CHAPTER 3

LONG-TERM BENEFITS ANALYSIS OF EERE'S PROGRAMS

Introduction

This chapter provides an overview of the modeling approach used in MARKAL-GPRA07 to evaluate the benefits of the Office of Energy Efficiency and Renewable Energy (EERE) R&D programs and technologies.[1] The program benefits reported in this section result from comparisons of each Individual Program Goal Case to the Baseline Case, as modeled in MARKAL-GPRA07.

The Baseline Case used to evaluate the impact of the EERE portfolio was benchmarked to EIA's *Annual Energy Outlook 2005* (*AEO2005*) for the period between 2005 and 2025. To the extent possible, the same input data and assumptions were used in MARKAL-GPRA07 as were used to generate the *AEO2005* Reference Case. For example, the macroeconomic projections for GDP, housing stock, commercial square footage, industrial output, and vehicle miles traveled were taken from the *AEO2005*. At the sector level, both supply-side and demand-side technologies were characterized to reflect the *AEO2005* assumptions 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 *AEO2005* 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 2005 *Annual Report* to the Board of Trustees. **Appendix A** provides a more complete discussion of the MARKAL-GPRA07 Baseline Case.[2]

For each EERE RD3 program, analysts make modifications to the characteristics of the technologies involved to generate an Individual Program Goal Case. Individual Program Goal 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.

[1] For three programs—Weatherization and Intergovernmental Activities (WIP), Federal Energy Management Program (FEMP), and the Industrial Technologies program—EERE did not report long-term benefits in the FY 2007 Congressional Budget request, but were nonetheless modeled in MARKAL-GPRA '07. For consistency with the budget submission, this benefits report will not show the individual contributions of those three programs beyond 2025. Nevertheless, the programs' long-term benefits are embedded in EERE's aggregate long-term benefits.

[2] For a detailed documentation of the standard MARKAL model, please see http://www.etsap.org/MrklDoc-I_StdMARKAL.pdf .

Table 3.1 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-GPRA07. For the long-term analysis, off-line tools are those that are used to provide input to MARKAL-GRPA07 and to estimate benefits for technologies outside the scope of MARKAL-GRPA07. 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 3.1** at the end of this chapter. Descriptions of the off-line models are provided in the related program appendix.[3] The indication that a particular program was modeled using off-line tools should not be interpreted to mean that the program was not included in the MARKAL-GPRA07 modeling, or that the results of the program analysis are not impacted by the MARKAL-GPRA07 modeling.

Table 3.1. Long-Term Benefits Modeling by Primary Type of Model Used and Activity Area

Program	Activities	Off-Line Tools	MARKAL-GPRA07
Biomass	Ethanol from Corn Fiber & Residual Starch		✓
	Cellulosic Ethanol		✓
Buildings Technologies	Technology R&D	✓	✓
	Regulatory Actions	✓	✓
	Market Enhancement	✓	
FEMP	FEMP	✓	
Hydrogen, Fuel Cells, and Infrastructure Technologies	Fuel Cells		✓
	Production		✓
Industrial Technologies	Industrial Programs	✓	
Solar Energy Technologies	Central Solar Power		✓
	Photovoltaics	✓	✓
Vehicle Technologies	Light Duty Vehicle Hybrid and Diesel		✓
	Heavy Trucks	✓	
Weatherization and Intergovernmental	Weatherization	✓	
	Domestic Intergovernmental	✓	
Wind Technologies	Wind		✓

The following sections summarize how each EERE program is formulated in MARKAL-GPRA07. In many cases, analysts convert the technological data and their projected market potentials in each program directly to MARKAL-GPRA07 input. When this is not feasible, the quantitative analyses undertaken in the program and market analyses are used, in part, to generate the Individual Program Goal 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. The current analysis is based on

[3] It is important to note that the off-line analyses were used to feed appropriate parameters and other factors into MARKAL-GPRA07, which was then run for all the programs.

biorefineries that produce ethanol fuel as a primary output along with specialized bio-based products. Future analyses could include additional fuels that the program may identify in the longer term. Additionally, the program is working on increasing the yields of corn ethanol plants through the conversion of the fiber in corn kernels and residual (recalcitrant) kernel starch left over after conventional corn ethanol processing. The research undertaken to improve the harvesting of agricultural residue feedstocks has not been included in the GPRA analysis.

Corn and cellulosic ethanol: EERE is sponsoring research aimed at reducing the cost of producing ethanol from corn and cellulosic biomass.[4] In the Biomass Individual Program Goal Case, the conversion of corn fiber and residual starch to ethanol becomes available for dry mills beginning in 2012 and yields a 20% increase in a dry mill's ethanol output. The projected revenue from producing bio-based products was treated as a cost credit toward producing ethanol in dry mills. Cellulosic biorefineries that produce ethanol, electricity, and bioproducts become available in 2015 in the Individual Program Goal Case and in 2033 in the Baseline Case. The cellulosic biorefineries are assumed to include a cogeneration unit, which will convert residual biomass to process heat and electricity.

Table 3.2 depicts the production and use of corn and cellulosic ethanol projected by MARKAL-GPRA07, for both the Baseline Case and the Individual Program Goal Case, which reflects ethanol's penetration, if program cost goals are met. Note that these scenarios are based on the *AEO2005* Reference Case and do not include any of the incentives for biofuels from the Energy Policy Act of 2005. **Table 3.3** shows the cellulosic ethanol plant cogeneration capacity and net electric generation that would be available for sale to the grid.

Table 3.2. Projected Ethanol Production and Use (billion gallons/year)

	2030	2040	2050
Corn			
Baseline Case	5.3	5.8	6.1
Individual Program Goal Case	5.9	6.0	6.1
Incremental	**0.5**	**0.2**	**0.0**
Cellulosic			
Baseline Case	0.0	1.9	4.5
Individual Program Goal Case	20.1	28.0	30.9
Incremental	**20.1**	**26.1**	**26.4**
Total Ethanol			
Baseline Case	5.3	7.7	10.6
Individual Program Goal Case	25.9	33.9	37.0
Incremental	**20.6**	**26.2**	**26.4**

[4] 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 3.3. Cellulosic Biorefinery Cogeneration Capacity and Net Generation

	2030	2040	2050
Capacity (GW)			
Baseline Case	0	1	2
Individual Program Goal Case	10	13	14
Incremental	**10**	**12**	**12**
Generation (Bill. kWh)			
Baseline Case	0	6	14
Individual Program Goal Case	86	112	114
Incremental	**86**	**106**	**100**

The benefits of the Biomass Program derived in MARKAL-GPRA07 (**Table 3.4**) are the results of direct substitution of biomass-based energy for fossil fuels. Ethanol displaces an increasing fraction of the gasoline used in light-duty vehicles (LDVs), while the cogeneration of electricity at cellulosic biorefineries displaces coal and natural gas-fired power generation. The reduction in fossil fuel consumption at high marginal cost generates savings both in carbon emissions and energy-system costs.

Table 3.4. Annual Benefits Estimates for Biomass Program (MARKAL-GPRA07)[5]

Annual Benefits	2030	2040	2050
Energy Displaced			
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	2.3	2.9	2.8
Economic			
Energy-System Cost Savings (billion 2003 dollars/yr)	2	2	2
Environmental			
Carbon Savings (million metric tons carbon equivalent/yr)	45	60	57
Security			
Oil Savings (mbpd)	0.9	1.1	1.1
Natural Gas Savings (quadrillion Btu/yr)	0.2	ns	ns

More details on the Biomass Program's benefits analysis can be found in **Appendix C**.

Building Technologies Program

MARKAL-GPRA07 models technologies and activities in the Buildings Program, based on three general types of activities: technology R&D, regulatory actions, and market enhancement.

[5] Note that in the Biomass Individual Program Goal Case, the advanced transportation technologies available in Freedom Car and Vehicle Technologies Individual Program Goal Case are unavailable, despite the market synergies of the two suites of technologies. In the EERE portfolio case, both suites are modeled.

Technology R&D: New and improved technologies are introduced into MARKAL-GPRA07 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 furnaces, air conditioners, heat pumps, and water heaters.

Technologies that lower service demand (e.g., building-shell technologies and lighting controls) are modeled in MARKAL-GPRA07 as steps in a conservation supply curve. 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 Individual Program Goal 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 capacity 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 capacity of capital stock carried over from the previous period.

Technologies such as solid-state lighting, although available in the Baseline Case, do not have a significant market share initially because of their high consumer hurdle rate (44%). These hurdle rates are lowered to 18% when running the Buildings Technology Case to reflect consumer acceptance of these products with improved performance.[6] The 18% 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-GPRA07 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-GPRA07 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-GPRA07 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 equipment) have a long service lifetime, the stock turnover constraints modeled in MARKAL-GPRA07 limit near-term energy savings.

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[6] The hurdle rates in MARKAL-GPRA07 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 toward 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.

Deployment activities: Deployment programs, such as the Energy Star Program, which is 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.

In MARKAL-GPRA07, 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) compact fluorescent light bulb (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-GPRA07.

Tables 3.5 and 3.6 depict the projected delivered energy savings in residential and commercial buildings by demand and fuel generated from the use of more efficient end-use devices and cost-effective conservation measures covered under the Buildings Program. Additional savings accrue from new standards for distribution transformers, and commercial and industrial electric motors up to 200 hp. The electricity savings from these activities are shown in **Table 3.7**.

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 envelope 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 3.5. Residential Delivered Energy Savings by Demand and Fuel (Quadrillion Btu/year)

	2030	2040	2050
Reduction by Service Demand			
Space Heating	0.575	0.877	1.221
Space Cooling	0.132	0.164	0.134
Water Heating	0.025	0.063	0.146
Lighting	0.301	0.640	0.742
Other	0	0	0
Total	**1.033**	**1.744**	**2.243**
Reduction by Fuel			
Petroleum	147	638	1,015
Natural Gas	568	486	568
Coal	10	22	25
Electricity	308	598	621
Total	**1,033**	**1,744**	**2,243**

Table 3.6. Commercial Delivered Energy Savings by Demand and Fuel (Quadrillion Btu/year)

	2030	2040	2050
Reduction by Service Demand			
Space Heating	0.117	0.080	0.101
Space Cooling	0.130	0.177	0.162
Water Heating	ns	ns	ns
Lighting	0.234	0.507	0.781
Other	ns	ns	ns
Total[7]	0.471	0.754	1.034
Reduction by Fuel			
Petroleum	0.080	-0.018	-0.018
Natural Gas	0.011	0.069	0.111
Coal	0	0	0
Electricity	0.380	0.703	0.941
Total	0.471	0.754	1.034

Table 3.7. Electricity Savings from Distribution Transformer and Electric Motor Standards (billion kWh/year)

	2030	2040	2050
Distribution Transformers	45.9	49.1	51.9
Electric Motors	43.3	43.3	43.3

Table 3.8. Annual Benefits Estimates for Building Technologies Program (MARKAL-GPRA07)

Annual Benefits	2030	2040	2050
Energy Displaced			
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	2.6	5.0	5.4
Economic			
Energy-System Cost Savings (billion 2003 dollars/yr)	57	103	135
Environmental			
Carbon Savings (million metric tons carbon equivalent/yr)	56	117	124
Security			
Oil Savings (mbpd)	0.2	0.3	0.5
Natural Gas Savings (quadrillion Btu/yr)	0.8	0.5	0.7
Electricity Capacity Avoided (gigawatts)	67	103	118

More details on the Building Technologies Program's benefits analysis are available in **Appendix G.**

[7] The total service demand reduction does not sum to the constituent parts of Table 3.6, because of the model's "ns" (not significant) results. There are minor changes in parts of the energy system unrelated to the Buildings Program RD3, and the magnitude of these changes are deemed be in the "noise" of the model results.

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, which has a well-documented track record, provided estimates of future savings based on past results and current budgets.

In order to quantify the broader benefits of these savings in MARKAL-GPRA07, 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. 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 activities of the Federal Energy Management Program are more "midterm" in nature. Thus, the long-term annual benefits estimates, which are calculated by MARKAL-GPRA07, were not included in the EERE budget submission or in this section of the report. However, the program's activities were modeled for the EERE Portfolio Scenario and included in the long-term annual benefits of the EERE Portfolio, as shown in **Chapter 1.**

More details on the Federal Energy Management Program's benefits analysis can be found in **Appendix E.**

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-GPRA07 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-GPRA07, analysts measure energy-service demands for road transportation in vehicle miles traveled (VMT). Projected VMTs are taken directly from the *Annual Energy Outlook 2005* and extended past 2025, based on historical relationships between passenger and commercial VMTs and population and economic growth. Projected VMTs for light-duty vehicles and commercial light trucks are shown in **Table 3.9**.

Table 3.9. LDV and Commercial Light-Truck Vehicle Miles Traveled (billion VMTs/year)

	2030	2040	2050
Light-Duty Vehicles	4,420	5,156	5,628
Commercial Light Trucks	118	140	159

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. These life-cycle costs include initial vehicle cost, annual maintenance costs, and annual fuel 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 *AEO2005* assumptions, although hybrid vehicle costs were reduced from *AEO2005* levels in accordance to the Vehicle Technologies Program's view of likely market developments exclusive of program R&D activities. The effect of this baseline change is to increase the market share of hybrid vehicles in the Baseline Case and, thus, reduce the level of benefits attributed to the Vehicle Technologies and HFCIT Programs. For the Hydrogen Individual Program Goal Case, capital costs, operation and maintenance costs, and fuel efficiency goals were provided by the HFCIT Program for hydrogen fuel cell vehicles from 2020 to 2050.

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 Individual Program Goal Case, analysts modeled nine hydrogen production technologies: distributed natural gas reformers, central natural gas reformers, central coal gasification (with and without cogeneration), central biomass gasification, distributed ethanol reformers, central electrolytic production (both grid electricity and wind-dedicated electrolysis), and distributed 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-GPRA07 model. We expect that more hydrogen production technologies will be modeled in future GPRA analyses, as the data become available.

Carbon sequestration pathways were available for central coal and natural gas hydrogen production. However, because no carbon policies were assumed in the GPRA07 Baseline Case, 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 Individual Program Goal Case.

HFCIT Program goals were used to estimate capital and O&M costs and production efficiencies for distributed natural gas reformers, central biomass gasifiers, distributed ethanol reformers, and central and distributed electrolytic production technologies. Assumptions for central coal and natural gas production technologies were adapted from H2A analysis results. 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 65 cents per gallon of gasoline equivalent (gge)[8]—was assumed for hydrogen distribution costs, based on published data from NREL.[9] We will be enhancing the representation of the distribution and fueling costs for hydrogen in future analysis, as data becomes available.

Unlike other Individual Program Goal Cases, analysts ran the Hydrogen Individual Program Goal Case with both HFCIT and Vehicle Technologies Programs' 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 3.10**.

Table 3.10. Light-Duty Vehicle Market Shares for the Hydrogen Case (% of VMT)

	2030	2040	2050
Gasoline	40%	5%	0%
Advanced Gasoline	17%	10%	0%
Gasoline Hybrid	21%	49%	60%
Diesel Hybrid	7%	7%	0%
Hydrogen	2%	13%	37%
Diesel and Other	13%	16%	3%

Because the Hydrogen Individual Program Goal 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 Individual Program Goal Case and the Baseline Case. Instead, analysts based the calculation of oil and carbon benefits for the Hydrogen Program by multiplying the average Baseline Case LDV and commercial light-truck fleet fuel/carbon intensities per vehicle miles traveled (VMTs) by the Individual Program Goal Case 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 Individual Program Goal Case to estimate how much oil would be consumed if these VMTs were traveled by traditional gasoline vehicles. These calculations are shown in **Table 3.11**.

[8] 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).

[9] 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 3.11. Calculation of Petroleum Savings

	2030	2035	2040	2045	2050
Baseline Case Oil Intensities (TBtu/billion VMT)					
Light-Duty Vehicles	5.56	5.35	5.11	5.09	4.90
Light Trucks	8.46	8.34	8.18	8.00	7.87
Hydrogen Vehicle (VMTs/yr)					
Light-Duty Vehicles	109	325	674	1,240	2,101
Light Trucks	8	17	38	69	115
Petroleum Savings (TBtu/yr)					
Light-Duty Vehicles	605	1,741	3,442	6,307	10,299
Light Trucks	68	143	307	554	901
Total	**673**	**1,884**	**3,750**	**6,862**	**11,200**
Total (million barrels per day)	**0.32**	**0.89**	**1.77**	**3.24**	**5.29**

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 3.12**.

Table 3.12. Calculation of Carbon Emission Reduction

	2030	2035	2040	2045	2050
Decreased CO2 Emissions from Decline in Gasoline Consumption					
Decrease in Gasoline Consumption (TBtu/yr)	**673**	**1,884**	**3,750**	**6,862**	**11,200**
Carbon Intensity of Gasoline (MT of Carbon per MMBtu)	19.3	19.3	19.3	19.3	19.3
Decline in Carbon (MMT/yr)	**13.0**	**36.4**	**72.5**	**132.7**	**216.6**
CO2 Emissions from Hydrogen Production					
Production of Hydrogen (TBtu/yr)	255	695	1,383	2,432	3,920
Carbon Intensity of Hydrogen (MT of Carbon per MMBtu)	30.5	32.2	32.2	27.0	30.0
Increase in Carbon (MMT/yr)	**7.8**	**22.3**	**43.9**	**64.5**	**116.2**
Net decrease in Carbon Emissions (MMT/yr)	**5.2**	**14.2**	**28.6**	**68.2**	**100.4**

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 3.13**. It should be noted that this analysis was conducted with a single-region MARKAL-GPRA07 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 3.13. Hydrogen Production by Feedstock (% of total hydrogen production)

	2030	2035	2040	2045	2050
Central Coal - No Co-Product	17%	6%	3%	2%	1%
Central Coal - With Electric Co-Product	34%	46%	55%	46%	53%
Remote Natural Gas	50%	48%	26%	25%	25%
Central Natural Gas	0%	0%	0%	0%	0%
Central Biomass	0%	0%	16%	27%	21%
Distributed Biomass	0%	0%	0%	0%	0%
Central Electrolytic H2 – Grid	0%	0%	0%	0%	0%
Central Electrolytic H2 – Wind	0%	0%	0%	0%	0%
Distributed Electrolytic H2	0%	0%	0%	0%	0%

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. 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 3.14. Annual Benefits Estimates for Hydrogen, Fuel Cells, and Infrastructure Technologies Program (MARKAL-GPRA07)

Annual Benefits	2030	2040	2050
Energy Displaced			
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	0.4	2.6	7.7
Economic			
Energy-System Cost Savings (billion 2003 dollars/yr)	0	4	28
Environmental			
Carbon Savings (million metric tons carbon equivalent/yr)	5	29	100
Security			
Oil Savings (mbpd)	0.3	1.8	5.3
Natural Gas Savings (quadrillion Btu/yr)	0.0	-0.3	-0.6

More details about the Hydrogen, Fuel Cells, and Infrastructure Technologies Program's benefits analysis can be found in **Appendix B**.

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-GPRA07 framework. Instead, the projected ITP goals by various industries were aggregated into MARKAL-GPRA07 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**

3.15). 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 3.15. 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. Furthermore, the reduction in electricity demand also leads to the reduction in coal, gas, and wind-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.

The activities of the Industrial Technologies Program are more "midterm" in nature. Thus, the long-term annual benefits estimates, which are calculated by MARKAL-GPRA07, were not included in the EERE budget submission or this section of the report. However, the program's activities were modeled for the EERE Portfolio Scenario and included in the long-term annual benefits of the EERE Portfolio, as shown in **Chapter 1.**

More details about the Industrial Technology Program's benefits analysis can be found in **Appendix H.**

Solar Energy Technologies Program

The Solar Energy Technologies Program covers 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.

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 reflect program technology goals. In addition, analysts set the discount rates of these technologies at 8% (instead of the industrial average of 10%) to reflect the Modified Accelerated Cost Recovery System (MACRS)-accelerated depreciation schedule available for solar, wind, and geothermal generation technologies. The total installed capacity of the decentralized units reflects the Solar America 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.

Solar photovoltaic capacity increases dramatically over the Baseline Case (**Table 3.16**). By 2050, the Solar Energy Technologies Individual Program Goal Case shows an additional 238 GW of photovoltaic capacity over the Baseline Case. Additionally, the Solar Energy Technologies Individual Program Goal Case shows an additional 26.5 GW of central solar-thermal generation. By 2050, the improved PV and thermal technologies generate an incremental 698.8 billion kWh of generation over the Baseline Case (**Table 3.17**).

Table 3.16. Solar-Generation Capacity by Case and Type (gigawatts)

	2030	2040	2050
Baseline Case			
Central PV	0.4	0.4	0.4
Distributed PV	5.3	11.0	17.4
Central Thermal	1.3	0.8	0.5
Total	**7.0**	**12.2**	**18.4**
Individual Program Goal Case			
Central PV	0.2	0.0	0.0
Distributed PV	68.6	149.0	255.4
Central Thermal	11.6	22.3	27.0
Total	**80.4**	**171.3**	**282.4**
Increase			
Central PV	-0.2	-0.4	-0.4
Distributed PV	63.3	138.0	237.9
Central Thermal	10.3	21.5	26.5
Total	**73.4**	**159.1**	**264.0**

Table 3.17. Solar-Generation by Case and Type (Billion kWh)

	2030	2040	2050
Baseline Case	0.5	0.8	0.8
Central PV	11.9	24.6	39.1
Distributed PV	3.9	2.4	1.6
Central Thermal	**16.2**	**27.9**	**41.6**
Total	0.5	0.8	0.8
Solar Individual Program Goal Case			
Central PV	0.3	0.0	0.0
Distributed PV	154.0	334.5	573.3
Central Thermal	68.3	136.6	167.1
Total	**222.6**	**471.1**	**740.4**
Increase			
Central PV	-0.2	-0.8	-0.8
Distributed PV	142.1	309.9	534.2
Central Thermal	64.4	134.2	165.5
Total	**206.4**	**443.3**	**698.8**

Central and distributed PV and central thermal generation technologies in the Solar Energy Technologies Individual Program Goal 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 3.18.**

Table 3.18. Annual Benefits Estimates for Solar Energy Technologies Program (MARKAL-GPRA07)

Annual Benefits	2030	2040	2050
Energy Displaced			
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	1.7	3.2	5.2
Economic			
Energy-System Cost Savings (billion 2003 dollars/yr)	3	6	10
Environmental			
Carbon Savings (million metric tons carbon equivalent/yr)	40	65	111
Security			
Oil Savings (mbpd)	ns	ns	ns
Natural Gas Savings (quadrillion Btu/yr)	0.2	1.4	2.1
Capacity (gigawatts)	73	159	264

More details about the Solar Energy Technologies Program's benefits analysis can be found in **Appendix D.**

Vehicle Technologies Program

The Vehicle Technologies Program[10] 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 2005 (AEO2005)* and extended past 2025, based on historical relationships between passenger and commercial VMTs, and population and economic growth. Projected VMTs for light duty vehicles[11], commercial light trucks,[12] and heavy trucks are shown in **Table 3.19**.

Table 3.19. Projected Vehicle Miles Traveled by Vehicle Class (billion VMTs/year)

Vehicle Class	2030	2040	2050
Light-Duty Vehicles	4,420	5,156	5,628
Commercial Light Trucks	118	140	159
Heavy Trucks	414	484	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

[10] The Vehicle Technologies Program is run by the Office of FreedomCAR and Vehicle Technologies.
[11] Light-duty vehicles include passenger cars and light trucks with a gross vehicle weight under 8,500 pounds and may include pickups, vans, or light trucks.
[12] Commercial light trucks are light trucks with a gross vehicle weight between 8,500 and 10,000 pounds and may include pickups, vans, or light trucks.

from the *AEO2005* assumptions, although hybrid-vehicle costs were reduced from *AEO2005* levels in accordance to the Vehicle Technologies Program's view of likely market developments exclusive of program R&D activities. The effect of this baseline change is to increase the market share of hybrid vehicles in the Baseline Case and, thereby, reduce the level of benefits attributed to the Vehicle Technologies Program.

For the Vehicle Technologies Individual Program Goal Case, the costs and efficiencies for hybrid-electric vehicles ("hybrids" or HEV) and advanced diesel vehicles were changed for passenger cars, light trucks, 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, light trucks, 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.

The oil savings generated from the Vehicle Technologies Program are attributable to the market penetration of more efficient LDVs, commercial trucks, and heavy trucks. **Table 3.20** shows the market shares for traditional gasoline and alternative light-duty vehicles for the Vehicle Technologies Individual Program Goal Case, while **Table 3.21** shows transportation-sector petroleum consumption for the Baseline and Vehicles Technologies Individual Program Goal Case.

The reduction in transportation-sector petroleum consumption (**Table 3.22**) 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 3.20. Light-Duty Vehicle Market Shares for the Vehicles Technologies Individual Program Goal Case (% of total fleet)

	2030	2040	2050
Gasoline	38%	4%	0%
Advanced Gasoline	17%	12%	0%
Gasoline Hybrid	25%	58%	96%
Diesel Hybrid	7%	10%	2%
Adv. Diesel & Other	14%	16%	3%

Table 3.21. Petroleum Consumption by Vehicle Class and Case (trillion Btu/year)

	2030	2040	2050
Baseline Case			
Light-Duty Vehicles	24,367	25,868	27,063
Commercial Light Trucks	1,002	1,141	1,253
Heavy Trucks	7,779	8,849	9,681
Total Transportation Sector	**40,426**	**43,625**	**46,107**
Individual Program Goal Case			
Light-Duty Vehicles	19,422	16,889	16,382
Commercial Light Trucks	819	894	927
Heavy Trucks	7,192	7,529	8,126
Total Transportation Sector	**34,711**	**33,080**	**33,546**
Savings			
Light-Duty Vehicles	4,945	8,978	10,681
Commercial Light Trucks	183	247	326
Heavy Trucks	587	1,320	1,555
Total Transportation Sector	**5,715**	**10,545**	**12,561**

Table 3.22. FY07 Benefits Estimates for Vehicle Technologies Program (MARKAL-GPRA07)[13]

Annual Benefits	**2030**	**2040**	**2050**
Energy Displaced			
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	6.2	11.4	13.5
Economic			
Energy-System Cost Savings (billion 2003 dollars/yr)	4	37	70
Environmental			
Carbon Savings (million metric tons carbon equivalent/yr)	117	217	260
Security			
Oil Savings (mbpd)	2.9	5.4	6.5
Natural Gas Savings (quadrillion Btu/yr)	ns	ns	ns

More details about the Vehicle Technologies Program's benefits analysis are available in **Appendix F.**

Weatherization and Intergovernmental Program

The Weatherization and Intergovernmental Program (WIP) Case formulated in MARKAL-GPRA07 focuses on deployment programs that have an impact on the energy consumption in the residential and commercial sectors. Projected program goals of the Weatherization Assistance Program and State Energy Program are transformed into conservation-supply curves that reduce the heating and cooling loads in households and commercial buildings benefiting from these programs. The Tribal Energy Program provides assistance in preparing feasibility studies for

[13] Note that in the Vehicle Technologies Individual Program Goal Case, the advanced ethanol production technologie available in the Biomass Program's Case are unavailable, despite the market synergies of the two suites of technologies. In the EERE portfolio case, both suites are modeled.

renewable generation projects on tribal lands. The impact of this program was modeled by placing lower bounds on the penetration of wind turbines and biomass-fired power generation, which are projected to be developed on tribal lands as a result of this program. The Renewable Energy Production Incentive (REPI) provides payments to publicly owned utilities for renewable power generation. Off-line estimates of the amount of additional renewable generation was made and implemented in the MARKAL model through lower bounds on new wind-generation capacity investment.

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.

The activities of the Weatherization and Intergovernmental Program are more "midterm" in nature. Thus, the long-term annual benefits estimates, which are calculated by MARKAL-GPRA07, were not included in the EERE budget submission or in this section of the report. However, the program's activities were modeled for the EERE Portfolio Scenario and included in the long-term annual benefits of the EERE Portfolio, as shown in **Chapter 1**.

More detail about the WIP Program's benefits analysis can be found in **Appendix J.**

Wind Technologies Program

The Wind Technologies Program R&D aims to reduce capital and O&M costs and improve capacity factors for both onshore and offshore wind turbines. The program goals are represented in the MARKAL-GPRA07 model by changing the capital and O&M costs and capacity factors for wind turbines.

The discount rate for wind generators is set at 8% (instead of the utility average of 10%) to reflect the accelerated depreciation schedule available for renewable-generation technologies. Wind generators are modeled as centralized plants to compete with fossil fuel-based plants.

The 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 resulting generation capacity is different from the NEMS results described in **Chapter 2,** due to differences in model structure and the treatment of offshore wind resources. As with the treatment of onshore wind in both NEMS and MARKAL, a "resource" multiplier is applied to MARKAL's treatment of offshore wind turbine costs. These resource-cost multipliers increase the installed cost of wind turbines as the most suitable wind sites are taken. Furthermore, because the current MARKAL model is a single-region model, offshore and onshore wind technologies compete directly, although they are expected to supply different markets. The change in wind capacity and generation is shown in **Table 3.23**.

Table 3.23. Total Wind Capacity and Generation

	2030	2040	2050
Wind Capacity (GW)			
Baseline Case			
Onshore	20.3	20.6	28.7
Offshore	4.7	11.1	24.7
Total	**25.1**	**31.8**	**53.4**
Individual Program Goal Case			
Onshore	75.0	97.6	107.1
Offshore	16.2	32.9	72.9
Total	**91.2**	**130.5**	**180.0**
Increase			
Onshore	54.7	77.0	78.4
Offshore	11.5	21.8	48.2
Total	**66.1**	**98.8**	**126.6**
Wind Generation (Billion kWh)			
Baseline Case			
Onshore	80	87	129
Offshore	21	50	110
Total	**101**	**137**	**239**
Individual Program Goal Case			
Onshore	316	414	457
Offshore	73	149	330
Total	**389**	**563**	**787**
Increase			
Onshore	236	327	328
Offshore	52	99	219
Total	**288**	**426**	**548**

When the MARKAL model dispatches electric generation capacity, wind generation displaces the generation from the dispatchable unit with the highest marginal cost. This is normally a gas-fired combustion turbine. However, MARKAL also determines new generation capacity additions over the full projection period. Natural gas price forecasts have increased during the past several years in many energy models' forecasts of the U.S. economy. As a consequence, these same models have often forecast more base-load coal-fired capacity. MARKAL is included in this group, and the MARKAL-GPRA07 Baseline Case projects more base-load coal than in past projections. Thus, coal is increasingly becoming the marginal capacity to be built. As such, for capacity builds on the margin, wind is actually competing with coal, not with gas. Because wind is an intermittent power source and much of the coal technology is non-rampable, gas-fired turbines are installed with wind generation to provide backup and peaking. Toward the end of the forecast horizon in the Individual Program Goal Case, wind and gas-fired capacity are installed in place of coal technology, resulting in lower overall coal capacity.

This difference in marginal capacity has implications for the competition for dispatch. Specifically, the Baseline Case increase in coal, combined with the Individual Program Goal Case increase in wind, forces the model to dispatch more natural gas when wind is not available or to meet peak demands, thus increasing natural gas consumption over the Baseline Case in the out years. We will be examining this result in further detail over the coming year. The estimated benefits for the Wind Program are shown in **Table 3.24**.

Table 3.24. Annual Benefits Estimates for Wind Technologies Program (MARKAL-GPRA07)

Annual Benefits	2030	2040	2050
Energy Displaced			
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	2.1	3.6	3.9
Economic			
Energy-System Cost Savings (billion 2003 dollars/yr)	2	2	2
Environmental			
Carbon Savings (million metric tons carbon equivalent/yr)	47	95	101
Security			
Oil Savings (mbpd)	ns	ns	ns
Natural Gas Savings (quadrillion Btu/yr)[14]	0.6	-0.3	-0.2
Capacity (gigawatts)	66	99	127

More details on the Wind Program's benefits analysis are available in **Appendix E.**

[14] The net increase in natural gas consumption in "out" years is due to a shift from installed marginal coal capacity in the Baseline Case to wind supported by natural gas in the Individual Program Goal Case.

Box 3.1—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 3.1** 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 3.1. An Illustrative Reference Energy System