	$120.4
South			
Step 1	$30	$22	$15
Step 2	$279.9	$209.9	$140.0
Step 3	$353	$265	$176
West			
Step 1	$18.2	$13.6	$9.1
Step 2	$211	$158	$106
Step 3	$215	$161	$107

For information on the other Technologies Program inputs, please refer to **Appendix C.**

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.

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

	2010	2020	2030	2040	2050
Reduction by Service Demand					
Space Heating	42	284	502	660	641
Space Cooling	20	69	132	169	201
Water Heating	0	0	-1	-16	-28
Lighting	0	11	56	148	279
Other	0	0	0	0	0
Total	**62**	**364**	**690**	**961**	**1,093**
Reduction by Fuel					
Petroleum	1	37	92	124	131
Natural Gas	35	243	380	410	252
Coal	0	2	0	1	0
Electricity	27	82	218	425	710
Total	**62**	**364**	**690**	**961**	**1,093**

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	0	38	42	42	36
Space Cooling	3	24	44	36	30
Ventilation Equipment	5	19	41	26	2
Water Heating	0	0	0	0	0
Lighting	3	61	201	435	781
Other	0	0	0	0	0
Total	**11**	**141**	**327**	**539**	**849**
Reduction by Fuel					
Petroleum	6	38	18	13	-1
Natural Gas	-12	-18	-41	-37	-30
Coal	0	0	0	0	0
Electricity	16	120	350	562	879
Total	**11**	**141**	**327**	**539**	**849**

Table 5.10. FY06 Benefits Estimates for Building Technologies Program (MARKAL-GPRA06)

Annual Benefits	**2020**	**2030**	**2040**	**2050**
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	1.3	2.4	3.5	4.2
Economic				
Energy-System Cost Savings (billion 2002 dollars/yr)	12.8	28.7	43.3	62.4
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	23	45	64	92
Security				
Oil Savings (mbpd)	0.06	0.06	0.10	0.08
Natural Gas Savings (quadrillion Btu/yr)	0.81	1.42	2.26	1.38
Electricity Capacity Avoided (gigawatts)	24	62	76	108

Distributed Energy Program

The Distributed Energy (DE) 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 DE Program Case in MARKAL-GPRA06 is formulated by the introduction and performance improvements in industrial and commercial sector combined heat and power technologies and a 1 MW distributed electric utility generator to meet local peaking demands. All of these technologies are modeled explicitly as decentralized systems in MARKAL-GPRA06 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.

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 DE Program. The assumptions for commercial, industrial, and distributed electric utility technologies are shown in **Tables 5.11**, **5.12** and **5.13,** respectively.

Table 5.11. Commercial Sector Distributed Generation Technology Assumptions

	2005	2010	2015	2020	2025
200 kW Gas Engine					
Installed Cost (2001$/kW)	$1,112	$793	$729	$729	$729
Electric Efficiency	32%	39%	39%	39%	39%
Overall Efficiency	88%	92%	92%	92%	92%
1 MW Gas Turbine					
Installed Cost (2001$/kW)	$1,781	$1,653	$1,597	$1,542	$1,514
Electric Efficiency	23%	28%	28%	28%	28%
Overall Efficiency	77%	84%	84%	84%	84%
100 kW Micro Turbine					
Installed Cost (2001$/kW)	$1,595	$1,317	$1,212	$1,212	$1,212
Electric Efficiency	30%	36%	37%	38%	39%
Overall Efficiency	71%	80%	81%	81%	81%

Table 5.12. Industrial Sector Distributed Generation Technology Assumptions

	2005	2010	2015	2020	2025
1 MW Internal Combustion Engine					
Installed Cost (2001$/kW)	$914	$643	$592	$592	$592
Overall Heat Rate (Btus/kWh)	9,871	8,066	8,066	8,066	8,066
Overall Efficiency	71%	75%	75%	75%	75%
3 MW Internal Combustion Engine					
Installed Cost (2001$/kW)	$909	$639	$588	$588	$588
Overall Heat Rate (Btus/kWh)	9,538	7,797	7,797	7,797	7,797
Overall Efficiency	69%	73%	73%	73%	73%

1 MW Gas Turbine					
Installed Cost (2001$/kW)	$1,881	$1,881	$1,881	$1,881	$1,881
Overall Heat Rate (Btus/kWh)	15,580	12,030	12,030	12,030	12,030
Overall Efficiency	65%	73%	73%	73%	73%
5 MW Gas Turbine					
Installed Cost (2001$/kW)	$986	$932	$879	$827	$773
Overall Heat Rate (Btus/kWh)	12,344	9,721	9,721	9,721	9,721
Overall Efficiency	67%	75%	75%	75%	75%
10 MW Gas Turbine					
Installed Cost (2001$/kW)	$900	$860	$821	$778	$738
Overall Heat Rate (Btus/kWh)	11,551	9,084	9,084	9,084	9,084
Overall Efficiency	69%	77%	77%	77%	77%
25 MW Gas Turbine					
Installed Cost (2001$/kW)	$776	$747	$717	$694	$664
Overall Heat Rate (Btus/kWh)	9,817	7,679	7,679	7,679	7,679
Overall Efficiency	70%	78%	78%	78%	78%
40 MW Gas Turbine					
Installed Cost (2001$/kW)	$688	$677	$667	$650	$640
Overall Heat Rate (Btus/kWh)	9,146	7,119	7,119	7,119	7,119
Overall Efficiency	72%	81%	81%	81%	81%
100 MW Combined Cycle					
Installed Cost (2001$/kW)	$677	$667	$658	$645	$635
Overall Heat Rate (Btus/kWh)	6,894	6,400	6,400	6,400	6,400
Overall Efficiency	70%	84%	85%	85%	86%

Table 5.13. Electric Utility Distributed Peaker Technology Assumptions

	2005	2010	2015	2020	2025
Installed Cost (2001$/kW)	$523	$641	$631	$621	$621
Heat Rate (Btus/kWh)	10,169	8,348	8,298	8,249	8,249
Variable O&M (mills/kWh)	19.8	15.9	15.9	15.9	15.9

In addition to the GPRA Scenario technology assumption changes, the Baseline Case assumptions for these technologies were changed from those used to create the 2004 AEO projection. The Baseline Case assumptions for distributed technologies were changed such that the cost and efficiency of these distributed generation technologies would achieve the same levels in the DE GPRA Scenario with a 10-year delay. Thus, the Baseline Case assumptions for the industrial sector 1MW gas engine technology in 2025 would be the same as the GPRA Scenario assumptions for 2015. This assumption change results in increased penetration of distributed generation technologies in the Baseline Case, relative to the penetration of these technologies using the 2004 AEO cost and efficiency assumptions. The MARKAL-GPRA06 results show accelerated market penetration of DE technologies relative to the Baseline Case. However, by 2050 the incremental installed capacity is diminished and is primarily the result of cumulative capacity investment. The installed distributed generation capacity is shown in **Table 5.14.**

Table 5.14. Installed Distributed Generation Capacity by Sector and Case (gigawatts)

	2010	2020	2030	2040	2050
Baseline Scenario					
Buildings	2	5	15	28	29
Industry	33	43	54	67	78
Electric Utility	1	11	36	82	72
Total	**36**	**59**	**105**	**177**	**179**
GPRA Scenario					
Buildings	2	5	12	26	27
Industry	35	49	62	75	80
Electric Utility	1	15	46	97	88
Total	**37**	**69**	**121**	**198**	**195**
Increase					
Buildings	0	0	-3	-1	-1
Industry	1	6	9	8	2
Electric Utility	0	4	10	14	16
Total	**1**	**10**	**16**	**21**	**16**

With the increase in distributed generation capacity, MARKAL-GPRA06 directly reduces the investment in central gas and coal-fired generators. On the demand side, the heat generated 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 5.15**).

Table 5.15. FY06 Benefits Estimates for DE Program (MARKAL-GPRA06)

Annual Benefits	**2020**	**2030**	**2040**	**2050**
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	0.4	0.4	0.5	0.3
Economic				
Energy-System Cost Savings (billion 2002 dollars/yr)	1.3	2.1	1.3	1.4
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	8	10	10	4
Security				
Oil Savings (mbpd)	0.08	0.03	0.05	0.03
Natural Gas Savings (quadrillion Btu/yr)	0.05	0.03	0.13	0.31
Capacity (gigawatts)	11	20	22	17
Total Displaced Need for New Electric Capacity (gigawatts)	9	25	22	17

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 5.16**. For the period after 2030, the amount of energy displaced was held constant.

Table 5.16. FEMP Annual Energy Savings Projections

Year	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)
2006	0.45	1.37	0.11	0.022
2007	0.85	2.82	0.20	0.048
2008	1.22	4.29	0.30	0.071
2009	1.61	5.61	0.40	0.094
2010	2.01	6.88	0.49	0.115
2015	2.41	10.78	0.73	0.171
2020	2.98	13.80	0.97	0.220
2025	3.61	16.59	1.18	0.264
2030	4.09	19.63	1.38	0.307

In order to quantify the broader benefits of these savings in MARKAL-GPRA06, 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 5.16**. 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 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 5.17**.

Table 5.17. FY06 Benefits Estimates for FEMP (MARKAL-GPRA06)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	0.06	0.08	0.07	0.06
Economic				
Energy-System Cost Savings (billion 2002 dollars/yr)	2.4	3.5	3.5	3.6
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	1	1	0	0
Security				
Oil Savings (mbpd)	0.00	0.00	0.00	0.01
Natural Gas Savings (quadrillion Btu/yr)	0.06	0.06	0.05	0.05

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-GPRA06 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 represented in the MARKAL-GPRA06 model's reference case scenario. 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 5.18** 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 5.18. EGS Generation Assumptions

		2000 Cost		2050 Cost	
EGS Type	Projected Resource MWe	Capital Cost 2002$/kW	O&M 2002$/kW/yr	Capital Cost 2002$/kW	O&M 2002$/kW/yr
I	3,400	$2,486	$155	$949	$51
II	25,000	$2,859	$179	$1,091	$59
III	60,000	$3,232	$202	$1,233	$67

Geothermal plants compete directly with fossil fuel-based plants for both electricity generation and meeting peak power requirements. In MARKAL-GPRA06, 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 5.19** shows both Baseline Case and Geothermal Technologies Program Case capacity, while **Table 5.20** shows geothermal power generation for both cases.

Table 5.19. Total Geothermal Capacity by Type (gigawatts)

	2000	2010	2020	2030	2040	2050
Baseline Case						
Conventional	2.9	3.9	7.7	8.2	11.4	10.9
EGS	0.0	0.0	0.0	0.0	0.0	0.0
Total	**2.9**	**3.9**	**7.7**	**8.2**	**11.4**	**10.9**
Geothermal Program Case						
Conventional	2.9	4.3	9.4	11.2	13.5	12.9
EGS	0.0	0.0	1.0	8.0	23.4	36.1
Total	**2.9**	**4.3**	**10.4**	**19.1**	**36.9**	**49.0**
Increase						
Conventional	0.0	0.4	1.7	3.0	2.1	1.9
EGS	0.0	0.0	1.0	8.0	23.4	36.1
Total	**0.0**	**0.4**	**2.7**	**11.0**	**25.5**	**38.0**

Table 5.20. Total Geothermal Power Generation by Type (billion kilowatt hours/year)

	2000	2010	2020	2030	2040	2050
Baseline Case						
Conventional	22	30	59	62	87	83
EGS	0	0	0	0	0	0
Total	**22**	**30**	**59**	**62**	**87**	**83**
Conventional	22	33	71	85	103	98
EGS	0	0	8	68	199	307
Total	**22**	**33**	**80**	**153**	**302**	**405**
Increase						
Conventional	0	3	13	23	16	15
EGS	0	0	8	68	199	307
Total	**0**	**3**	**21**	**90**	**215**	**322**

The projected market penetration of geothermal generation technologies in MARKAL-GPRA06'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 5.21**.

Table 5.21. FY06 Benefits Estimates for Geothermal Technologies Program (MARKAL-GPRA06)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	0.23	0.82	1.89	2.36
Economic				
Energy-System Cost Savings (billion 2002 dollars/yr)	0.3	1.4	3.9	5.2
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	5	16	38	59
Security				
Natural Gas Savings (quadrillion Btu/yr)	0.13	0.43	0.98	0.15
Capacity (gigawatts)	3	11	25	38

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-GPRA06 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-GPRA06, analysts measure energy service demands for road transportation in vehicle miles traveled (VMT). Projected VMTs are taken directly from the *Annual Energy Outlook 2004* 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 5.22**.

Table 5.22. LDV and Commercial Light Truck Vehicle Miles Traveled (billion VMTs/year)

	2000	2010	2020	2030	2040	2050
Total Light-Duty Vehicles	2,355	3,041	3,768	4,507	5,086	5,277
Cars	1,498	1,686	2,007	2,415	2,600	2,568
Light Trucks	857	1,355	1,761	2,092	2,485	2,709
Commercial Light Trucks	69	79	101	129	157	167

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 *AEO2004* 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 hydrogen fuel cell vehicles from 2015 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 hydrogen-fuel cell passenger car with a cost ratio of 1.07 and an efficiency ratio of 2.54 would cost 7 percent more than the average 2020 traditional gasoline passenger car and have 154 percent higher fuel economy. The cost and efficiency assumptions for passenger cars, sport utility vehicles (SUVs), and commercial light trucks are shown in **Table 5.23**.

Table 5.23. Cost and Efficiency Assumptions for Fuel Cell Vehicles

	2010	2020	2030	2040	2050
Passenger Cars					
Cost Ratio to Conventional	n.a.	1.07	1.05	1.045	1.04
Efficiency Ratio to Conventional	n.a.	2.54	3.03	3.03	3.03
SUVs & Commercial Light Trucks					
Cost Ratio to Conventional	n.a.	1.07	1.05	1.045	1.04
Efficiency Ratio to Conventional	n.a.	2.49	2.96	2.96	2.96

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-GPRA06 model. We expect that more hydrogen production technologies will be modeled in future GPRA analysis, as the data becomes available.

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*.[3] 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.[4] (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).) As with production technologies, we will be enhancing the representation of the distribution and fueling costs for hydrogen in future analysis

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

[4] 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.

as data becomes available. **Table 5.24** 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.).

Table 5.24. Hydrogen Production Costs by Technology and Component (2002 $/gge)

Central Coal								
Unit Costs	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Capital Costs				$0.49	$0.49	$0.49	$0.49	$0.49
O&M				$0.27	$0.27	$0.27	$0.27	$0.27
Feedstock Costs				$0.24	$0.24	$0.24	$0.26	$0.27
Plant Gate				$1.00	$1.01	$1.01	$1.03	$1.03
Distribution, Storage & Tax				$1.07	$1.07	$1.07	$1.07	$1.07
Total				$2.06	$2.06	$2.07	$2.08	$2.09
Distributed Natural Gas Reformer								
Unit Costs	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Capital Costs		$0.43	$0.43	$0.43	$0.43	$0.51		
O&M		$0.57	$0.57	$0.53	$0.55	$0.54		
Feedstock Costs		$1.02	$0.95	$0.90	$0.99	$1.11		
Plant Gate		$2.01	$1.95	$1.87	$1.96	$2.14		
Tax		$0.40	$0.40	$0.40	$0.40	$0.40		
Total		$2.42	$2.35	$2.27	$2.37	$2.55		
Central Natural Gas Reformer**								
Unit Costs	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Capital Costs				$0.16	$0.16	$0.16	$0.16	$0.16
O&M				$0.09	$0.08	$0.08	$0.08	$0.08
Feedstock Costs				$0.94	$0.96	$1.08	$1.09	$1.18
Plant Gate				$1.20	$1.21	$1.32	$1.33	$1.42
Distribution, Storage & Tax				$1.07	$1.07	$1.07	$1.07	$1.07
Total				$2.25	$2.28	$2.39	$2.39	$2.49
Central Biomass								
Unit Costs	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Capital Costs			$1.02	$0.99	$0.98	$0.98	$0.96	$0.96
O&M			$0.31	$0.31	$0.31	$0.31	$0.31	$0.31
Feedstock Costs			$0.33	$0.33	$0.33	$0.33	$0.33	$0.33
Plant Gate			$1.66	$1.63	$1.61	$1.61	$1.60	$1.60
Distribution & Storage*			$0.66	$0.66	$0.66	$0.66	$0.66	$0.66
Total			$2.33	$2.29	$2.29	$2.29	$2.27	$2.27
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
O&M				$0.29	$0.29	$0.29	$0.29	$0.29
Feedstock Costs				$1.87	$2.18	$2.07	$2.06	$2.02
Plant Gate				$2.29	$2.60	$2.49	$2.47	$2.43
Distribution, Storage & Tax				$0.66	$0.66	$0.66	$0.66	$0.66
Total				$2.96	$3.26	$3.15	$3.14	$3.10

* Note: Hydrogen produced from biomass was assumed to receive preferential tax treatment.
** Central electrolytic and natural gas reformer 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.

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 5.25 and 5.26**

Table 5.25. 5 kW Residential Combined Heat and Power System Assumptions

Year	CHP System Efficiency	Electrical Efficiency	Thermal Recovery Efficiency	Equip. Cost (2002 $/kW)	Maint. Cost (2002$/kW-yr)
2005	68%	29%	54%	$2,274	$261
2010	72%	32%	59%	$1,780	$182
2015	72%	32%	59%	$1,780	$166
2025	72%	32%	59%	$1,780	$166

Table 5.26. 200 kW Commercial Combined Heat and Power System Assumptions

Year	CHP System Efficiency	Electrical Efficiency	Thermal Recovery Efficiency	Equip. Cost (2002 $/kW)	Maint. Cost (2002$/kW-yr)
2005	68%	29%	54%	$1,908	$229
2010	72%	36%	56%	$1,414	$127
2015	72%	36%	56%	$1,414	$127
2025	72%	36%	56%	$1,414	$127

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 5.27**.

Table 5.27. Light-Duty Vehicle Market Shares for the Hydrogen Case (% of VMT)

	2000	2010	2020	2030	2040	2050
Gasoline	99%	95%	78%	47%	14%	2%
Advanced Gasoline	0%	2%	7%	15%	10%	0%
Gasoline Hybrid	0%	4%	13%	27%	55%	79%
Diesel Hybrid	0%	0%	1%	5%	7%	1%
Hydrogen	0%	0%	1%	6%	14%	18%
Diesel & Other	1%	0%	0%	0%	0%	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 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 hydrogen fuel cell vehicles in the Hydrogen Program Case to estimate how much oil would be consumed if these VMTs were traveled by traditional gasoline vehicles. These calculations are shown in **Table 5.28**.

Table 5.28. Calculation of Petroleum Savings

	2010	2020	2030	2040	2050
Baseline Case Oil Intensities (TBtu/billion VMT)					
Light-Duty Vehicles	6.48	5.94	5.70	5.47	5.30
Light Trucks	10.26	9.35	8.89	8.77	8.14
Hydrogen Vehicle (VMTs/yr)					
Light-Duty Vehicles	0	40	271	725	1,009
Light Trucks	0	0	4	21	55
Petroleum Savings (TBtu/yr)					
Light-Duty Vehicles	0	238	1,543	3,967	5,344
Light Trucks	0	0	36	182	446
Total	**0**	**238**	**1,579**	**4,150**	**5,790**
Total (million barrels per day)	**0.00**	**0.11**	**0.75**	**1.96**	**2.74**

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 5.29**.

Table 5.29. Calculation of Carbon Emission Reduction

	2010	2020	2030	2040	2050
Decreased CO2 Emissions from Decline in Gasoline Consumption					
Decrease in Gasoline Consumption (TBtu/yr)	0	5	30	77	103
Carbon Intensity of Gasoline (MT of Carbon per MMBtu)	0.0	0.0	0.7	3.5	8.6
Decline in Carbon (MMT/yr)	**0.0**	**4.6**	**30.5**	**80.2**	**112.0**
CO2 Emissions from Hydrogen Production					
Production of Hydrogen (TBtu/yr)	0.0	1	9	36	49
Carbon Intensity of Hydrogen (MT of Carbon per MMBtu)	0.0	0.0	0.2	1.6	3.9
Increase in Carbon (MMT/yr)	**0.0**	**1.4**	**9.6**	**37.6**	**52.4**
Net decrease in Carbon Emissions (MMT/yr)	**0.0**	**3.2**	**20.9**	**42.7**	**59.6**

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 5.30**. It should be noted that this analysis was conducted with a single-region MARKAL-GPRA06 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 5.30. Hydrogen Production by Feedstock (% of total hydrogen production)

	2015	2020	2025	2030	2035	2040	2045	2050
Central Coal	0%	0%	0%	32%	53%	77%	79%	81%
Remote Natural Gas	0%	100%	85%	46%	28%	10%	0%	0%
Central Natural Gas	0%	0%	0%	0%	0%	0%	0%	0%
Central Biomass	0%	0%	15%	22%	19%	13%	21%	19%

Overall, the Hydrogen, Fuel Cells, and Infrastructure Technologies Program reduces gasoline consumption in the transportation sector through the deployment of hydrogen fuel cell LDVs and commercial light trucks (**Table 5.31**). 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 5.31. FY06 Benefits Estimates for Hydrogen, Fuel Cells, and Infrastructure Technologies Program (MARKAL-GPRA06)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	0.09	1.04	3.03	4.32
Economic				
Energy-System Cost Savings (billion 2002 dollars/yr)	-0.8	1.5	11.2	26.4
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	3	21	43	60
Security				
Oil Savings (mbpd)	0.11	0.75	1.96	2.73
Natural Gas Savings (quadrillion Btu/yr)	-0.04	-0.27	0.29	0.71

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-GPRA06 framework. Instead, the projected ITP goals by various industries were aggregated into MARKAL-GPRA06 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 5.32**). 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 5.32. Industrial Program Integration Factors

Subprogram	Integration Factor
Industries of the Future	0%
Crosscutting R&D	10%
Industrial Assessment Centers	10%
Best Practices	0%

The potential savings represented in these conservation measures yield an overall reduction in delivered energy consumption, as shown in **Table 5.33**.

The reduction in electricity demand also leads to the reduction in coal and 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 5.34**).

Table 5.33. Delivered Energy Savings in the Industrial Sector (trillion Btu/year)

	2010	2015	2020	2025	2030	2040	2050
Petroleum	44	103	140	110	112	90	-48
Natural Gas	135	422	990	1,166	1,062	399	173
Coal	4	29	54	79	105	105	62
Electricity	39	132	243	275	314	172	53
Heat	1	2	11	-19	0	-53	0
Renewable	0	0	0	0	0	0	0
Subtotal	222	687	1,438	1,612	1,593	713	239
Petrochemicals	5	31	86	84	69	38	12
Total	**227**	**718**	**1,524**	**1,696**	**1,662**	**751**	**251**

Table 5.34. FY06 Benefits Estimates for Industrial Technologies Program (MARKAL-GPRA06)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	2.07	2.26	1.26	0.45
Economic				
Energy-System Cost Savings (billion 2002 dollars/yr)	13.6	15.7	9.8	3.2
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	34	42	23	8
Security				
Oil Savings (mbpd)	0.11	0.09	0.06	-0.01
Natural Gas Savings (quadrillion Btu/yr)	1.48	1.26	0.77	0.29
Displaced Capacity (gigawatts)	11	20	9	2

Solar Energy Technologies Program

The Solar Energy Technologies Program covers solar water-heating technologies, photovoltaic (PV)-based electricity generation and central solar thermal generation with energy storage. 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-GPRA06 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 and central solar thermal 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. The cost and performance characteristics of the Solar Energy Technologies Program Case for water heaters, PV systems, and central thermal stations are shown in **Table 5.35**.

Solar photovoltaic capacity increases dramatically over the Baseline Case (**Table 5.36**). By 2050, the Solar Energy Technologies Program Case shows an additional 36.5 GW of photovoltaic capacity over the Baseline Case. Additionally, the Solar Energy Technologies Program Case shows an additional 25.4GW of central solar thermal generation. By 2050, the improved PV and thermal technologies generate an incremental 268 billion kWh of generation over the Baseline Case (**Table 5.37**).

Table 5.35. Solar Energy Technologies Program Assumptions

Photovoltaics

	Central Generation		Residential Buildings		Commercial Buildings	
Year	Installed Price (2002$/kW)	O&M (2002$/kW)	Installed Price (2002$/kW)	O&M (2002$/kW)	Installed Price (2002$/kW)	O&M (2002$/kW)
2005	$4,845	$51	$9,828	$170	$5,707	$170
2010	$3,178	$34	$6,224	$40	$4,362	$40
2015	$2,615	$22	$4,844	$28	$3,667	$28
2020	$2,054	$10	$3,464	$16	$2,912	$16
2025	$1,741	$9	$2,783	$10	$2,697	$10
2030	$1,596	$9	$2,567	$9	$2,481	$9
2035	$1,450	$8	$2,352	$9	$2,266	$9
2040	$1,374	$7	$2,235	$8	$2,214	$8
2050	$1,349	$7	$2,131	$7	$2,110	$7

Central Solar Thermal

Year	Installed Price (2002$/kW)	O&M (2002$/kW)	Annual Capacity Factor
2005	$5,031	$69	53%
2010	$3,565	$45	65%
2020	$2,501	$26	72%
2025	$2,234	$22	72%
2030	$2,024	$20	72%
2035	$1,909	$19	72%
2040	$1,855	$19	72%
2050	$1,825	$19	72%

Solar Water Heaters

Vintage	Installed Cost	Backup Fuel Use
2000	$2,844	50%
2010	$1,524	45%
2020	$1,320	40%
2030	$1,180	36%
2040	$2,844	33%

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

	2000	2010	2020	2030	2040	2050
Baseline Case						
Central PV	0.0	0.2	0.3	0.4	0.4	0.4
Distributed PV	0.1	1.6	4.8	14.6	25.2	26.3
Central Thermal	0.3	0.5	0.9	1.0	0.8	0.5
Total	**0.4**	**2.2**	**6.0**	**16.0**	**26.4**	**27.3**
Solar Program Case						
Central PV	0.0	0.1	0.1	0.1	1.0	1.0
Distributed PV	0.1	1.7	6.7	17.2	36.1	62.3
Central Thermal	0.3	0.5	2.5	9.4	19.7	25.9
Total	**0.4**	**2.2**	**9.3**	**26.7**	**56.8**	**89.1**
Increase						
Central PV	0.0	-0.1	-0.3	-0.4	0.6	0.6
Distributed PV	0.0	0.1	1.9	2.6	11.0	35.9
Central Thermal	0.0	0.0	1.6	8.4	18.9	25.4
Total	**0.0**	**0.0**	**3.2**	**10.6**	**30.4**	**61.9**

Table 5.37. Solar-Generation by Case and Type (Billion kWh)

	2000	2010	2020	2030	2040	2050
Baseline Case						
Central PV	0.0	0.4	0.8	0.5	0.9	0.9
Distributed PV	0.2	3.9	12.1	36.4	62.8	65.8
Central Thermal	1.1	1.7	3.0	3.5	2.7	1.8
Total	**1.3**	**6.0**	**15.9**	**40.5**	**66.5**	**68.5**
Solar Program Case						
Central PV	0.0	0.2	0.2	0.1	2.5	2.5
Distributed PV	0.2	4.1	16.8	42.9	90.2	155.5
Central Thermal	1.1	1.7	14.3	62.0	133.9	178.4
Total	**1.3**	**5.9**	**31.2**	**105.0**	**226.6**	**336.5**

	2000	2010	2020	2030	2040	2050
Increase						
Central PV	0.0	-0.2	-0.7	-0.5	1.6	1.6
Distributed PV	0.0	0.2	4.7	6.5	27.4	89.7
Central Thermal	0.0	0.0	11.3	58.5	131.2	176.7
Total	**0.0**	**0.0**	**15.3**	**64.5**	**160.2**	**268.0**

Central and distributed PV and central thermal generation technologies in the Solar Energy Technologies Program Case directly displace central gas and coal-fired generation capacity. However, because of the PV technologies' lower availability factor and reduced contribution to peak power supply, the total gas and coal capacity replaced is less than the installed solar capacity. Benefits estimates for the Solar Energy Technologies Program are shown in **Table 5.38.**

Table 5.38. FY06 Benefits Estimates for Solar Energy Technologies Program (MARKAL-GPRA06)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	0.18	0.56	1.23	1.71
Economic				
Energy-System Cost Savings (billion 2002 dollars/yr)	0.4	1.7	2.5	2.3
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	4	11	23	36
Security				
Oil Savings (mbpd)	ns	ns	ns	ns
Natural Gas Savings (quadrillion Btu/yr)	0.10	0.29	0.71	0.62
Capacity (gigawatts)	3	11	30	62

Vehicle Technologies Program

The Vehicle Technologies Program[5] 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 2004 (AEO 2004)* and extended past 2025, based on historical relationships between passenger and commercial VMTs, and population and economic growth. Projected VMTs for cars, light trucks[6], commercial light trucks,[7] and heavy trucks are shown in **Table 5.39**.

[5] The Vehicle Technologies Program is run by the Office of FreedomCAR and Vehicle Technologies.
[6] Light trucks include trucks with a gross vehicle weight under 8,500 pounds and may include pickups, vans, or sport utility vehicles (SUVs).
[7] 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.

Table 5.39. Projected Vehicle Miles Traveled by Vehicle Class (billion VMTs/year)

Vehicle Class	2000	2010	2020	2030	2040	2050
Light-Duty Vehicles	2,355	3,041	3,768	4,507	5,086	5,455
Cars	1,498	1,686	2,007	2,415	2,600	2,502
Light Trucks	857	1,355	1,761	2,092	2,485	2,953
Commercial Light Trucks	69	79	101	129	157	176
Heavy Trucks	207	242	313	392	461	506

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 *AEO2004* 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), 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 advanced diesel and diesel hybrid Class 3-6 trucks and advanced diesel Class 7-8 trucks also were provided for the period 2010 to 2050. 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 1.96 would cost 5 percent more than the average 2020 traditional gasoline passenger car and have 96 percent better fuel economy. MARKAL does not currently distinguish the different heavy truck classes and usage profile (i.e. short haul vs. long haul). For the Vehicle Technologies Program Case, the analysts created a single advanced truck technology based on the cost and efficiency assumptions and market shares for the different truck classes and usage profile that were calculated in the off-line analysis. The cost and efficiency assumptions for passenger cars, SUVs, and commercial light trucks are shown in **Table 5.40**, while **Table 5.41** shows these assumptions for heavy trucks.

Table 5.40. Cost and Efficiency Assumptions for Light-Duty Vehicles

	2010	2020	2030	2040	2050
Passenger Cars					
Cost Ratio to Conventional in Same Year					
Advanced Gasoline	1.01	1.02	1.03	1.02	1.01
Gasoline HEV	1.07	1.05	1.03	1.02	1.02
Advanced Diesel	1.05	1.03	1.03	1.02	1.02
Diesel HEV	1.10	1.08	1.06	1.04	1.03
Efficiency Ratio to Conventional in Same Year					
Advanced Gasoline	1.01	1.09	1.25	1.25	1.25
Gasoline HEV	1.50	1.96	2.22	2.22	2.22
Advanced. Diesel	1.40	1.60	1.80	1.80	1.80
Diesel HEV	1.60	2.05	2.36	2.36	2.36

	2010	2020	2030	2040	2050
Light Trucks and SUVs					
Cost Ratio to Conventional in Same Year					
Advanced Gasoline	1.01	1.03	1.03	1.02	1.01
Gasoline HEV	1.07	1.05	1.03	1.02	1.02
Advanced Diesel	1.04	1.03	1.02	1.02	1.02
Diesel HEV	1.10	1.08	1.06	1.04	1.03
Efficiency Ratio to Conventional in Same Year					
Advanced Gasoline	1.05	1.23	1.37	1.37	1.37
Gasoline HEV	1.40	1.85	2.00	2.00	2.00
Advanced Diesel	1.35	1.50	1.70	1.80	1.80
Diesel HEV	1.50	1.90	2.13	2.13	2.13

Table 5.41. Cost and Efficiency Assumptions for Heavy Trucks*

	2010	2020	2030	2040
Class 7-8 – Diesel				
Efficiency Ratio – Short Haul	1.30	1.45	1.45	1.45
Efficiency Ratio – Intermediate Haul	1.50	1.61	1.61	1.61
Efficiency Ratio – Long Haul	1.50	1.76	1.76	1.76
Cost Ratio	1.23	1.10	1.05	1.05
Class 3-6 – Diesel				
Efficiency Ratio	1.02	1.37	1.37	1.37
Cost Ratio	1.12	1.04	1.04	1.04
Class 3-6 – Diesel Hybrid				
Efficiency Ratio	1.70	1.70	1.70	1.70
Cost Ratio	1.42	1.12	1.06	1.06

* 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 5.42** shows the market shares for traditional gasoline and alternative light-duty vehicles for the Vehicle Technologies Program Case, while **Table 5.43** shows transportation-sector petroleum consumption for the Baseline and Vehicles Technologies Program Case.

The reduction in transportation-sector petroleum consumption (**Table 5.44**) 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 5.42. Light-Duty Vehicle Market Shares for the Vehicles Technologies Program Case (% of total fleet)

	2000	2010	2020	2030	2040	2050
Gasoline	99%	95%	79%	53%	25%	9%
Advanced Gasoline	0%	2%	7%	15%	12%	0%
Gasoline Hybrid	0%	4%	13%	27%	55%	89%
Diesel Hybrid	0%	0%	1%	5%	7%	2%
Diesel & Other	1%	0%	0%	0%	0%	0%

Table 5.43. Petroleum Consumption by Vehicle Class and Case (trillion Btu/year)

	2000	2010	2020	2030	2040	2050
Baseline Case						
Light-Duty Vehicles	15,725	19,697	22,376	26,234	28,768	29,871
Commercial Light Trucks	788	811	944	1,129	1,333	1,383
Heavy Trucks	4,236	5,102	6,458	7,677	8,805	9,456
Vehicle Technologies Program Case						
Light-Duty Vehicles	15,725	19,564	21,169	21,431	18,583	15,527
Commercial Light Trucks	788	794	763	682	728	776
Heavy Trucks	4,236	5,091	5,949	5,879	6,377	6,680
Savings						
Light-Duty Vehicles	0	133	1,207	4,803	10,185	14,344
Commercial Light Trucks	0	16	181	447	605	608
Heavy Trucks	0	11	509	1,798	2,428	2,776
Total Transportation Sector	**0**	**160**	**1,897**	**7,047**	**13,218**	**17,728**

Table 5.44. FY06 Benefits Estimates for Vehicle Technologies Program (MARKAL-GPRA06)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	2.01	7.67	14.17	18.92
Economic				
Energy-System Cost Savings (billion 2002 dollars/yr)	2.1	28.4	94.6	177.4
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	38	148	272	365
Security				
Oil Savings (mbpd)	0.97	3.59	6.59	8.77
Natural Gas Savings (quadrillion Btu/yr)	0.02	0.03	0.16	0.31

Weatherization and Intergovernmental Program

The Weatherization and Intergovernmental Program (WIP) Case formulated in MARKAL-GPRA06 focuses on deployment programs that have an impact on the energy consumption in the residential sector and vehicle fuel use. Projected program goals of the Weatherization Assistance Program, State Energy 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. Other deployment programs aimed at promoting individual technologies were either modeled by adjusting the technologies discount rate or by applying lower bounds on the technology investment based on off-line analysis.

Table 5.45 depicts the projected funds and program goals of the Weatherization Assistance Program used to develop the MARKAL-GPRA06 input. Analysts distributed the aggregated market potentials for Weatherization Assistance Program energy savings in proportion to household savings in the four MARKAL-GPRA06 residential regions: Northeast, Midwest, South, and West.

Table 5.45. Weatherization Assistance Program Projected Budget and Goals[8]

Year	Cost per House	No. Houses Weatherized[9]	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)
2006	$2,390	189,650	189,650	5.93	3.80	1.19	0.95
2010	$2,444	184,267	934,764	29.21	18.70	5.84	4.67
2015	$2,458	182,983	1,849,681	57.76	36.97	11.55	9.24
2020	$2,458	182,983	2,764,599	86.31	55.24	17.26	13.81
2025	$2,458	182,983	2,744,752	85.64	54.81	17.13	13.70
2030	$2,458	182,983	2,744,752	85.64	54.81	17.13	13.70

As with the Weatherization Assistance Program, the State Energy Program, Rebuild America, Inventions and Innovations, and Code Training and Assistance energy savings goals were transformed into conservation-supply curves that reduce the heating and cooling loads in households benefiting from these programs. However, due to the potential overlap in target markets for these programs, the projected energy savings were reduced by 30 percent. For more information about these programs and projected savings, please refer to **Appendix K.** Analysts modeled the Clean Cities Program by applying lower bounds on the investment of alternative-fueled vehicles based on program estimates of market penetration, as shown in **Table 5.46**.

Table 5.46. Projection of Baseline Case and Clean Cities Program Case Alternative-Fueled Vehicles (number of vehicles on the road)

	Cumulative No. of Vehicles	Type of Fuel	% of Fleet
2010	423,178	Natural Gas	44%
2015	474,185	LPG	17%
2020	676,235	Ethanol	34%
2025	856,370	Electric	4%

Tables 5.47 and 5.48 depict the energy savings by end-use demand and fuel type in the residential and commercial sectors respectively, while **Table 5.49** reports the reduction in energy consumption in the industrial sector due to the I&I Program.

Table 5.47. Delivered Energy Demand Reductions in the Residential Sector (trillion Btu/year)

	2010	2020	2030	2040	2050
Reductions by Demand Service					
Space Heating	53	138	165	162	154
Space Cooling	2	9	22	21	20
Water Heating	1	2	-2	0	1
Lighting	40	168	201	188	133
Other	0	0	0	0	0
Total	**96**	**317**	**386**	**371**	**308**
Reduction by Fuel					
Petroleum	0	0	1	0	-16
Natural Gas	87	132	150	158	144
Coal	1	0	0	-1	1
Electricity	8	185	235	215	179
Total	**96**	**317**	**386**	**372**	**308**

[8] See Appendix K for additional documentation on these goals.
[9] Includes homes weatherized using leveraged state and local funds.

Table 5.48. Delivered Energy Demand Reductions in the Commercial Sector (trillion Btu/year)

	2010	2020	2030	2040	2050
Reductions by Demand Service					
Space Heating	19	34	40	35	33
Space Cooling	4	10	11	9	8
Water Heating	3	4	6	5	5
Lighting	24	70	99	99	99
Other	0	0	0	0	0
Total	**50**	**117**	**157**	**148**	**144**
Reduction by Fuel					
Petroleum	5	0	0	5	0
Natural Gas	13	31	25	1	5
Coal	0	0	6	7	7
Electricity	32	87	126	141	132
Total	**50**	**117**	**157**	**154**	**144**

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

	2010	2020	2030	2040	2050
Petroleum	3	0	4	8	61
Natural Gas	16	97	127	130	66
Coal	0	0	0	0	0
Electricity	3	31	31	31	31
Total	**22**	**128**	**162**	**169**	**158**

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 5.50**).

Table 5.50. FY06 Benefits Estimates for Weatherization and Intergovernmental Program (MARKAL-GPRA06)

Annual Benefits	**2020**	**2030**	**2040**	**2050**
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	1.23	1.43	1.29	1.10
Economic				
Energy System Cost Savings (billion 2002 dollars/yr)	11.6	15.8	17.1	17.1
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	22	29	24	23
Security				
Oil Savings (mbpd)	0.02	0.03	0.03	0.06
Natural Gas Savings (quadrillion Btu/yr)	0.85	0.66	0.80	0.40
Displaced Capacity (gigawatts)	12	21	17	16

Wind Technologies Program

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-GPRA06 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 5.51**.

Table 5.51. Wind-Power Assumptions

	2010	2020	2030	2040	2050
Capital Costs with Contingency Factor (2002 $/kW)					
Onshore					
Class 6	893	819	788	767	746
Class 5	893	819	788	767	746
Class 4	982	893	866	856	840
Shallow Offshore					
Class 6	1,129	1,070	1,016	989	962
Class 4	1,129	1,070	1,016	989	962
Deep Offshore					
Class 7	1,723	1,177	1,024	977	945
Class 6	1,723	1,177	1,024	977	945
Class 4	1,723	1,177	1,024	977	945
Fixed O&M Cost (2002 $/kW/year)					
Onshore	20.0	15.0	13.8	13.2	12.8
Shallow Offshore	47.0	38.0	36.0	34.0	32.0
Deep Offshore	49.3	41.0	39.0	37.0	36.0
Capacity Factor					
Onshore					
Class 6	50%	51%	52%	52%	52%
Class 5	44%	46%	46%	46%	46%
Class 4	40%	47%	48%	48%	48%
Shallow Offshore					
Class 6	45%	50%	50%	50%	50%
Class 4	36%	40%	40%	40%	40%
Deep Offshore					
Class 7	55%	60%	60%	60%	60%
Class 6	45%	50%	50%	50%	50%
Class 4	36%	40%	40%	40%	40%

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 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 5.52**.

Table 5.52. Total Wind Capacity and Generation

	2000	2010	2020	2030	2040	2050
Wind Capacity (GW)						
Reference Case						
Onshore	2.5	7.8	13.5	12.8	18.6	14.8
Offshore	0.0	0.2	1.7	4.9	9.3	13.2
Total	**2.45**	**8.01**	**15.13**	**17.66**	**27.96**	**27.97**
GPRA Scenario						
Onshore	2.5	10.9	37.5	80.9	112.6	112.6
Offshore	0.0	0.2	1.7	4.9	11.7	26.5
Total	**2.5**	**11.1**	**39.2**	**85.7**	**124.3**	**139.1**
Increase						
Onshore	0.0	3.0	24.0	68.0	94.0	97.8
Offshore	0.0	0.0	0.0	0.0	2.4	13.3
Total	**0.0**	**3.0**	**24.0**	**68.0**	**96.3**	**111.1**
Wind Generation (Billion kWh)						
Reference Case						
Onshore	10	31	57	55	83	66
Offshore	0	1	8	24	49	71
Total	**10**	**32**	**65**	**79**	**132**	**137**
GPRA Scenario						
Onshore	10	46	171	372	519	521
Offshore	0	1	10	28	69	156
Total	**10**	**47**	**180**	**400**	**588**	**677**
Increase						
Onshore	0	14	114	316	436	455
Offshore	0	0	1	5	20	85
Total	**0**	**14**	**115**	**321**	**457**	**540**

In the Wind Technologies Program Case, wind 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. The estimated benefits for the Wind Program are shown in **Table 5.53**.

Table 5.53. FY06 Benefits Estimates for Wind Program (MARKAL-GPRA06)

Annual Benefits	2020	2030	2040	2050
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	1.14	2.81	3.71	3.66
Economic				
Energy-System Cost Savings (billion 2002 dollars/yr)	1.2	1.2	3.4	3.7
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	21	60	73	87
Security				
Oil Savings (mbpd)	ns	ns	ns	ns
Natural Gas Savings (quadrillion Btu/yr)	0.67	1.09	1.99	0.50
Capacity (gigawatts)	24	68	96	111

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 5.1. An Illustrative Reference Energy System