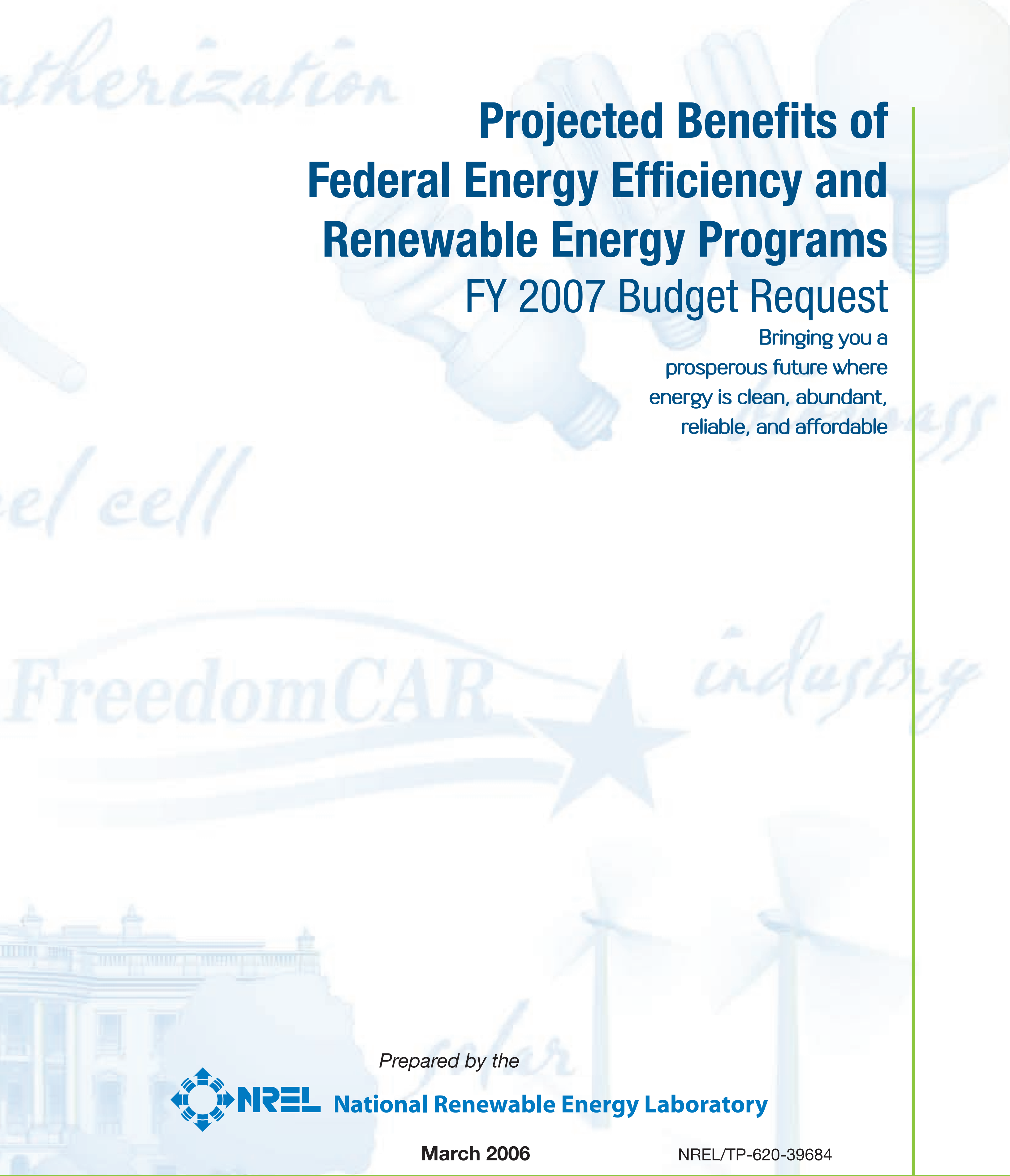

Projected Benefits of Federal Energy Efficiency and Renewable Energy Programs

FY 2007 Budget Request

Bringing you a
prosperous future where
energy is clean, abundant,
reliable, and affordable

Prepared by the

National Renewable Energy Laboratory

March 2006

NREL/TP-620-39684

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

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Projected Benefits of Federal Energy Efficiency and Renewable Energy Programs: FY 2007 Budget Request

Technical Report
NREL/TP-620-39684
March 2006

Prepared under Task No. SA01.0510

National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401-3393
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EXECUTIVE SUMMARY

The Office of Energy Efficiency and Renewable Energy (EERE) of the U.S. Department of Energy (DOE) leads the Federal Government's efforts to provide clean, reliable, and affordable energy for America, through its nine research, development, demonstration, and deployment (RD^3) programs. EERE invests in high-risk, high-value research and development (R&D) that—conducted in partnership with the private sector and other government agencies—accelerates the development and facilitates the deployment of advanced clean energy technologies and practices. EERE designs its RD^3 activities to improve the Nation's readiness for addressing current and future energy needs.

Key Findings

Under a business-as-usual energy future, realization of these goals and the associated projected market outcomes would:

- Reduce the expected increase in U.S. demand for nonrenewable energy by 28% in 2025 and 78% in 2050.
- Reduce nonrenewable energy consumption starting in 2030. (**Figure ES.1**)
- Reduce the expected increase in U.S. consumer energy expenditures by 51% in 2025. (**Figure ES.2**)
- Save more than $200 billion per year in U.S. energy system net costs in 2050. (**Table ES.2**)
- Reduce the expected increase in annual U.S. carbon emissions by 31% in 2025 and 68% in 2050. (**Figure ES.3**)
- Reduce the expected increase in U.S. oil consumption (most of which is expected to originate from outside the United States) by 28% in 2025 and 120% in 2050.
- Result in declining oil consumption after 2025. (**Figure ES.4**)
- Reduce the expected increase in U.S. natural gas consumption, much of which is expected to originate outside the United States, by 10% in 2025 and 20% in 2050. (**Figure ES.5**)
- Avoid 118 gigawatts of additions to central conventional power in 2025. (**Table ES.2**)

Why Measure Benefits?

EERE develops benefits projections annually to maintain compliance with the Government Performance and Results Act (GPRA) of 1993 and the President's Management Agenda (PMA). GPRA requires Federal Government agencies to develop and report on output and outcome measures for each program. This analysis helps meet GPRA requirements by identifying the potential outcomes and benefits of realizing EERE program goals (outputs). The benefits estimates do not reflect the technical risks or probabilities of realizing these goals, which are being addressed separately.[1]

The reported benefits reflect only the net annual improvement from 2005 to 2050 of program activities included in EERE's FY 2007 Budget Request (including subsequent-year funding) and do not include the benefits from past work. The benefits estimates assume continued funding for program activities consistent with multiyear program plans.[2] By basing estimated benefits on budget levels, the analysis addresses the performance-budget integration goal of the PMA.

Modeling the Market Outcomes of EERE's Technology Portfolio

EERE uses two energy-economy models—NEMS-GPRA07 and MARKAL-GPRA07—to estimate the impacts of EERE programs on energy markets. The NEMS-GPRA07 model is a modified version of the National Energy Modeling System (NEMS), the midterm energy model used by the Department of Energy's Energy Information Administration (EIA). The MARKAL-GPRA07 model is a modified version of the MARKet ALlocation (MARKAL) model, developed by Brookhaven National Laboratory and used by numerous countries worldwide. EERE uses NEMS-GPRA07 to estimate the midterm benefits of its programs, and MARKAL-GPRA07 to estimate the long-term benefits of its programs.

Choosing Metrics for EERE's Technology Portfolio

EERE has adopted a benefits framework developed by the National Research Council (NRC)[3] to represent the various types of benefits resulting from the energy efficiency technology improvements and renewable energy technology development supported by EERE programs. Specifically, EERE's benefits analysis focuses on three main categories of energy-linked benefits—economic, environmental, and security. The specific measures or metrics of these benefits estimated for FY 2007 are identified in **Table ES.1**. These metrics are not a complete representation of the benefits or market roles of efficiency and renewable technologies, but provide an indication of the range of benefits provided. EERE is continuing to take steps to more fully represent the NRC framework.

Assessing the Integrated Portfolio versus the Individual Programs

Analysts assess the impacts of EERE's technology development programs in two ways: 1) as an integrated portfolio, and 2) as a set of individual program goal cases. The integrated portfolio assessment involves running NEMS-GPRA07 and MARKAL-GPRA07 with all programs simultaneously represented. This provides a picture of the overall EERE portfolio that takes into account synergy and competition among the different technologies offered by each program. The individual program goal cases measure the isolated impact of technology development and

---

[1] A standard approach to teatment of risk is being developed for EERE's multiyear program plans.

[2] Funding levels may increase, decrease, or remain constant, depending on the program. See Appendices B through M for information on individual multiyear program plans.

[3] *Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000*, National Research Council (2001). The NRC is the principal operating agency of the National Academy of Sciences (NAS) and the National Academy of Engineering (NAE), providing services to the government, the public, and the scientific and engineering communities.

deployment success for each program. For these cases, each program is represented by itself in NEMS-GPRA07 and MARKAL-GRPA07 (in the absence of the other EERE programs).

Table ES.1. EERE FY 2007 Benefits Metrics

Primary Outcome	
Energy displaced	• Reductions in nonrenewable energy consumption (quadrillion Btu/yr)
Resulting Benefits	
Economic	• Reductions in consumer energy expenditures (NEMS-GPRA07 - billion 2002 dollars/yr) • Reductions in energy-system costs (MARKAL-GPRA07 - in billion 2002 dollars/yr)
Environmental	• Reductions in carbon dioxide emissions (mmtc equivalent/yr)
Security	• Reductions in oil consumption (mbpd) • Reductions in natural gas consumption (quadrillion Btu/yr) • Avoided additions to central conventional power (cumulative gigawatts)

The Annual Impacts of EERE's Technology Portfolio

Table ES.2 shows the estimated energy displaced and resulting benefits to the Nation of realizing the EERE program goals associated with the FY 2007 budget request. These impacts are the benefits expected in the reported year—that is, the benefits are annual, not cumulative (with the exception of avoided additions to conventional central power).

Table ES.2. Summary of Annual EERE Integrated Portfolio Benefits for FY 2007 Budget Request

EERE Midterm Benefits (NEMS-GPRA07)	**2010**	**2015**	**2020**	**2025**
Energy Displaced				
• Primary nonrenewable energy savings (quadrillion Btu/yr)	0.35	1.4	4.4	7.8
Economic				
• Energy-expenditure savings (billion 2003 dollars/yr)*	2.1	18	70	107
Environment				
• Carbon dioxide emission reductions (mmtce/yr)	8	26	86	166
Security				
• Oil savings (mbpd)	0.03	0.43	1.07	1.69
• Natural gas savings (quadrillion Btu/yr)	0.07	0.35	1.04	0.82
• Avoided additions to central conventional power (cumulative gigawatts)	0.53	11	54	118

EERE Long-Term Benefits (MARKAL-GPRA07)	**2030**	**2040**	**2050**
Energy Displaced			
• Primary nonrenewable energy savings (quadrillion Btu/yr)	14	25	32
Economic			
• Energy-system net cost savings (billion 2003 dollars/yr)*	63	138	207
Environment			
• Carbon dioxide emission reductions (mmtce/yr)	279	527	648
Security			
• Oil savings (mbpd)	3.9	8.0	11
• Natural gas savings (quadrillion Btu/yr)	2.0	2.0	2.8

* Midterm energy-expenditure savings only include reductions in consumer energy bills, while long-term energy-system cost savings also include the incremental cost of the advanced energy technology purchased by the consumer.

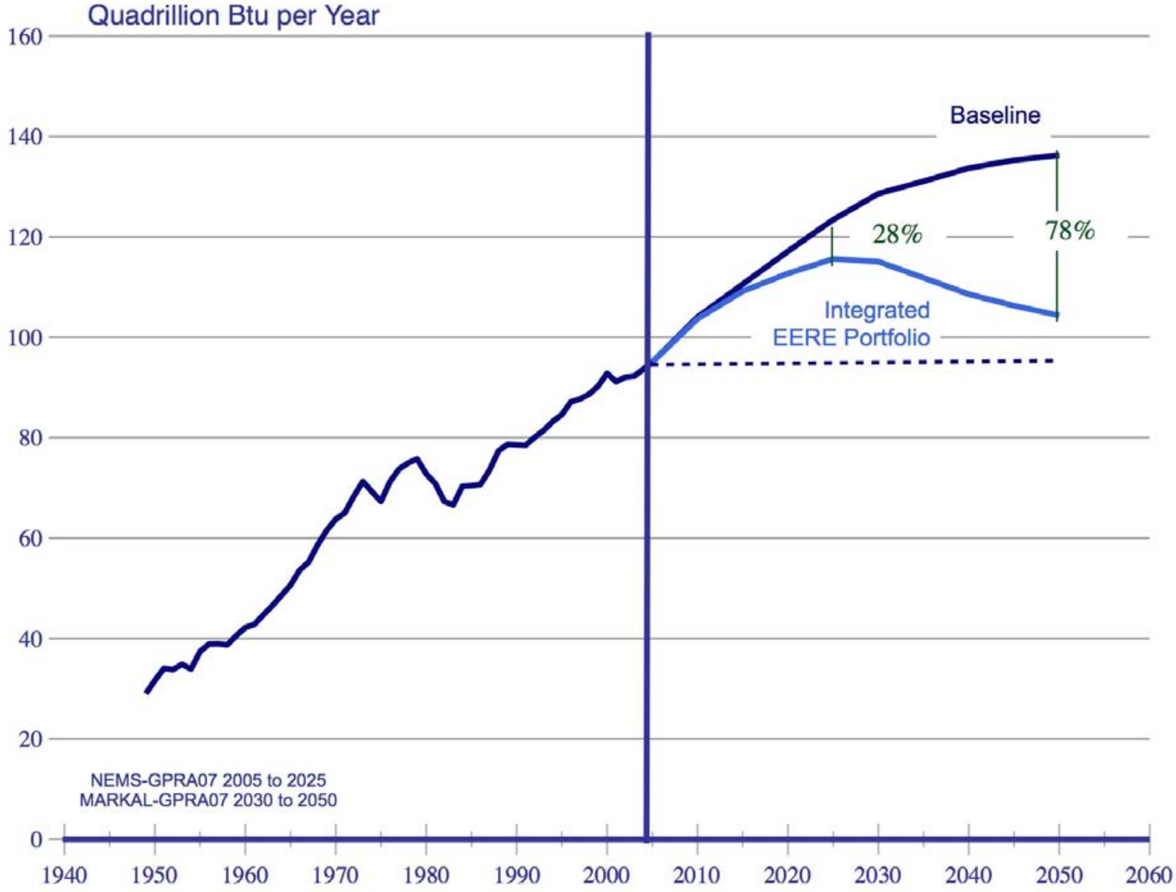

Figure ES.1. U.S. Nonrenewable Energy Consumption, 1949-2005, and Projections to 2050: Baseline and Portfolio Cases

Note: The percentage change in the chart shown for 2025 and 2050 is the difference between the Baseline Case and the Portfolio Case, compared to the difference between the values of the Baseline Case in 2025 (or 2050) versus 2005 Data Source: 1949-2005, Energy Information Administration, *Annual Energy Review 2004*, DOE/EIA-0384 (2004) (Washington, D.C., August 2005), Table 1.1, Web site http://www.eia.doe.gov/emeu/aer/contents.html.

The portfolio of EERE technologies avoids 28% of the anticipated growth in annual U.S. nonrenewable energy demand in 2025.

By 2050, EERE's technology portfolio avoids almost 80% of the anticipated growth in annual U.S. nonrenewable energy demand.

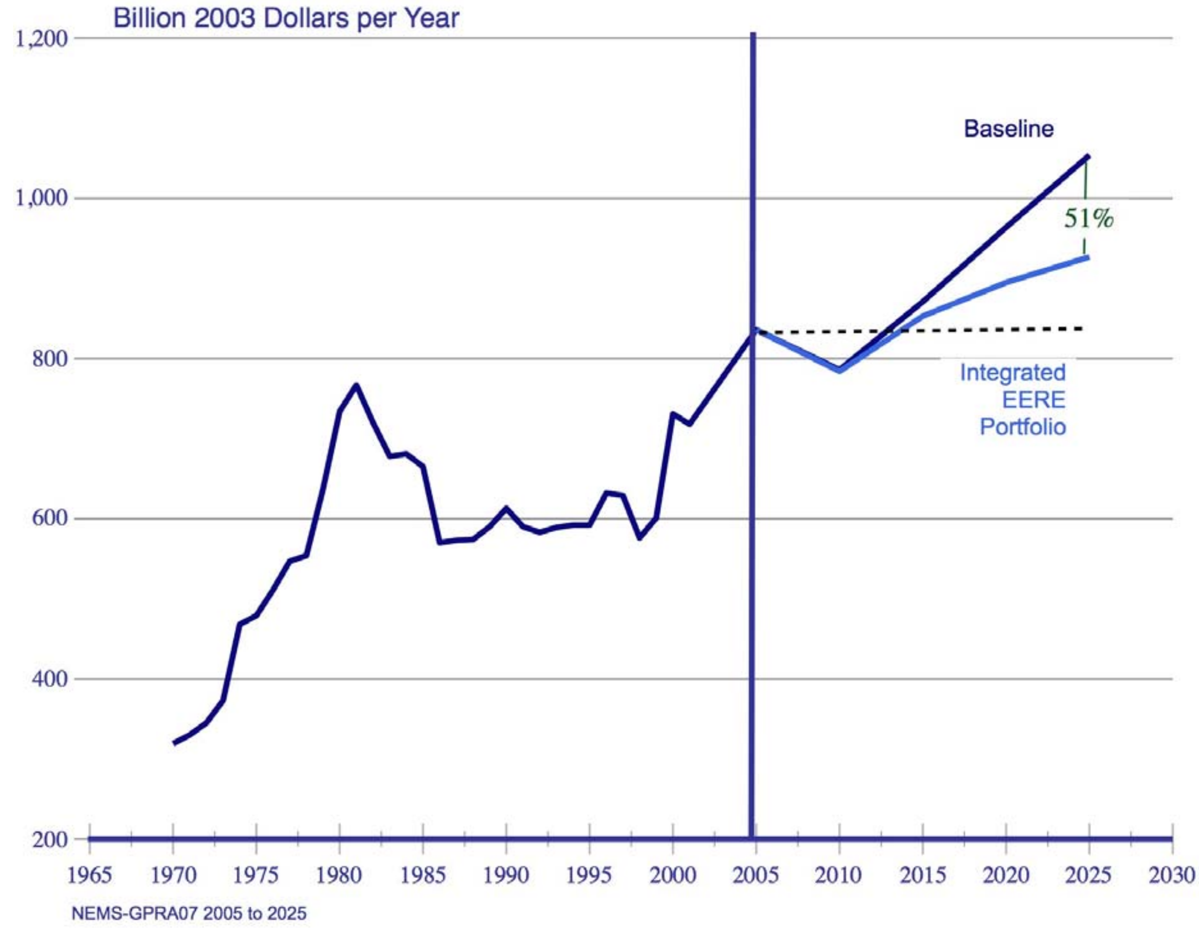

Figure ES.2. U.S. Total Energy Expenditures, 1965-2005, and Projections to 2025: Baseline and Portfolio Cases

Note: The percentage change in the chart shown for 2025 and 2050 is the difference between the Baseline Case and the Portfolio Case, compared to the difference between the values of the Baseline Case in 2025 (or 2050) versus 2005. Data Source: 1970-2001, Energy Information Administration, *Annual Energy Review 2004*, DOE/EIA-0384 (2004) (Washington, D.C., August 2005), Table 3.5 and Table D1, Web site http://www.eia.doe.gov/emeu/aer/contents.html.

.

The portfolio of EERE technologies reduces the anticipated growth in annual U.S energy expenditures by 51% in 2025.

By 2050, EERE's technology portfolio provides annual U.S. energy-system net savings of more than $200 billion (see Table ES.2).

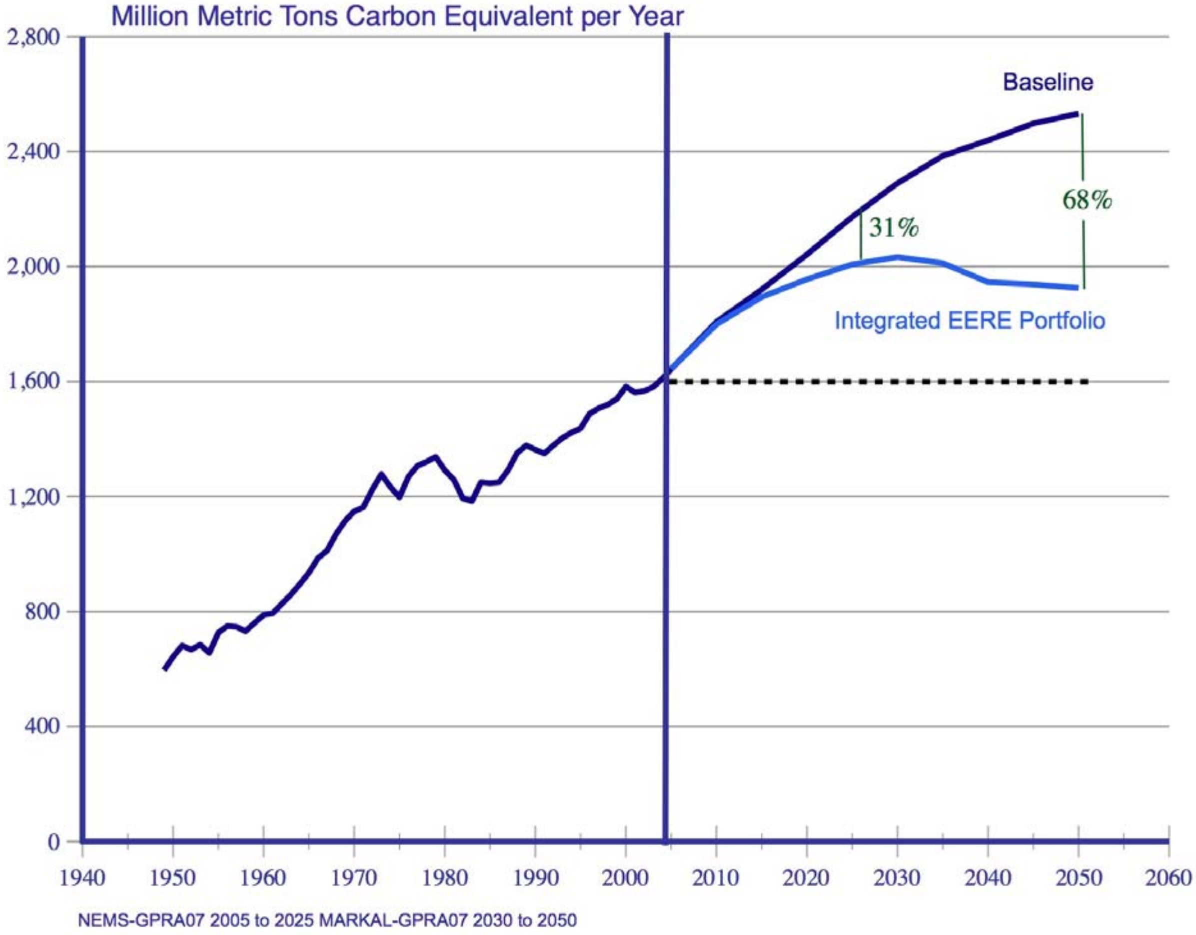

Figure ES.3. U.S. Energy-Related Carbon Emissions, 1949-2005, and Projections to 2050: Baseline and Portfolio Cases

Note: The percentage change in the chart shown for 2025 and 2050 is the difference between the Baseline Case and the Portfolio Case, compared to the difference between the values of the Baseline Case in 2025 (or 2050) versus 2005. Data Source: 1980-2000, Energy Information Administration, *Annual Energy Review 2004*, DOE/EIA-0384 (2004) (Washington, D.C., August 2005), Table 12.2, Web site http://www.eia.doe.gov/emeu/aer/contents.html.

The portfolio of EERE technologies avoids 31% of the anticipated growth in annual energy-related carbon emissions in 2025.

By 2050, EERE's technology portfolio avoids 68% of the anticipated growth in annual energy-related carbon emissions.

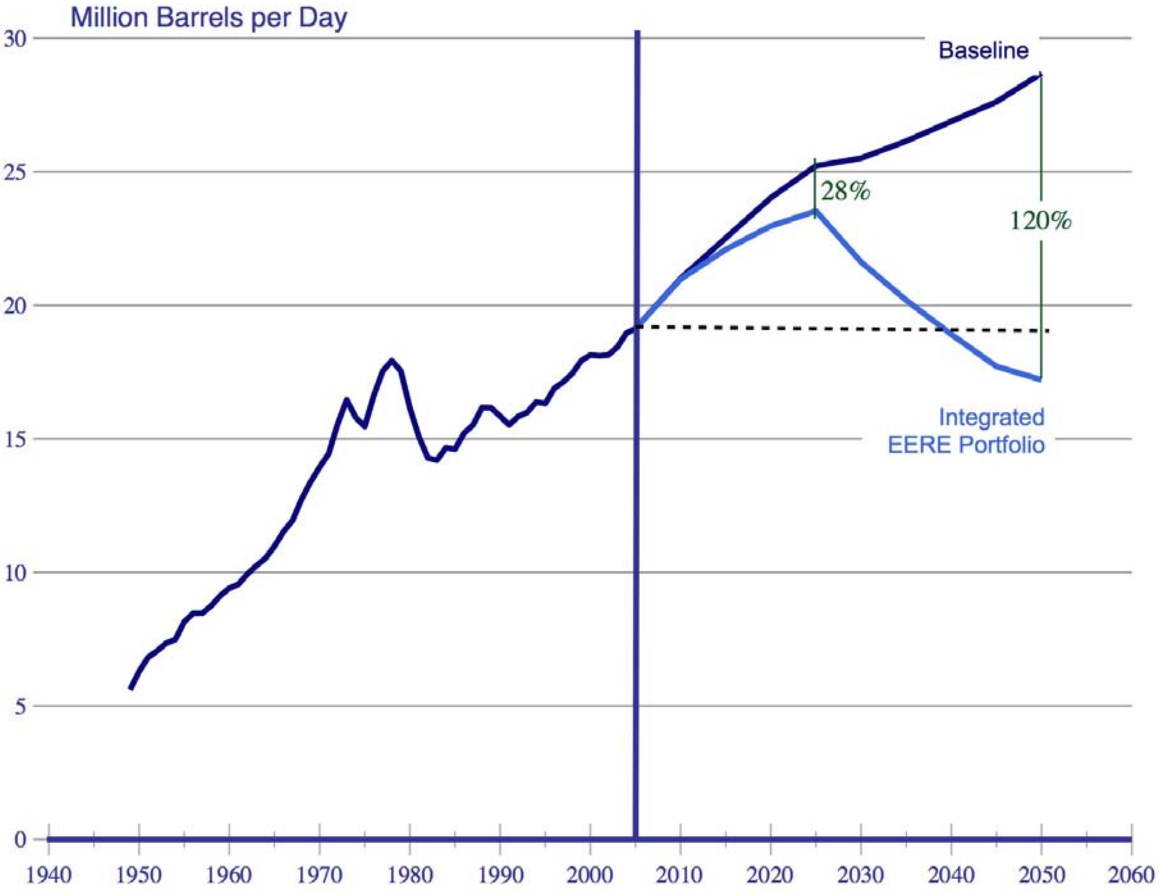

Figure ES.4. U.S. Oil Consumption, 1949-2005, and Projections to 2050: Baseline and Portfolio Cases

Note: The percentage change in the chart shown for 2025 and 2050 is the difference between the Baseline Case and the Portfolio Case, compared to the difference between the values of the Baseline Case in 2025 (or 2050) versus 2005. Data Source: 1949-2000, Energy Information Administration, *Annual Energy Review 2004*, DOE/EIA-0384 (2004) (Washington, D.C., August 2005), Table 1.3, Web site http://www.eia.doe.gov/emeu/aer/contents.html. Data were converted from quads per year to mbpd using conversion factor of 5.8 million Btus per barrel of crude oil.

The portfolio of EERE technologies avoids 28% of the anticipated growth in annual U.S. oil demand in 2025.

By 2050, EERE's technology portfolio avoids 120% of the anticipated growth in annual U.S. oil demand in 2050.

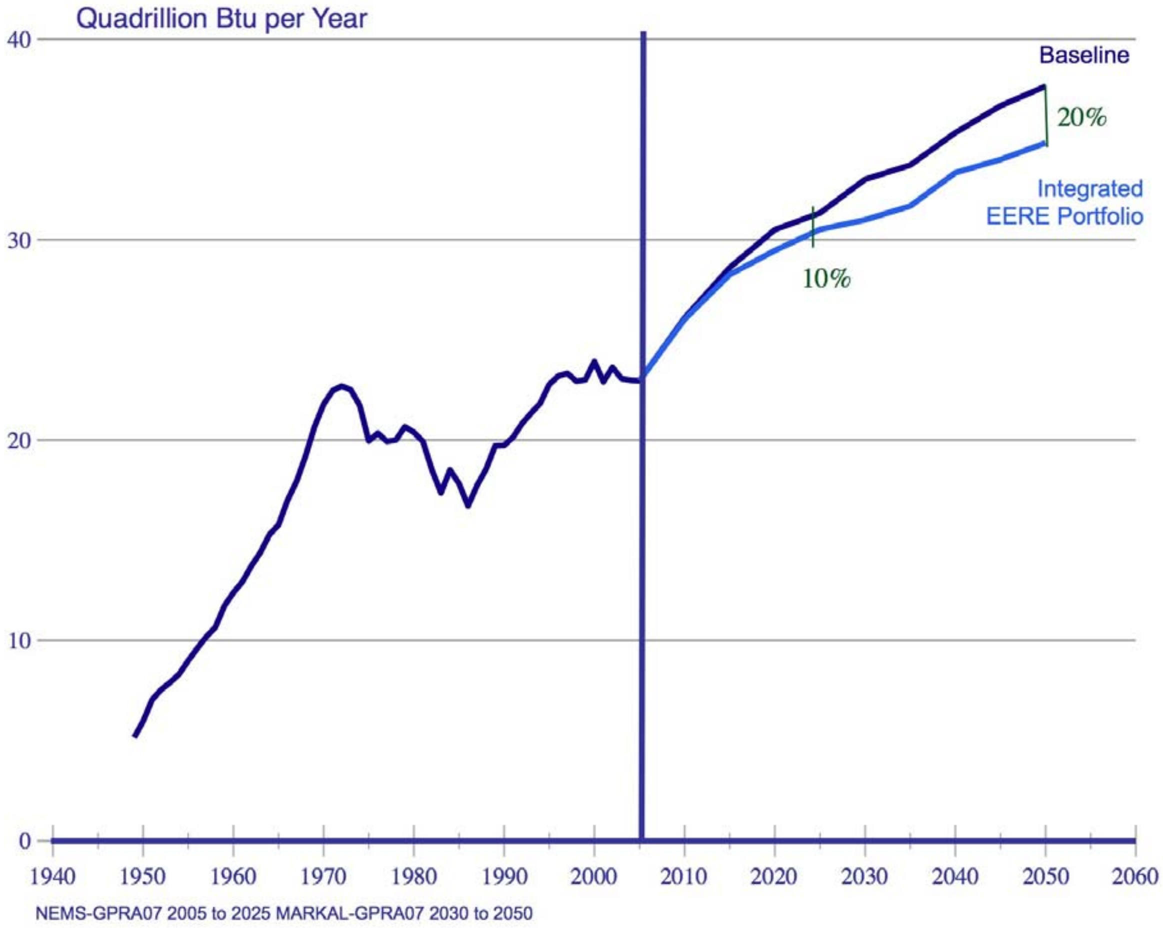

Figure ES.5. U.S. Natural Gas Consumption, 1949-2005, and Projections to 2050: Baseline and Portfolio Cases

Note: The percentage change in the chart shown for 2025 and 2050 is the difference between the Baseline Case and the Portfolio Case, compared to the difference between the values of the Baseline Case in 2025 (or 2050) versus 2005. Data Sources: 1980-2000, EIA, *Annual Energy Review 2004*, DOE/EIA-0384 (2004) August 2005, Table 1.3, Web site http://www.eia.doe.gov/emeu/aer/contents.html; 2005-2025, NEMS-GPRA07; 2030-2050, MARKAL-GPRA07.

The portfolio of EERE technologies avoids 10% of the anticipated growth in annual U.S. natural gas demand in 2025.

In the long run, EERE's technology portfolio avoids 20% of the anticipated growth in annual U.S. natural gas demand in 2050

Individual Program Budgets and Benefits

Figure ES.6 and **Table ES.3** summarize individual program budgets and the results of the benefits analysis for individual program goal cases. Individual program benefits are shown for the midterm (2025) and for the long term (2050). The largest program budget is $225 million for the Weatherization and Intergovernmental Program (WIP), which includes $164 million for Low-Income Weatherization Assistance.

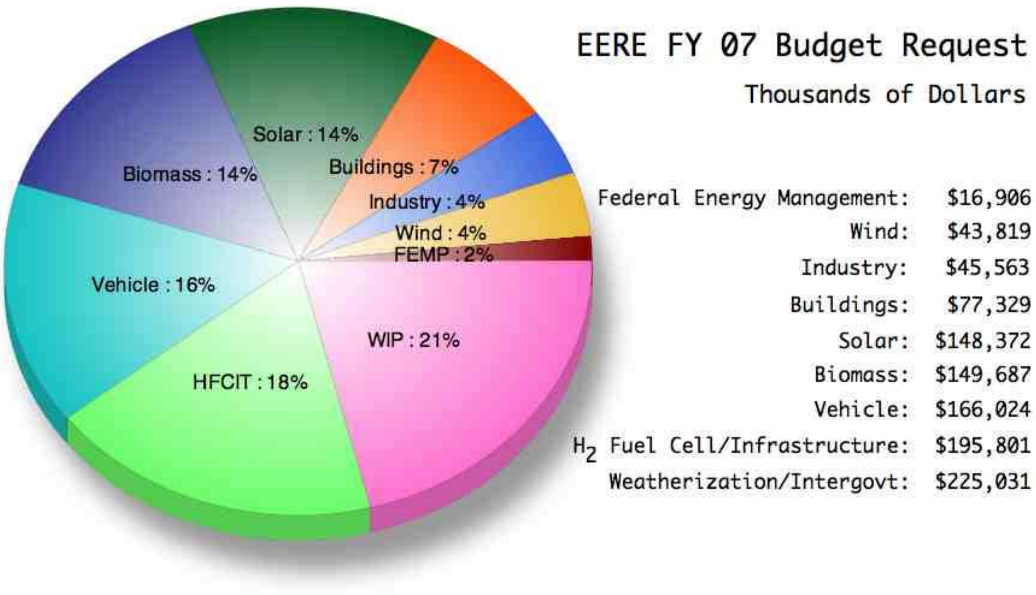

Figure ES.6. Proposed FY 2007 Budget Request for Technology Development

Data Sources: FY 2007 proposed budget information is available at
http://www1.eere.energy.gov/ba/pba/budget_07.html

The picture that emerges from the individual program benefits presented here is one of robustness. Different technologies are positioned to dominate in the mid- and long term. Some technologies are best-suited to improving energy security by reducing our dependence on foreign oil. In addition, different programs emerge as important contributors to consumer energy savings versus those that emerge as important contributors to total energy system net cost savings.

While incomplete (because the estimates of the individual program goal cases are not based on integrated runs), the results indicate both the range and approximate level of benefits available to the Nation from funding the efficiency and renewable investments in EERE’s portfolio of programs. They indicate a potential for making better use of existing technologies and for accelerating technological advances to make significant changes in our energy markets, which can drive the Nation to a period of level energy consumption.

Table ES.3. U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE): FY 2007 Funding Summary and Selected 2025 and 2050 Benefits by Program[4]

Program	**FY 2007 Request (thousands $)**	**Nonrenewable Energy Displaced (quads/yr)**		**Energy Expenditure Savings (billions 2002$/yr)**		**Energy System Cost Savings (billions 2002$/yr)**		**Carbon Dioxide Emissions Reductions (million mtce/yr)**		**Oil-Use Reductions (mbpd)**	
		2025	2050	2025	2050	2025	2050	2025	2050	2025	2050
Biomass	149,687	0.39	2.8	5.4	N/A	N/A	2.3	6.8	57.2	0.22	1.115
Building Technologies	77,329	1.99	5.4	17.3	N/A	N/A	130.0	44.7	124.2	0.04	0.475
Federal Energy Management	$16,906	0.02	0.1	0.2	N/A	N/A	0.0	0.4	0.7	0.00	0.002
Hydrogen, Fuel Cells, and Infrastructure Technologies	195,801	0.22	7.7	2.4	N/A	N/A	27.5	5.8	100.4	0.28	5.291
Industrial Technologies	45,563	ns	ns	ns	N/A	N/A	0.3	0.0	ns	0.00	ns
Solar Energy Technologies	148,372	1.07	5.2	7.9	N/A	N/A	9.2	28.8	110.8	0.00	0.025
Vehicle Technologies[5]	166,024	2.32	13.5	49.3	N/A	N/A	67.5	41.5	260.2	1.07	6.482
Weatherization and Intergovernmental	225,031	0.20	0.1	2.3	N/A	N/A	2.1	3.8	2.2	0.01	ns
Wind	43,819	3.10	3.9	17.6	N/A	N/A	2.1	69.1	100.8	0.09	0.006
Facilities and Infrastructure	5,935	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Program Direction and Management Support	104,954	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total EERE Integrated Portfolio Benefits**	**1,179,421**	**7.80**	**32**	**107**	**N/A**	**N/A**	**207**	**166**	**648**	**1.7**	**11**

** The total benefits of the EERE integrated portfolio differ from the sum of the individual program benefits, because interactions among programs are not accounted for in the individual programs

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[4] Data Sources: FY 2007 proposed budget information is available at http://www1.eere.energy.gov/ba/pba/budget_07.html

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

Scenario Analysis

In prior years, benefits estimates were reported for a single future energy scenario. Because of the uncertainties of energy and economic projections, this view of our energy future has limited value, especially in assessing the benefits of the full suite of technologies in the EERE portfolio. Assessing only one possible future may be particularly misleading for programs in which a significant part of the worth of the program may lie as a hedge against less likely, but possible, futures. Evaluating EERE's portfolio for a variety of possible futures offers insight about the robustness of the portfolio.

This year, we have taken the first step toward introducing scenario analysis for the EERE portfolio. Two scenarios were evaluated: 1) a high oil-price case, and 2) a carbon-constrained future. Because this is EERE's first foray into scenario analysis for GPRA benefits, we report the results as an appendix to this report (see **Appendix K**). Given the recent and sustained increases in crude oil and natural gas prices, the high fuels-price case is particularly relevant in understanding the value of EERE's portfolio, in what is likely to be the Base Case in future years. Similarly, understanding the impact of these programs under different carbon emissions scenarios is an increasingly important topic. We will evaluate our methodology for scenario analysis this year; and we expect that scenario analysis will be a part of the main benefits report for the FY 2008 budget request.

Future GPRA Benefits Development

As part of DOE's continuing efforts to implement the President's Management Agenda—and to be responsive to the advice offered by the National Academy of Sciences/National Research Council—DOE is in the process of integrating its GPRA benefits analyses across the offices of Energy, Science, and Environment (ESE). This integration process is expected to be fully completed for the FY 2010 budget request, but significant and important steps and progress will be evident along the way. The GPRA benefits analysis for the FY08 budget request will show a DOE-wide portfolio case, in which all offices' RD3 programs are combined. Further, EERE technologies' benefits will be evaluated relative to an ESE-wide baseline (as opposed to a baseline in which only EERE advanced technologies are removed from the AEO reference). Moreover, the inputs to the integrating models will be developed using common methodologies across all ESE offices. The result will be a much clearer picture of the benefits of the full DOE portfolio than has been represented to date.

Another major development afoot in DOE's benefits analysis is the treatment of risk and uncertainty. As in prior years, the benefits in this report are shown for Programs and the Portfolio assuming that RD3 goals are achieved and that they are achieved on time. It is also assumed that RD3 funding is continued as required. These assumptions represent a considerable simplification in a number of ways. First, for R&D there is considerable technical risk in what the actual output of the program activities might be. In fact, the output in a given year could be greater or less than the specified goal; or, alternatively, a specified goal may be achieved earlier or later than scheduled. Moreover, for a given output, the outcome is not known with certainty, because it will be affected by market risk considerations.

PROJECTED BENEFITS OF FEDERAL ENERGY EFFICIENCY AND RENEWABLE ENERGY PROGRAMS (FY 2007-FY 2050)

This report summarizes program benefits analysis undertaken by experts in energy technology programs, energy markets, and energy-economic modeling. The primary team members and areas of responsibility are listed below.

Report Managers, Writers, and Editors

- EERE
    - Report Coordinator: Michael Leifman
    - Biomass: Tien Nguyen
    - Buildings: Brian Card and Charlie Hemmeline
    - Federal Energy Management: David Boomsma
    - Hydrogen, Fuel Cells, and Infrastructure Technologies: Jeff Dowd
    - Industry: Peggy Podolak
    - Solar: Michael York
    - Vehicle Technologies: Phil Patterson
    - Weatherization and Intergovernmental: Cathy Short
    - Wind: Linda Silverman

- Contractors
    - Project Manager: John Sheehan, National Renewable Energy Laboratory (NREL)
    - Guidance and Review: Doug Arent (NREL), Thomas Jenkin (NREL), Lynn McLarty (TMS), Tobey Winters (NREL)
    - Editorial: Michelle Kubik (NREL)

- Chapter Authors
    - Preface and Chapter 1: John Sheehan (NREL)
    - Energy-Economic Integration–NEMS: Frances Wood (OnLocation Inc).
    - Energy-Economic Integration–MARKAL: Chip Friley, Brookhaven National Laboratory (BNL)
    - Biomass: David Andress, David Andress and Associates (DAA)
    - Buildings: Donna Hostick, Pacific Northwest National Laboratory (PNNL)
    - Federal Energy Management: Donna Hostick (PNNL)
    - Hydrogen and Fuel Cells: Margaret Singh, Argonne National Laboratory (ANL)
    - Industry: Jim Reed (Energetics)
    - Solar: Robert Margolis (NREL), Jim McVeigh, Princeton Energy Resources International (PERI)
    - Vehicle Technologies: Margaret Singh (ANL)
    - Weatherization and Intergovernmental Programs (WIP): Donna Hostick (PNNL)
    - Wind: Joe Cohen (PERI)

In all cases, these lead analysts drew from the studies and expertise of many others. Other members of the Benefits Analysis Team include:
EERE: Mark Bailey, Darrell Beschen, Jack Cadogan, Jerry Dion, Joan Glickman, Scott Hassell, Fred Joseck, Quonnie Laughlin, Neil Rossmeissl, John Ryan, Lee Slezak, Randy Steer, Glenn Strahs
ANL: Don Hillebrand, Steve Plotkin
Navigant Consulting: Ed Barbour
NREL: Ian Baring-Gould, Kelly Ibsen, John Jechura, Cindy Riley, Laura Vimmerstedt
OnLocation: John Holte, Laura Train, Will Georgi
PERI: Jim McVeigh
PNNL: David Anderson, David Belzer, Daryl Brown, Jim Dirks, Doug Elliott, Sean McDonald, Nancy Moore, Andrew Nicholls, Joe Roop
Sentech; Bill Zwack
TA Engineering: Jim Moore
TMS: Brian Lavoie, Doug Norland

PREFACE

The Office of Energy Efficiency and Renewable Energy (EERE) develops—and encourages consumers and business to adopt—technologies that improve energy efficiency and increase the use of renewable energy. This report describes analysis undertaken by EERE to better understand the extent to which the Research, Development, Demonstration, and Deployment (RD3) technology and market improvements funded by its fiscal year (FY) 2007 Budget Request[1] will make energy more affordable, cleaner, and more reliable.

This benefits analysis helps EERE meet the provisions of the Government Performance and Results Act (GPRA) of 1993 and the President's Management Agenda (PMA). GPRA requires Federal Government agencies to develop and report on output and outcome measures for each program.[2] This EERE benefits analysis supports these GPRA requirements by developing an assessment of the benefits that may accrue to the Nation if the performance goals (outputs) of EERE's programs are realized. The estimates of consumer energy-expenditure savings, energy-system cost savings,[3] carbon emission savings, and reduced reliance on fossil fuels (outcomes) that are reported here result from the increased use of energy-efficient technologies and increased production and use of renewable energy resources—which are supported by the technology advances and market-adoption activities pursued by EERE programs.

Shortly after GPRA was enacted, EERE initiated a corporate approach to benefits analysis that examined the energy, economic, and environmental impacts of program efforts. Through the 1990s, EERE program offices continued to refine their benefits-analysis methodologies and assumptions. Although the benefits analysis has changed since it was initiated 12 years ago, the amount of energy saved or displaced continues to be a key measure of the EERE program impact. Other key metrics include measurement of economic and environmental benefits, as well as increasingly important security and dependency metrics, such as oil and natural gas saved.

This benefits analysis also supports the President's Management Agenda. The analysis summarized in this report is based on modeling the impact of meeting program performance goals (or outputs). EERE's programs develop these goals based on the following key assumptions:[4]

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[1] See http://www.eere.energy.gov/office_eere/budget.html.

[2] See the Government Performance and Results Act (GPRA) of 1993 at http://www.whitehouse.gov/omb/mgmt-gpra/gplaw2m.html and http://www.whitehouse.gov/omb/circulars/a11/02toc.html

[3] Our integrating energy model for calculating midterm benefits (through 2025), NEMS-GPRA07, and our integrating energy model for calculating long-term benefits (through 2050), MARKAL-GPRA07, report different economic measures. NEMS-GPRA07 estimates consumer-expenditure savings, which are the gross savings from avoiding purchased energy. They do not include all incremental investment required to achieve these savings. MARKAL-GPRA07 estimates energy-system cost savings, which includes both the savings from avoiding purchased energy and the incremental investment required for the advanced energy technology. In future GPRA reports, it is intended that both models will report the same economic metric.

[4] Achieving program goals is generally not dependent on a single technical pathway, but instead encompasses a number of alternative approaches, of which some may fall short without jeopardizing realization of the final goal. The pursuit of multiple pathways can increase the likelihood of achieving program goals, thereby reducing the risk of the program. Risk is being addressed in a separate EERE effort to develop a standard approach to risk assessment.

- Programs will be funded at levels consistent with DOE's FY 2007 Budget Request.
- Funding levels will remain constant in inflation-adjusted dollars or increase to accommodate key initiatives in particular cases, as indicated.
- Funding is assumed to be in place until goals are achieved.

Role of Benefits Analysis in Performance Management

EERE employs a widely used logic model[5] as the foundation for managing its portfolio of efficiency and renewable investments, and for ensuring that these investments provide energy benefits to the Nation. In its simplest form, a logic model identifies budget and other *inputs* to a program, *activities* conducted by the program, and the resulting *outputs* and *outcomes* of those activities. The logic model employed by EERE (**Figure P.1**) provides an integrated approach that explicitly links requested budget levels to performance goals and estimated benefits—and helps ensure that estimated benefits reflect the funding levels requested. The elements of the logic model, which are specified in GPRA, are included in the annual budget request.

Multiyear Program Plans (MYPPs), developed by each of EERE's nine programs, address the *inputs* required, the *activities* that will be undertaken with their requested budget, the performance *milestones* they expect to achieve as they pursue these activities, and the resulting products or *outputs* of the RD3 effort.[6] Inputs may include cost-shared or leveraged funds, as well as EERE program dollars—and may also include advances by others on which the program builds. Performance milestones capture intermediate points of discernable progress toward outputs and are used by program managers, DOE, OMB, and others to track program progress toward their outputs. Outputs, often referred to as "program goals" or "program performance goals,"[7] are the resulting products or achievements of an overall area of activity. EERE's R&D programs typically specify their outputs in terms of technology advances (e.g., reduced costs, improved efficiency), while deployment programs develop outputs related to their immediate market impacts (e.g., number of homes weatherized). Outputs evolve over time as the program pursues increasing levels of technology performance or market penetration.[8]

This benefits analysis links these program outputs to their market impacts or outcomes. EERE's programs have discernable effects on energy markets, both by reducing the level of energy demand (through efficiency improvements) and by changing the mix of our energy supplies (through increased renewable and distributed energy production). The program goals or outputs

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[5] The logic model is a fundamental program planning-and-evaluation tool. For more information on logic models, see: Wholey, J. S. (1987). *Evaluability assessment: developing program theory. Using Program Theory in Evaluation*. L. Bickman. San Francisco, Calif., Jossey-Bass. 33. Jordan, G. B. and J. Mortensen (1997). "Measuring the performance of research and technology programs: a balanced scorecard approach." *Journal of Technology Transfer* 22(2). McLaughlin, J. A. and G. B. Jordan (1999). "Logic models: a tool for telling your program's performance story." *Evaluation and Program Planning* 22(1): 65-72.

[6] Appendices B through J provide more information on each program's multiyear program plan and the inputs, activities, milestones, and outputs contained therein.

[7] Some programs derive their outputs through technology-cost simulation models to develop the specific requirements to meet overall program cost and performance goals. Specific details of the representation of the program outputs in NEMS-GPRA07, MARKAL-GPRA07, and the underlying program analysis and documentation are found in Chapters 2 and 3 of this report and Appendices B through J.

[8] The level of risk for the programs is assessed qualitatively as part of the Office of Management and Budget (OMB) R&D Investment Criteria. EERE is developing a standard approach to assessing technology and program risk.

are therefore often used as input to the integrating energy models. Further, the changed energy mix has environmental and economic implications. EERE incorporates these effects in its *outcomes*—the displacement of conventional energy demand, the avoidance of carbon emissions, and the energy expenditure or net cost savings.

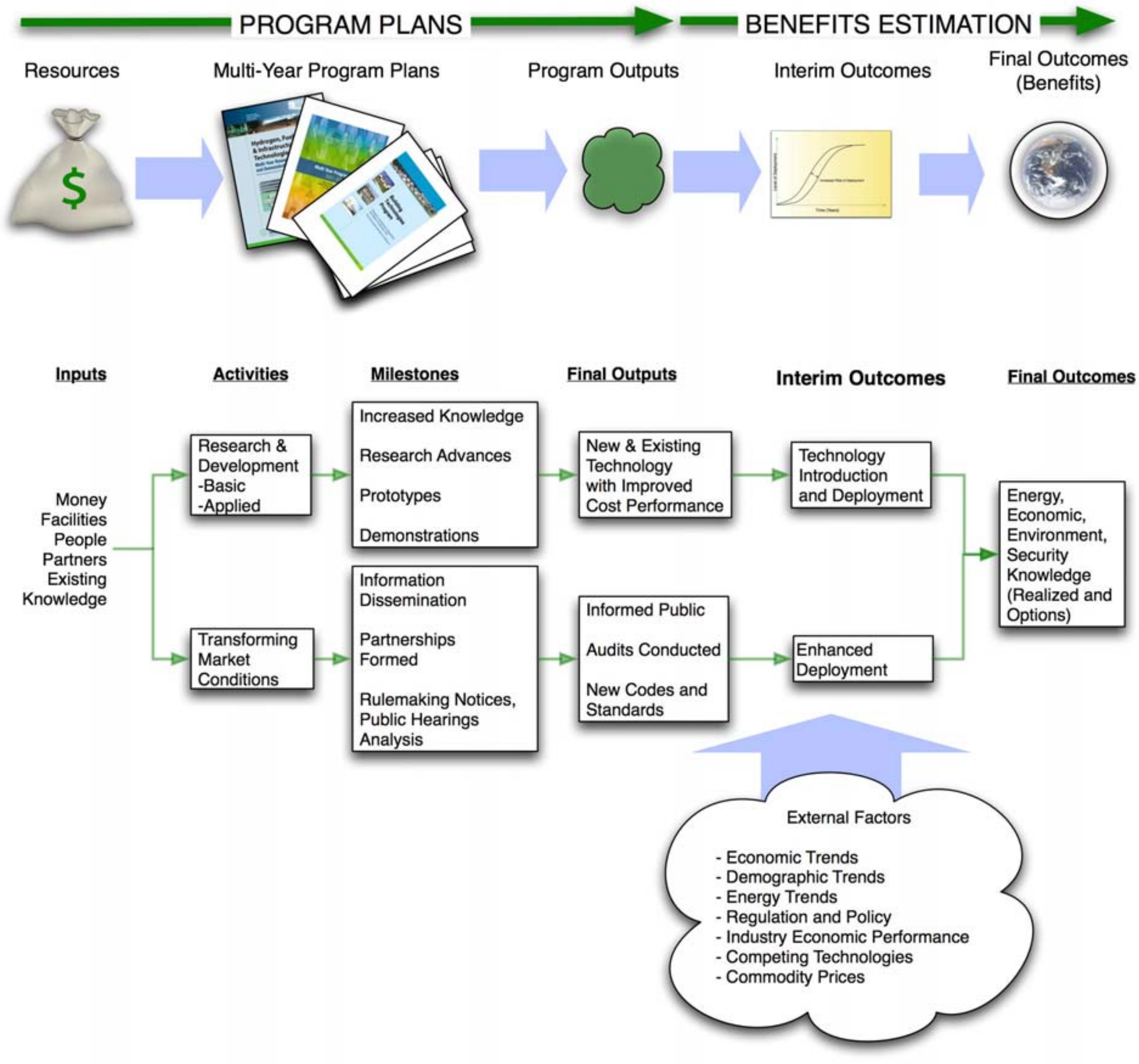

Figure P.1. Generalized EERE Logic Model

These changes in energy use provide the basis for the economic, environmental, and security benefits estimated here. The extent to which a new technology or a deployment effort changes energy markets will depend on a variety of external factors. The future demand for energy, its price, the development of competing technologies, and other market features (such as consumer preferences) all will contribute to the marketability and total sales of a new technology.

While the logic model discussed here shows the linkage between resources and benefits for each program, it does not show the full scope of how benefits analysis fits in the overall process of performance management. **Figure P.2** shows a more holistic perspective on the role of benefits analysis in performance management. When used appropriately, benefits analysis serves as an important feedback loop at two levels: 1) individual program planning, and 2) EERE management assessment of its technology development and deployment portfolio. In the first case, this analysis can help individual program managers make better choices about the suite of activities and technology options that will maximize their program's benefits to the Nation. Looking at the benefits available from the entire suite of EERE programs in an integrated portfolio can help decision-makers maximize the overall return on government investment in energy efficiency and renewable energy technologies. Results of benefits analyses represent just one of many important criteria that must be weighed in prioritizing spending across the portfolio.

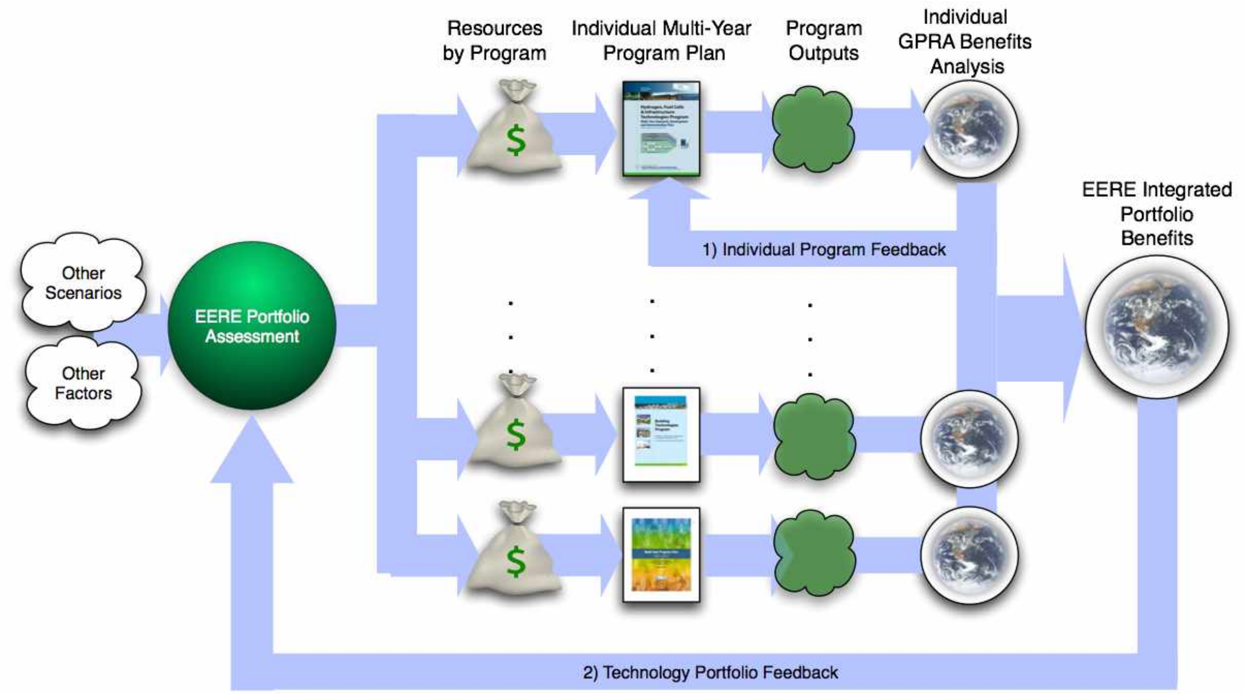

Figure P.2. Holistic View of the Role of Benefits Analysis in EERE Performance Management

Benefits Framework

The EERE Benefits Framework addresses the link between program outputs and their resulting outcomes—and, hence, benefits. EERE uses these R&D outputs to estimate its outcomes (benefits) by comparing the future U.S. energy system and its associated costs and environmental impacts with and without the contributions of its program outputs. The market impacts of each of the nine programs are first assessed separately and then combined to assess the benefits of EERE's overall portfolio.[9] The integrated portfolio benefits are not simply the sum of the individual program benefits, because the portfolio benefits reflect the interaction and interplay among the various programs.

EERE—along with the offices of Fossil Energy (FE), Nuclear Energy (NE), Electricity Delivery

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[9] EERE's benefits analysis, which measures final outcomes due to EERE programs and a host of other external factors as shown in Figure P.1, is distinct from impacts analysis, which determines the portion of outcomes having a causal relationship with EERE's actions.

and Energy Reliability (OE), and Science (Sc)—is in the process of adopting a common framework, building on work initially developed by the National Research Council (NRC) to assess the benefits associated with past DOE research efforts.[10] EERE's annual estimates of prospective benefits have been incorporated into an integrated framework addressing the benefits of both existing and future program activities. The framework can be represented by a matrix, in which the rows distinguish among four types of benefits, and the columns represent different elements of time and uncertainty.

This report addresses the three shaded cells of the matrix, reflecting benefits under a business-as-usual energy future (**Figure P.3**). EERE, FE, NE, OE, and Sc currently are developing methods for assessing the value to the country of developing technologies that prepare the Nation for unexpected energy needs. DOE and EERE metrics are still evolving, especially with regard to how knowledge benefits and real options[11] benefits are represented.

	Realized Benefits and Costs	Expected Prospective Benefits and Costs	Options Benefits and Costs
Economic Benefits and Costs		✓	
Environmental Benefits and Costs		✓	
Security Benefits and Costs		✓	
Knowledge Benefits and Costs			

Figure P.3. FY 2007 Benefits Metrics Reported

Completing the cells of this matrix in ways that provide comparable results across programs (and DOE offices) poses a number of analytical challenges, especially in light of the varied portfolio that EERE maintains:

- **Standard baseline(s) and methodological approaches.** EERE uses the Energy Information Administration's (EIA) *Annual Energy Outlook 2005* (*AEO2005*) Reference Case as a consistent starting point for analysis of all of its programs.[12] A standard set of methodological approaches (guidance) is used to assess the incremental improvements to energy efficiency and renewable energy production, resultant from realization of EERE

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[10] See *Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000*, National Research Council (2001) for the original framework. DOE's offices of Energy Efficiency and Renewable Energy, Fossil Energy, Nuclear Energy, and Science cosponsored DOE's "Estimating the Benefits of Government-Sponsored Energy R&D" conference in March 2002 to explore ways of extending this framework to include the prospective benefits of program activities. As a result of the conference, the matrix was revised by placing knowledge as a benefit and explicitly showing expected prospective benefits and costs in addition to realized benefits and costs. The conference report is available at www.esd.ornl.gov/benefits_conference.

[11] For its retrospective study, the NRC defined an option as a technology that is fully developed—but for which existing market or policy conditions are not favorable for commercialization. Because current technology choices are known, noncommercial (but developed technologies) are options, by default.

[12] See *The Annual Energy Outlook 2005 with Projections to 2025*, February 2005, DOE/EIA-0383 (2005), available at http://www.eia.doe.gov/oiaf/archive/aeo05/index.html. The timing of the release of the *Annual Energy Outlook* reports is such that we are always working with the prior year's outlook. Thus, in 2006, we developed benefits estimates for the proposed FY 2007 budget using AEO2005. In most years, this lag in the availability of the energy forecast poses little problem, because the changes in the energy outlook from year to year are relatively small. This year, however, the recently released AEO2006 reference case shows a dramatic increase in oil and gas prices relative to the AEO2005 forecast. When the new, higher, oil prices of AEO2006 are used next year, benefits estimates for the EERE programs will be substantially different. This year, we have added two new scenarios beyond the reference case to look at the impacts of higher oil prices and of possible constraints on carbon emissions.

program goals (outputs). This guidance is applicable to all of EERE's program activities and markets.

- **Varied markets.** Program activities target all end-use markets (buildings, industry, transportation, and government) and energy-supply markets (use of renewable energy as new sources of liquid and gaseous fuels, and electricity). Because these markets vary enormously in structure, regulation, and consumer preferences, a fairly detailed, market-specific analysis often is needed to gain sufficient understanding of the size and potential receptivity of each market to EERE's activities. EERE strives to incorporate these unique market features that are likely to have a significant impact on the resulting benefits.

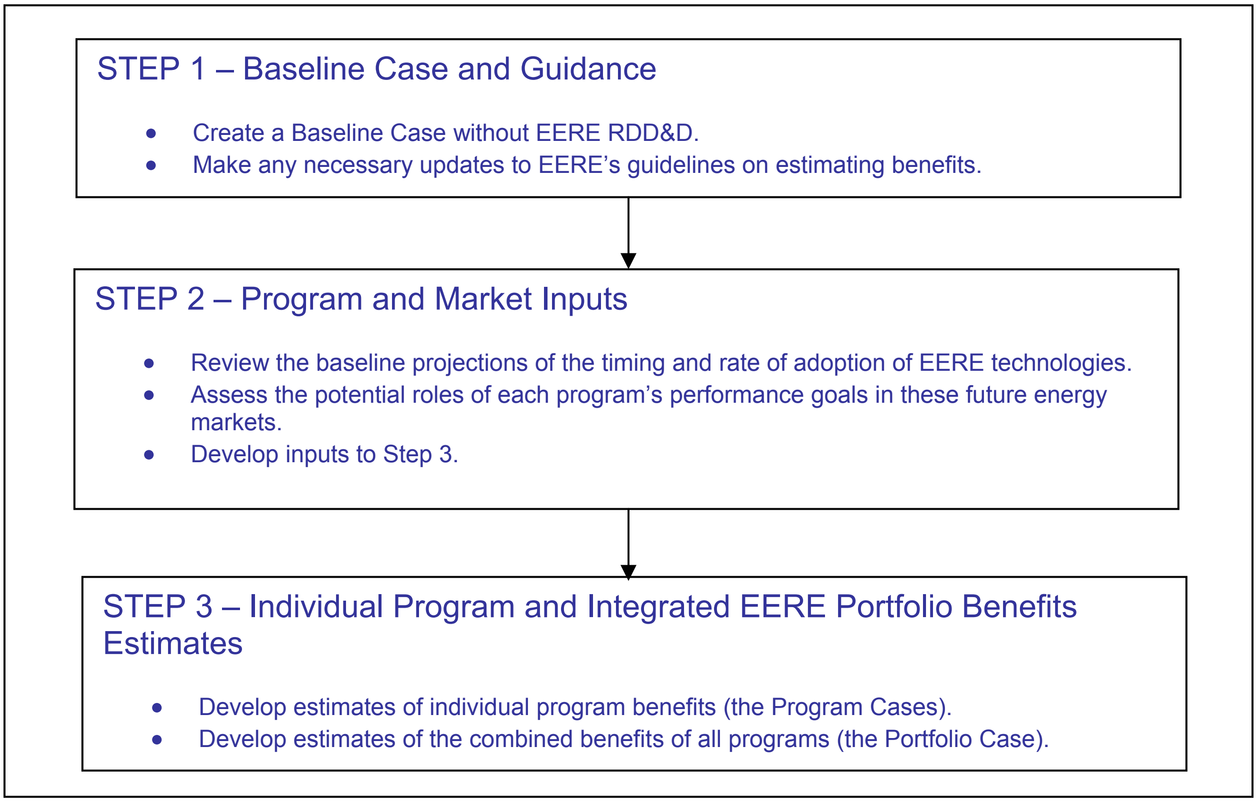
- **Varied time frames.** The analytical time frame extends from a few years to the decades that are required for the development of new energy sources, infrastructure, market penetration, and product life cycle. This expansive time frame requires a baseline and analytical tools that can address energy markets in the short, mid-, and long term. This report addresses midterm (5-20 years) and long-term (20-50 years) time frames.

Numerous market feedbacks. EERE technology and deployment efforts can have large enough effects on their respective energy markets that they generate supply or price feedbacks. EERE's technologies also can interact with each other across their respective energy markets. For example, efficiency improvements in end-use markets can be large enough to forestall the development of new electricity-generating plants, reducing the potential growth of wind and other renewable electricity sources. Past EERE experience indicates that failure to reflect market responses tends to overestimate benefit levels. EERE utilizes integrated energy-economic models to produce final benefit estimates that consider these feedbacks and interactions at the program and portfolio levels.

Benefits Analysis Process

EERE's benefits-analysis process involves three major steps (**Figure P.4**). In **Step 1,** EERE's Office of Planning, Budget, and Analysis (PBA) develops a standard baseline and methodological approach (guidance) to help ensure consistency in estimates across programs. In **Step 2,** EERE's programs develop specific technology and market information, which is necessary to understanding the potential roles of each program in its target markets. In **Step 3**, PBA uses this program and market information to assess the impacts of each EERE program (as well as the overall EERE portfolio) on energy markets in the United States using integrated energy-economic models.

The process by which the FY04 benefits estimates were developed largely reflects EERE's prior organization, although a few changes in net benefits estimation were adopted in the FY04 analysis, including an initial reflection of the benefits framework recommendations of the National Academy of Sciences (NAS).



STEP 1 – Baseline Case and Guidance

- Create a Baseline Case without EERE RDD&D.
- Make any necessary updates to EERE's guidelines on estimating benefits.

STEP 2 – Program and Market Inputs

- Review the baseline projections of the timing and rate of adoption of EERE technologies.
- Assess the potential roles of each program's performance goals in these future energy markets.
- Develop inputs to Step 3.

STEP 3 – Individual Program and Integrated EERE Portfolio Benefits Estimates

- Develop estimates of individual program benefits (the Program Cases).
- Develop estimates of the combined benefits of all programs (the Portfolio Case).

Figure P.4. EERE Program and Portfolio Benefits-Analysis Process

Step 1: Baseline Case

Baseline Case

The first step in the benefits analysis process is to establish an appropriate Baseline Case. The EERE Baseline Case is a projection intended to represent the future U.S. energy system without the effect of EERE programs. This Baseline Case ensures that program benefits are estimated based on the same initial forecasts for economic growth, energy prices, and levels of energy demand. It also ensures that these initial assumptions are consistent with each other; e.g., that the level of electricity demand expected under the economic growth assumptions could be met at the electricity price assumed. It provides a basis for assessing how well renewable and efficiency technologies might be able to compete against future, rather than current, conventional energy technologies (e.g., more efficient central power generation). Finally, it helps ensure that improvements in efficiency and renewable energy, which may occur absent EERE's RDD&D efforts, are not counted as part of the benefits of the EERE programs.

The most recent[13] *Annual Energy Outlook* Reference Case is used as the starting point for developing the Baseline Case. The Energy Information Administration (EIA) *Annual Energy Outlook* (*AEO*) Reference Case provides an independent representation of the likely evolution of energy markets. This forecast reflects expected changes in the demand for energy (e.g., to reflect the availability of new appliances), technology improvements that might improve the efficiency of energy use, and changes in energy resource production costs, including renewable energy. Current energy market policies, such as state renewable portfolio standards (RPS)—which facilitate the development and adoption of these technologies—are included in the Baseline Case. This approach ensures that EERE's benefits estimates do not include expected impacts of such policies. Neither the EIA Reference Case nor the EERE Baseline Case includes any changes in future energy policies.[14]

In establishing its Baseline Case, EERE makes a number of modifications to the *AEO2005* Reference Case (see **Table P.1**)[15]. Modifications are made to the same model—the National Energy Modeling System (NEMS)—used by EIA in developing the *AEO2005*. To distinguish it from EIA's version, the model is referred to as NEMS-GPRA07. The *AEO2005* Reference Case is also the starting point for the long-term (to 2050) benefits modeling using MARKAL-GPRA07. The Baseline Cases for both NEMS-GPRA07 and MARKAL-GPRA07 are aligned as closely as possible, but the two models are different in their internal design.[16]

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[13] Benefits analysis for the proposed FY 2007 budget began in January 2006. The most recent outlook available at the time was *AEO2005*. Final benefits estimates are submitted to OMB as part of the FY 2007 Budget Request in January 2007, before the new AEO2006 reference case was available. See *Annual Energy Outlook 2005* with projections to 2025, February 2005, DOE/EIA-0383 (2005) for Reference Case projections. Available at http://www.eia.doe.gov/oiaf/archive/aeo04/pdf/0383(2004).pdf.

[14] At the publication date of the *AEO2005*, the Energy Policy Act of 2005 (as well as the extension of the production tax credit) had not yet been affected. Because our GPRA benefits analysis is built off of *AEO2005*, our estimates are not reflective of these policies. While other changes are made to AEO's baseline case, a change of this magnitude was not within the scope of our analysis, given the available time.

[15] More detail on baseline construction may be found in Appendix A.

[16] See Box 2.1 in Chapter 2 for an overview of NEMS and Box 3.1 in Chapter 3 for an overview of MARKAL.

Table P.1. Summary of Baseline Changes from the AEO2005

	AEO2005	GPRA07 Baseline Case
Removal of EERE Programs		
Million Solar Roofs	0.3 GW installed 2007 to 2025	Removed
Photovoltaic system costs	Significant improvement	Slower rate of improvement
Residential high efficiency shell packages	Small penetration	Removed
Cellulosic ethanol production	Commercially available by 2015	Not commercially available by 2025
Greater Technology Improvement in Base		
Solid-state lighting	Very small improvement	Much greater improvement
Onshore wind performance	33% to 44% capacity factors, depending on wind class and year	35% to 53% capacity factors, depending on wind class and year
Onshore wind capital costs	1% reduction over 20 years	12% to 15% reduction (depending on wind class) over 20 years
Conventional corn ethanol production	Yield of 2.65 gallons per bushel	Yield of 2.80 gallons per bushel
Corn ethanol production with residual starch	Not included	Available in 2011
Hybrid Electric Vehicles	Sales share at 6% by 2025	Sales share at 11% by 2025
Energy Market Updates		
PV system size	2 kW residential, 25 kW commercial	4 kW residential, 100 kW commercial
PV maximum market share	30% for both residential and commercial	60% for residential and 55% for commercial
California PV subsidy	Not included	Included for residential systems
Solar water heat	Maximum 20% replacement market	New and up to 50% replacement market
Corn ethanol maximum production	5.7 billion gallons	10.0 billion gallons
Structural Changes		
Offshore wind	No offshore wind technology	Offshore wind
Commercial shell efficiency	Index	Technology representation
Commercial DG algorithms		Market share and stock accounting modified

Step 2: Program and Market Inputs

In **Step 2**, program goals and salient target-market characteristics are developed as inputs to modeling the benefits estimation in **Step 3**. The effort required under **Step 2** varies, depending on the form in which programs specify their output or performance goals and how NEMS-GPRA07 and MARKAL-GPRA07 utilize this information. It ranges from the compilation of technology goals to detailed market analyses that produce technology-penetration rates—and, in some cases, delivered energy savings.

NEMS-GPRA07 and MARKAL-GPRA07 contain detailed technology representations of electricity markets, most residential and commercial end uses, and vehicle choice—but use trends to represent industrial efficiency improvements and existing residential shell retrofits. For programs that address these markets, this step simply requires (1) confirming the adequacy of the target-market representation in the Baseline Case and (2) providing the program goals in a format consistent with the model. Any updated market-characteristic information is used to adjust NEMS-GPRA07 and MARKAL-GPRA07 for both the Baseline Case and the Program Case to avoid ascribing external factors as benefits. Analysts use the program goal information to adjust the commercialization date, technology characteristics, or market-penetration rate for the Program Case. The comparison of market technology introduction and market-penetration rates, with and without the program goal—and the calculation of the energy displaced—occur within NEMS-GPRA07 and MARKAL-GPRA07.

For much of EERE's portfolio, additional "off-line" analyses are needed to translate information about program technology and market characteristics into usable modeling inputs. This off-line **Step 2** analysis can range from spreadsheet calculations to the use of market-specific models for assessing technology or market features that cannot be adequately represented in a broad energy-economic model, or to translate program goals into the variables used in the modeling. In general, analysts perform the most detailed off-line analyses for the Industrial Technologies Program , Weatherization and Intergovernmental Program (WIP), Federal Energy Management Program (FEMP), and portions of the Building Technologies Program. Analysts tailor these off-line analytical approaches to the characteristics of the program and target market being analyzed; but, in all cases, they are conducted within the overall guidance provided through the GPRA benefits-estimation process.

The market applications for EERE technologies are often very specific, and resulting energy savings for a given technology can vary from one application to another. For example, the impact of upgrading building codes can vary, due to differences in climate and in existing building-code standards, and therefore require analysis at the State level. The Building, Industrial, and WIP programs are most likely to require tailored analytical approaches that address these submarkets.

Where NEMS-GPRA07 and MARKAL-GPRA07 do not include technology-by-technology information (e.g., cost, date of availability), or specific market-penetration rates, it is often necessary to translate program goals into the more general rates of technology improvement used by the models. This is true for the Industrial Technologies Program and some elements of the

Building Technologies Program, where numerous specific technology advances or market-deployment efforts will accelerate overall efficiency improvements in buildings or factories specified in the Baseline Case.

Off-line analysis also can be required for targeted submarkets that are simply not included in NEMS-GPRA07 or MARKAL-GPRA07—or for which the resulting technology use is not fully market-driven. Examples include the Federal sector (addressed by FEMP) and the Low-Income Weatherization Assistance Program, in which the Federal Government directly purchases home efficiency improvements.

Because estimating the benefits of achieving program performance goals requires the ability to realistically assess the extent to which future energy markets might adopt the technology and market improvements developed by EERE programs, analysts explore the following features in these off-line analyses:

> **Target Markets.** New technologies will not necessarily be well-suited to all applications served by existing markets. Technologies may occupy niche markets, especially in early years. In some cases, initial markets are geographically limited as well. Where integrated models do not represent these submarkets explicitly, it may be necessary to develop off-line estimates of the applicable market share for the technology being developed, at least in the early years.
>
> **Stock Turnover.** Modeling stock turnover is crucial to estimating benefits for both new technologies and deployment programs. Analyses of the market adoption of new technologies must consider the rate at which the specific type of energy-using or -producing capital equipment is replaced, in addition to the growth rate of the overall market. Even when a technology is suitable and cost-effective for a percentage of a market, it may take a decade or more for the capital stock in that portion of the market to retire and be replaced. Particularly attractive new technologies might accelerate that turnover. EERE includes this potential for early retirement only when market evidence suggests that the technology improvement is significant enough to overcome typical hurdle rates to new investment. Although stock turnover fluctuates with business cycles, EERE does not incorporate business cycles into its Baseline or Program cases. As a result, nearer-term estimates of benefits, in particular, do not take into account year-to-year fluctuations in energy use attributable to business cycles.
>
> **Market Penetration.** Over time, new technologies typically make their way into markets—and, therefore, affect energy use—gaining their share of new sales as consumers learn about the availability of the product. Manufacturing capacity then grows, and product prices fall with economies of scale and learning.[17] While price helps determine whether a product is cost-effective, on average, energy prices vary by type of customer and region, so that new products may be cost-effective for some customers (a niche market) before they are generally cost-effective. Price, or cost-effectiveness, is often not the only aspect of the new technology or deployment program that shapes its rate of market uptake. Many non-price or cost factors affect consumer behavior.

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[17] See Adam B. Jaffe, Richard G. Newell, and Robert N. Stavins, "Energy-Efficient Technologies and Climate Change Policies: Issues and Evidence," Climate Issue Brief No. 19, *Resources for the Future*, Washington, D.C. (December 1999).

As an example, the off-line analysis for the Industrial Technologies Program uses a spreadsheet model that provides several possible market-penetration curves. The analyst chooses a curve, based on specific information from possible R&D partners, comparison of the new technology to similar technologies, or his or her expert judgment. The benefits guidance for industrial benefits estimation includes historic penetration curves for 11 technologies and offers the analyst five choices of penetration-curve shapes. The five choices are accompanied by detailed data on technology equipment, financial, industry, regulatory, and impact characteristics to aid in making the choice. In addition to choosing the shape of the penetration curve, the analyst chooses the year—after all pilot testing and demonstration phases—that the new technology is expected to enter the market.

Through the use of specialized spreadsheets or other models,[18] program analysts produce estimates of market penetration and direct energy savings associated with these market sales. However, these "off-line" estimates of direct energy savings are not benefits estimates, because they do not account for market interactions. Analysts integrate these off-line estimates within the NEMS-GPRA07 and MARKAL-GPRA07 models as the final part (**Step 3**) of the process.

Step 3: Individual Program and Integrated EERE Portfolio Benefits Estimates

The final step for estimating the impacts of EERE's FY 2007 Budget Request is to analyze all of EERE's programs in a consistent economic framework and to account for the interactive effects among the various programs. Estimates of individual EERE program energy savings cannot be simply summed to create a value for all of EERE, because there are feedback and interactive effects resulting from (1) changes in energy prices resulting from lower energy consumption and (2) the interaction among programs affecting the mix of generation sources and those affecting the demand for electricity.

The process begins by modeling each EERE program individually within NEMS-GPRA07 and MARKAL-GPRA07. In each NEMS-GPRA07 and MARKAL-GPRA07 Program Case, only the modeling assumptions related to the outputs of the program being analyzed are changed. The modeling assumptions related to the other EERE programs remain as they were in the EERE Baseline Case. Analysts model each program separately to derive estimated energy savings without the interaction of the other programs. They then compare the results from the NEMS-GPRA07 and MARKAL-GPRA07 Program Cases to the Baseline Case to measure the individual benefits of the EERE program being analyzed. This process, while explicitly ignoring the potential market interactions of one EERE technology or program with all others, does provide a useful data point. Specifically, the Program Case represents neither the technical potential of a program (absent all market interactions) nor the full economic potential (with all market interactions), but somewhere in between those two points. It is admittedly unrealistic to assume that one program would meet its goals while all other programs fail to meet theirs. Nevertheless, the "Program Cases" allow the programs, analysts, and readers to examine the total potential benefits of each technology suite alone.

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[18] In one case (the Building Technologies Program), a portion of NEMS (the buildings module) was used for off-line analysis.

For programs modeled using NEMS-GPRA07 and MARKAL-GPRA07 directly, analysts compute the Individual Program Goal Case by changing the assumptions representing the program outputs; i.e. the goals or performance targets of the program, such as reducing low wind-speed turbine costs and improving their performance. The R&D programs are represented in NEMS-GPRA07 and MARKAL-GPRA07 through changes in technology characteristics that represent the program goals, to the extent possible. Activities designed to stimulate additional market penetration of existing technologies generally are modeled through changes in consumer hurdle rates or other appropriate market-penetration parameters, with the goal of representing the market share targeted by the program.

In cases where program goals cannot be easily modeled using NEMS-GPRA07 and MARKAL-GPRA07, analysts estimate benefits using a variety of off-line tools, as described in **Step 2**. These supporting analyses typically provide either estimates of market penetration and per-unit energy savings, or total site energy savings, which are then used as inputs to NEMS-GPRA07 and MARKAL-GPRA07. In cases where the off-line analyses produce a direct estimate of site energy savings, analysts adjust this information by an "integration factor" and incorporate it in NEMS-GPRA07 and MARKAL-GPRA07, in order to calculate primary energy savings. The amount of the integration factor is based on how much program overlap or "integration" was captured by the off-line tools. The revision is based on the expert judgment of the benefits analysis team. See **Chapters 2 and 3** for discussion of program-by-program benefit estimates, including such reductions.

Once each of the programs (or group of programs) is represented individually within NEMS-GPRA07 and MARKAL-GPRA07, the benefits of EERE's portfolio are estimated by combining all of the program goals into one EERE Portfolio Case. The portfolio case is not equal to the sum of the individual program cases, because the former accounts for various market interactions. Some of EERE's technologies and programs complement each other; others are competitive substitutes. The program cases do not capture the complementarity and substitutability inherent in the portfolio case. Detailed projections from the EERE Baseline and Portfolio Benefits Case are presented in **Chapters 1, 2 and 3.**

Scenario Analysis

In prior years, benefits estimates were reported for a single future energy scenario. Because of the uncertainties of energy and economic projections, this view of our energy future has limited value, especially in assessing the benefits of the full suite of technologies in the EERE portfolio. Assessing only one possible future may be particularly misleading for programs in which a significant part of the worth of the program may lie as a hedge against less likely, but possible, futures. Evaluating EERE's portfolio for a variety of possible futures offers insight about the robustness[19] of the portfolio.

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[19] One measure of a portfolio's "robustness" is the degree to which its composite parts become more or less important under a given future. In other words, the portfolio as a whole may be said to be robust, if it is resilient against a range of futures, even if the individual parts (or programs, in our case) may play differing roles. Note that portfolio robustness may be measured in a variety of ways, including how much redundancy there is in the portfolio – if contingency planning is valued; the degree to which the portfolio is subject to various risks; the expected performance of the portfolio alignment versus other possible alignments, etc.

This year, we have taken the first step toward introducing scenario analysis for the EERE portfolio. Two scenarios were evaluated: 1) a high oil-price case, and 2) a carbon-constrained future. Because this is EERE's first foray into scenario analysis for GPRA benefits, we report the results as an appendix to this report (see **Appendix K**). Given the recent and sustained increases in crude oil and natural gas prices, the high fuels-price case is particularly relevant in understanding the value of EERE's portfolio in what is likely to be the base case in future years. Similarly, understanding the impact of these programs under different carbon emissions scenarios is an increasingly important topic. We will evaluate our methodology for scenario analysis this year; and we expect that scenario analysis will be a part of the main benefits report for the FY 2008 budget request.

Future GPRA Benefits Development

As part of DOE's continuing efforts to implement the President's Management Agenda—and to be responsive to the advice offered by the National Academy of Sciences/National Research Council—DOE is in the process of integrating its GPRA benefits analyses across the offices of Energy, Science, and Environment (ESE). This integration process is expected to be fully completed for the FY 2010 budget request, but significant and important steps and progress will be evident along the way. The GPRA benefits analysis for the FY08 budget request will show a DOE-wide portfolio case, in which all offices' RD3 programs are combined. Further, EERE technologies' benefits will be evaluated relative to an ESE-wide baseline (as opposed to a baseline in which only EERE advanced technologies are removed from the AEO reference). Moreover, the inputs to the integrating models will be developed using common methodologies across all ESE offices. The result will be a much clearer picture of the benefits of the full DOE portfolio than has been represented to date.

Another major development afoot in DOE's benefits analysis is the treatment of risk and uncertainty. As in prior years, the benefits in this report are shown for Programs and the Portfolio assuming that RD3 goals are achieved and that they are achieved on time. It is also assumed that RD3 funding is continued as required. These assumptions represent a considerable simplification in a number of ways. First, for R&D there is considerable technical risk in what the actual output of the program activities might be. In fact, the output in a given year could be greater or less than the specified goal, or alternatively a specified goal may be achieved earlier or later than scheduled. Moreover, for a given output, the outcome is not known with certainty, because it will be affected by market risk considerations.

EERE and DOE, in coordination with NRC, are in the process of integrating the treatment of risk into the benefit process as part of a multiyear activity. This work will include the explicit treatment of technical risk and improved treatment market risk to lead to better estimates of both program outputs and outcomes. These refinements will also address the potential use of discount rates.

Report Organization

In addition to the Executive Summary and this Preface, this report contains three chapters. **Chapter 1** presents the overall results of the benefits and savings estimates from both the individual programs and the overall EERE portfolio. **Chapter 2** describes, in detail, the estimated midterm benefits (to 2025) of each program area using NEMS-GPRA07. **Chapter 3** describes, in detail, the estimated long-term benefits (to 2050) of each program area using MARKAL-GPRA07.

Eleven appendices are included. **Appendix A** provides the Baseline Cases and their implementation in NEMS-GPRA07 and MARKAL-GPRA07. **Appendices B through J** provide program-analysis team inputs for EERE's programs. **Appendix K** describes the results of new scenario analyses conducted this year to look at the effect of high fuel prices and a carbon constraint.

CHAPTER 1

FY 2007 BENEFITS ESTIMATES

The Office of Energy Efficiency and Renewable Energy (EERE) estimates expected benefits for its overall portfolio and for each of its nine programs. Benefits for the FY 2007 budget request[1] are estimated for the midterm (2010-2025) and long term (2030-2050). Two separate models suited to these periods are employed—NEMS-GPRA07 for the midterm and MARKAL-GPRA07 for the long term.

Benefits estimates are intended to reflect the value of program activities from 2007 forward. They do not include the impacts of past program success, nor technology development or deployment efforts outside EERE's programs. This distinction is difficult to implement in practice, because many research and deployment activities provide continuous improvements that build on past success; and because EERE programs are leveraged with private-sector and other government efforts (e.g., in addition to the Baseline Case, private-sector improvements).

Outcomes and Benefits Metrics

The energy efficiency improvements and additional renewable energy production facilitated by EERE's programs reduce the consumption of traditional energy resources. Reducing energy consumption affords the Nation a number of economic, environmental, and energy security benefits.[2] The extent of these benefits depends on numerous factors including which energy sources are reduced, the costs of the new technologies, and the emissions performance of the energy technologies used. Different EERE portfolios would produce a different mix of benefits, even if the overall level of primary energy savings were the same.

The public benefits resulting from these reductions in the use of traditional energy resources take many forms. Environmental improvements, for instance, can include reductions in local, regional, or global air emissions; reduced water pollution; noise abatement, etc. These public benefits are typically difficult to measure directly, and some aspects are not quantifiable. EERE has developed a set of *indicators* intended to provide a sense of the magnitude and range of the benefits its programs provide to the Nation. EERE estimates benefits for the following defined metrics:

> **Energy Displaced - the difference in nonrenewable energy consumption with and without the technologies and market improvements developed by EERE programs.** Analysts measure energy savings on a primary basis, accounting for the energy consumed in

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[1] EERE budget-request materials may be accessed at http://www1.eere.energy.gov/ba/pba/budget_formulation.html

[2] This is a categorization of EERE's benefits estimates, based on the framework developed by a National Research Council (NRC) committee. The framework is described in more detail in the Preface.

producing, transforming, and transporting energy to the final consumer. Energy savings from underlying private-sector improvements in technologies are not counted. Energy displaced is reported in quadrillion Btus per year (quads/yr).

Economic Benefits: Economic benefits are the potential for EERE technologies to make energy more affordable by reducing expenditures on energy and energy services, increase economic productivity and GDP through more efficient production processes, reduce the impact of energy price volatility on the U.S. economy by providing more efficient technologies and providing alternative energy sources, and improve the balance of trade by exporting energy technologies. Of these, EERE currently estimates two aspects of affordability—energy-expenditure savings and total system net cost savings:[3]

> **Energy-expenditure savings – The difference in total consumer energy bills with and without the availability of technologies and market improvements developed by EERE technologies.** This is an estimate of energy bill savings[4] and does not include all incremental costs to end users of acquiring the new technology. The NEMS model does not currently have the capability to directly calculate net cost savings.[5] Energy-expenditure savings are reported in billions of 2003 dollars per year.
>
> **Total system net cost savings – The difference in total system costs with and without the availability of technologies and market improvements developed by EERE technologies.** Total system cost represents the economic cost to society to produce, import, convert, and consume energy. It is calculated as the sum of domestic resource-extraction costs, imported fuel costs, and the annualized capital and operating and maintenance costs of energy technologies (including end-use demand devices). Total system net cost savings is a net estimate of system costs generated by MARKAL-GPRA07; which, unlike the energy expenditure savings estimates generated by NEMS-GPRA07, includes the incremental costs of end-use technologies. Total system net cost savings are reported in billions of 2003 dollars per year.

Environmental Benefits: Environmental benefits that can result from use of EERE technologies include, among many others, lower carbon, SOx, NOx, and other air emissions.[6] Of these, EERE currently estimates only the impacts of its programs on carbon emissions:

> **Carbon savings (i.e. emission reductions) – The difference in the level of U.S. energy-related carbon emissions with and without the availability of EERE technologies and associated market improvements.** Carbon emission reductions result from the reductions in fossil fuel consumption when these new supply (renewables) and

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[3] Energy-expenditure savings are calculated through 2025 using the NEMS-GPRA07. Total system net cost savings are calculated through 2050 using MARKAL-GPRA07.

[4] Energy efficiency improvements and increased use of nonfuel renewable energy (e.g., renewable-generated electricity) reduce energy bills in two ways. Consumers who make energy efficiency or renewable energy investments benefit directly through reduced purchases of energy (quantity component). In addition, the lower demand for energy reduces the price of energy for all consumers (price component).

[5] In future GPRA benefits reports, we expect the NEMS-GPRA model to show a net economic metric, in addition to the consumer expenditures it currently reports.

[6] Because the level of emissions of many air pollutants is "capped" by the U.S. Environmental Protection Agency, in some cases EERE technologies may make compliance with the caps more cost-effective or less costly, but may not actually lower emissions.

demand (energy-efficient) technologies are used in the market. As with the energy-savings metric, emission reductions count the effect of upstream energy savings in producing, transforming, and transporting energy to the end user. Carbon savings are reported in million metric tons of carbon equivalent (mmtce) per year.

Security Benefits: Security benefits include improvements in the reliability of fuel and electricity deliveries, reduced likelihood of supply disruptions, and reduced impacts from potential energy disruptions. EERE contributes to these security gains by reducing U.S. reliance on imported fuels, increasing the diversity of domestic energy supplies, increasing the flexibility and diversity of the Nation's energy infrastructure, and reducing peak demand pressure on that infrastructure. Of these aspects of energy security, EERE has developed indicators related to concerns about fuel supplies and the reliability and diversity of electricity supplies:[7]

Oil savings – The difference in total U.S. oil consumption with and without EERE technologies and market improvements. Oil savings are reported in million barrels per day (mbpd).

Natural gas savings – The difference in total U.S. natural gas consumption with and without EERE technologies and market improvements. Natural gas savings are reported in quadrillion Btu per year (quads/yr).

Avoided additions to central conventional power – The difference in central conventional power additions with and without EERE technologies and market improvements. Avoided central conventional power additions result from electricity capacity displaced by efficiency improvements, and central renewable power-generating capacity.[8] Avoided capacity additions are reported in cumulative gigawatts (GW).

In interpreting these metrics, it is important to remember that while the benefits of efficiency and renewable technologies are multifaceted, they are not always distinct or additive. Improvements in balance-of-trade or economic productivity, for instance, are contributory to improved GDP and not additional to improved GDP. Nonetheless, identifying the various types of economic or other contributions can help relate EERE's portfolio to various economic or other policy concerns.

Portfolio Benefits

Table 1.1 shows the estimated economic, environmental, and security benefits of EERE's overall portfolio of investments in improved energy-efficient technologies, renewable energy technologies, and assistance to consumers in adopting these technologies. Data by five-year

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[7] The inclusion of reliability improvements within the security category was part of the NRC suggestions on how to structure the types of EERE benefits.

[8] These measures are not additive and are not the same as a measure of peak-load reduction for conventional electricity or of improved reliability. Renewable capacity additions are not equivalent to capacity additions avoided because of differences in capacity factors and coincidence of renewable generation at system peak (i.e. peak electricity-generation output of wind, for example, may not coincide with the peak demand of the utility system to which it supplies power).

increments (2010 to 2025) are shown for NEMS-GPRA07 and by 10-year intervals (2030 to 2050) for MARKAL-GPRA07.[9]

Table 1.1. Annual EERE Portfolio Benefits for FY 2007 Budget Request for Selected Years[10,11]

EERE Midterm Benefits (NEMS-GPRA07)	2010	2015	2020	2025
Energy Displaced				
• Primary nonrenewable energy savings (quadrillion Btu/yr)	0.35	1.4	4.4	7.8
Economic				
• Energy-expenditure savings (billion 2003 dollars/yr)*	2.1	18	70	107
Environment				
• Carbon dioxide emission reductions (mmtce/yr)	8	26	86	166
Security				
• Oil savings (mbpd)	0.03	0.43	1.07	1.69
• Natural gas savings (quadrillion Btu/yr)	0.07	0.35	1.04	0.82
• Avoided additions to central conventional power (cumulative gigawatts)	0.53	11	54	118

EERE Long-Term Benefits (MARKAL-GPRA07)	2030	2040	2050
Energy Displaced			
• Primary nonrenewable energy savings (quadrillion Btu/yr)	14	25	32
Economic			
• Energy-system net cost savings (billion 2003 dollars/yr)*	63	138	207
Environment			
• Carbon dioxide emission reductions (mmtce/yr)	279	527	648
Security			
• Oil savings (mbpd)	3.9	8.0	11
• Natural gas savings (quadrillion Btu/yr)	2.0	2.0	2.8

* Midterm energy-expenditure savings only include reductions in consumer energy bills, while long-term energy-system net cost savings also include the incremental cost of the advanced energy technology purchased by the consumer.

Energy Displaced: In 2005, Americans consumed 95 quadrillion Btus of nonrenewable energy. Absent the results of EERE's programs,[12] annual consumption of nonrenewable energy could grow by 28 quads from 2005 to 2025, to about 123 quadrillion Btus of energy per year; and by 41 quads from 2005 to 2050, to about 136 quadrillion Btus of energy per year. If the goals of EERE's investment portfolio are achieved and the corresponding market outcomes realized, it will reduce nonrenewable energy consumption by 8 quadrillion Btus by 2025, or about 28% of the expected incremental growth in energy demand over this time period; and by 32 quadrillion Btus by 2050, or about 78% of the expected incremental

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[9] NEMS-GPRA07 runs using one-year intervals, while Markal-GPRA07 runs using five-year intervals.

[10] Estimates reflect the annual benefits in each year associated with program activities from FY 2007 to the benefit year, or to program completion (whichever is nearer), and are based on program goals developed in alignment with assumptions in the President's Budget. Midterm program benefits were estimated using the GPRA07-NEMS model, based on the Energy Information Administration's (EIA) National Energy Modeling System (NEMS) and using the EIA's *Annual Energy Outlook 2005* (*AEO2005*) reference case. Long-term benefits were estimated using the GPRA07-MARKAL model developed by Brookhaven National Laboratory. Results can differ among models, due to structural differences. The models used in this analysis estimate economic benefits in different ways, with MARKAL reflecting the cost of additional investments required to achieve reductions in energy bills.

[11] For some metrics, the benefits estimated by MARKAL-GPRA07 do not align well with those reported by NEMS-GPRA07. Every attempt is made in the integrated modeling to use consistent baselines, input data, and assumptions in both models to produce consistent results. However, NEMS and MARKAL are, in some respects, fundamentally different models (see Boxes 2.1 and 3.1). Discrepancies in the estimated benefits often occur simply because of these model differences.

[12] See the Preface, and Appendix A for information on how EERE's "no-program" Baseline Case is developed.

growth in annual energy demand over this time period (see **Figure1.1**). This results in a declining demand for nonrenewable energy consumption starting in 2030, despite a growing economy.

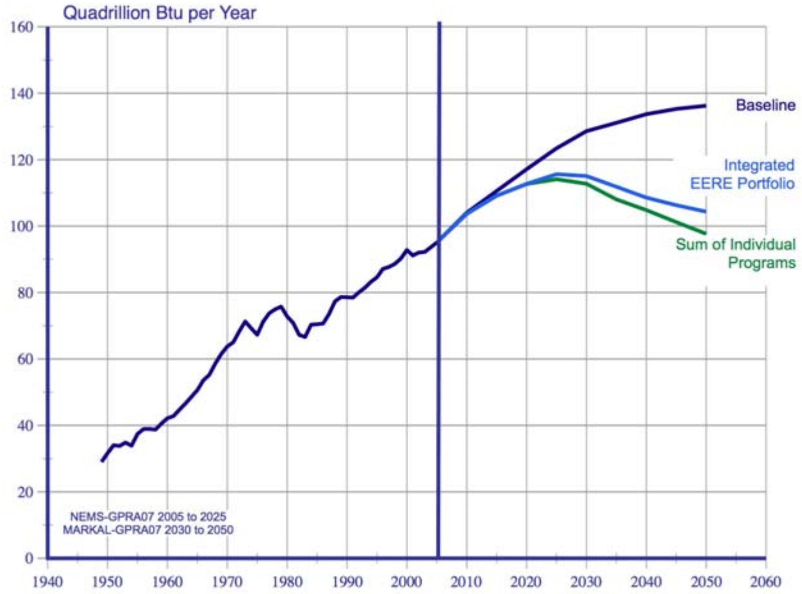


Figure 1.1. U.S. Nonrenewable Energy Consumption, 1949-2005, and Projections to 2050: Baseline, Individual Program Goal Cases and EERE Portfolio Case

Data Source: 1949-2005, Energy Information Administration, *Annual Energy Review 2004*, DOE/EIA-0384 (2004) (Washington, D.C., August 2005), Table 1.1 Web site http://www.eia.doe.gov/emeu/aer/contents.html.

Individual Program versus Portfolio Benefits

As discussed in the **Preface**, two sets of benefits are determined: a set of individual program goal cases and a portfolio case. The individual program goal cases are based on modeling the impact of each EERE program on its own, without the potential overlap or synergies that occur in the portfolio case. While some program activities reinforce each other to produce larger benefits than would be evident from each program's individual efforts, programs compete for the same markets in other cases. For example, the various renewable technology programs compete in the electricity-generation market. In addition, activities being funded by some programs reduce the potential market for technologies being developed in other programs. As an example, reductions in electricity demand due to efficiency improvements reduce the size of the generation market and, therefore, the market opportunity for renewable-generation technologies. A comparison of the "Sum of Program" and "Portfolio" curves shown in **Figure 1.1** illustrates the overall effect of these interactions among the programs. Estimated energy savings of the portfolio case are almost 2 quads less in 2025, compared to the sum of the individual program benefits; and almost 7 quads less in 2050, compared to the sum of the individual program benefits.

Supply Side and Demand Side Effects of EERE's Portfolio

To understand the relative contributions of EERE's portfolio on supply and demand, one needs to consider the total primary energy consumption changes associated with EERE's portfolio, and not just the nonrenewable energy savings (see **Figure 1.2**). Total annual U.S. primary energy consumption—without the benefits of EERE's portfolio—increases by 32 quads over the period of 2005 to 2025 to almost 134 quads per year, eventually increasing by 48 quads to a level of 150 billion quads per year in 2050. Accomplishment of the goals and associated market outcomes of EERE's technology portfolio reduces total primary energy consumption in 2025 by 5 quads per year, or about 15% of the incremental growth over that period; and by 24 quads per year in 2050, or 50% of the incremental growth over that period. By 2025, total primary energy consumption actually begins to decline slightly. As **Figure 1.2** shows, the rate of decline in nonrenewable energy consumption is greater than the rate of decline in total energy demand. The difference reflects the supply-side impacts of replacing nonrenewable energy resources with renewable energy resources.

In 2025, increased use of renewable energy accounts for 37% (or 3 out of 8 quads) of the annual nonrenewable energy savings generated by the EERE portfolio. About 25% of the annual nonrenewable energy savings (or 8 out of 32 quads) in 2050 is accounted for by increased use of renewable energy resources (see **Figure 1.3a**). Over the period of 2008 to 2025, EERE's portfolio adds a cumulative total of 25 quads of renewable energy over the amount that would have been used in the United States without these programs (see **Figure 1.3b**). Cumulative additions to use of renewable energy amount to just more than 170 quads by 2050. Cumulative savings in nonrenewable energy are 147 quads over the period of 2008 to 2025 and almost 600 quads by 2050. The differences between nonrenewable energy savings and use of renewable energy represent improvements in energy efficiency (that is, reductions in total primary energy demand).

While some of the technologies in EERE's portfolio focus strictly on energy efficiency or renewable energy production and use, many address both. Vehicle technologies, for example, reduce nonrenewable energy consumption through improvements in vehicle efficiency and through the introduction of vehicles capable of utilizing alternative fuels. Likewise, building technologies integrate the use of renewable energy and energy-efficient technologies. Renewable energy technologies in the electric sector can also lead to total primary energy-demand savings, because of their greater efficiency in converting primary renewable energy into electricity—compared to conventional electricity production technologies.

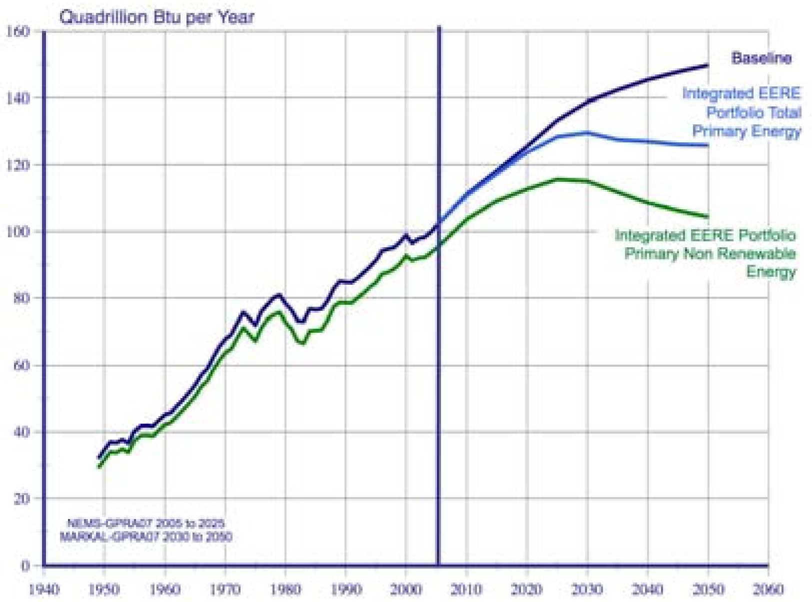
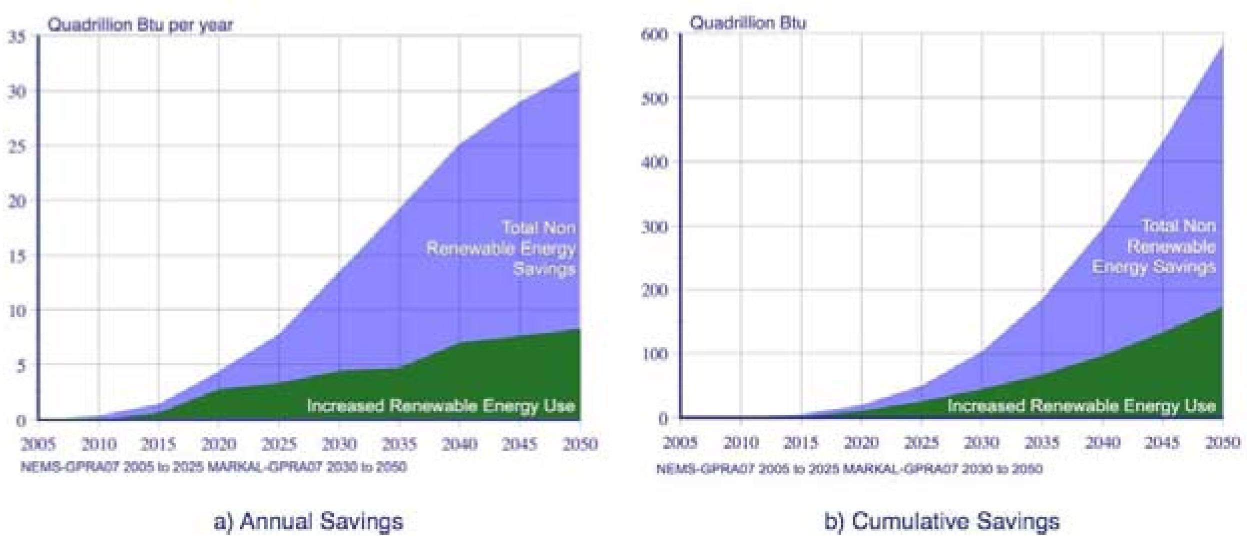


Figure 1.2 U.S. Total Energy Consumption versus Nonrenewable Energy Consumption, 1949-2005, and Projections to 2050: Baseline and Portfolio Cases

Data Source: 1949-2005, Energy Information Administration, *Annual Energy Review 2004*, DOE/EIA-0384 (2004) (Washington, D.C., August 2005), Table 1.1 Web site http://www.eia.doe.gov/emeu/aer/contents.html.



a) Annual Savings

b) Cumulative Savings

Figure 1.3 U.S. Total Nonrenewable Energy Savings and Total Renewable Energy Replacement Projections to 2050: EERE Portfolio Case

Economic Benefits: The NEMS-GPRA07 model estimates that energy savings to the consumer, resulting from these efficiency and renewable energy contributions, will reduce annual consumer energy expenditures in 2025 by $130 billion (expressed in real 2003 dollars) relative to the baseline projection of $1,050 billion (**Figure 1.4**), or about 12% of the Nation's expected energy bill.

While these energy bill savings appear to be large, they represent both reduced energy purchases and lower energy prices resulting from reductions in demand. They also exclude incremental costs to end users of acquiring the new technologies, because the NEMS model does not currently have the capability to calculate this measure directly. Lower energy demand dampens fuel costs and reduces the need for expensive new energy infrastructure expenditures. Lower energy prices improve affordability for all consumers, including those who make no additional efficiency or renewable investments as a result of EERE's activities.

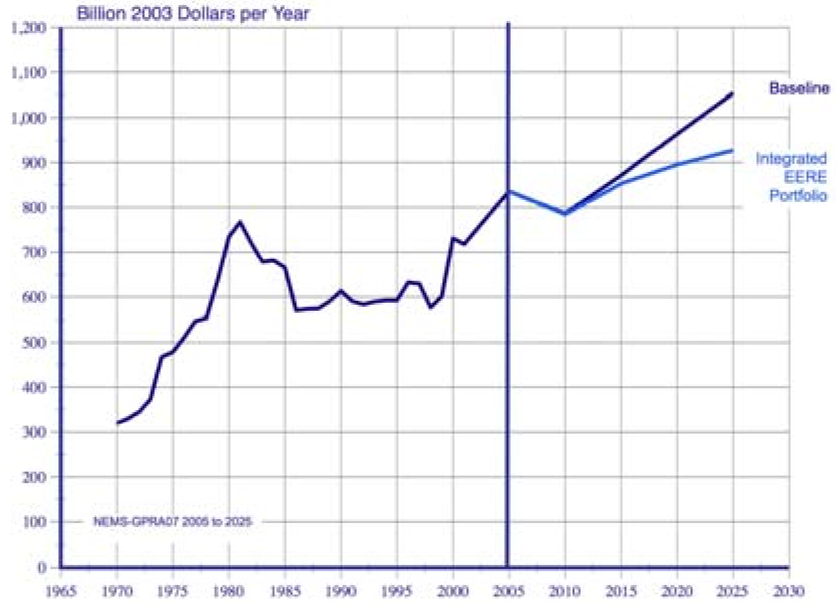


Figure 1.4. U.S. Total Energy Expenditure, 1970-2001, and Projections to 2025: Baseline and Portfolio Cases

Data Source: 1970-2001, Energy Information Administration, *Annual Energy Review 2004*, DOE/EIA-0384 (2004) (Washington, D.C., August 2005), Table 3.5 and Table D1, Web site http://www.eia.doe.gov/emeu/aer/contents.html.

The EERE portfolio also will reduce annual total system energy costs by more than $200 billion (in real 2003 dollars) in 2050 (**Figure 1.5**). This longer-term analysis is done using MARKAL-GPRA07, which includes the incremental costs to end users of acquiring the new technology.

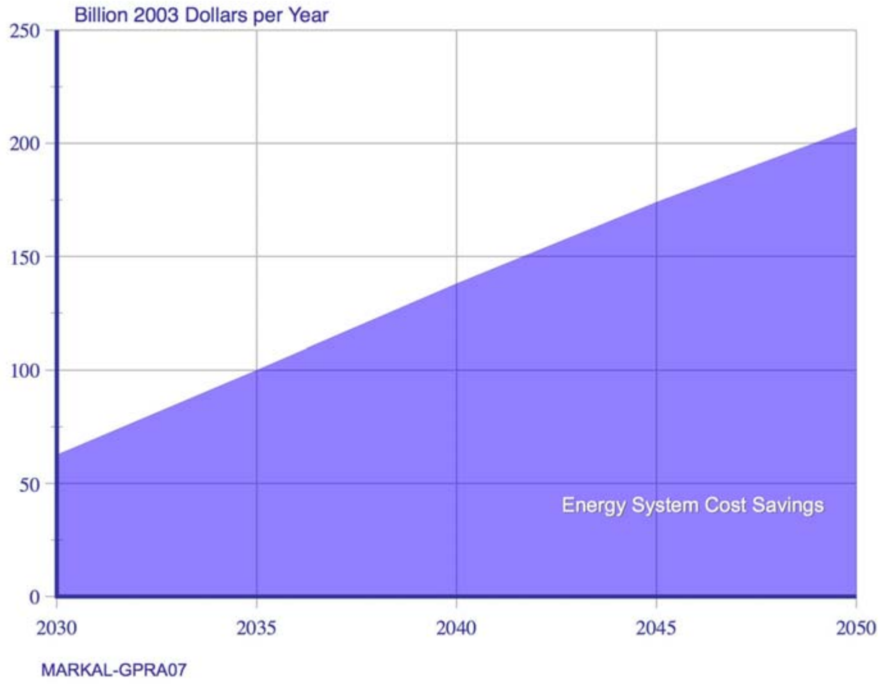


Figure 1.5 U.S. Total Energy-System Cost Savings 2030 to 2050

Environmental Benefits: Annual carbon emissions are projected to be 166 mmtce less than the 2025 baseline projection of 2,173 million metric tons—a reduction of about 8% (**Figure 1.6 and Figure 1.7a**), avoiding 32% of the expected increase from 2005 to 2025 in the absence of EERE's technology programs. Annual carbon emissions are projected to be 606 million metric tons (carbon equivalent) less than the 2050 baseline projection of 2,532 million metric tons—a reduction of about 24%, or 68% of the expected increase from 2005 to 2050 without the benefits of EERE's technology programs. During the period of 2008 to 2025, the EERE portfolio of energy efficiency and renewable energy technology avoids cumulative emissions of carbon to the atmosphere of 1 billion metric tons of carbon equivalent (see **Figure 1.7b**). From 2008 to 2050, cumulative avoided additions to the atmosphere are 12 billion metric tons of carbon equivalent.

The portfolio also provides State and local governments with additional options for meeting Clean Air Act ambient air quality standards. For instance, the Clean Cities activity in the Weatherization and Intergovernmental Program facilitates local purchases of alternative-fuel vehicles.

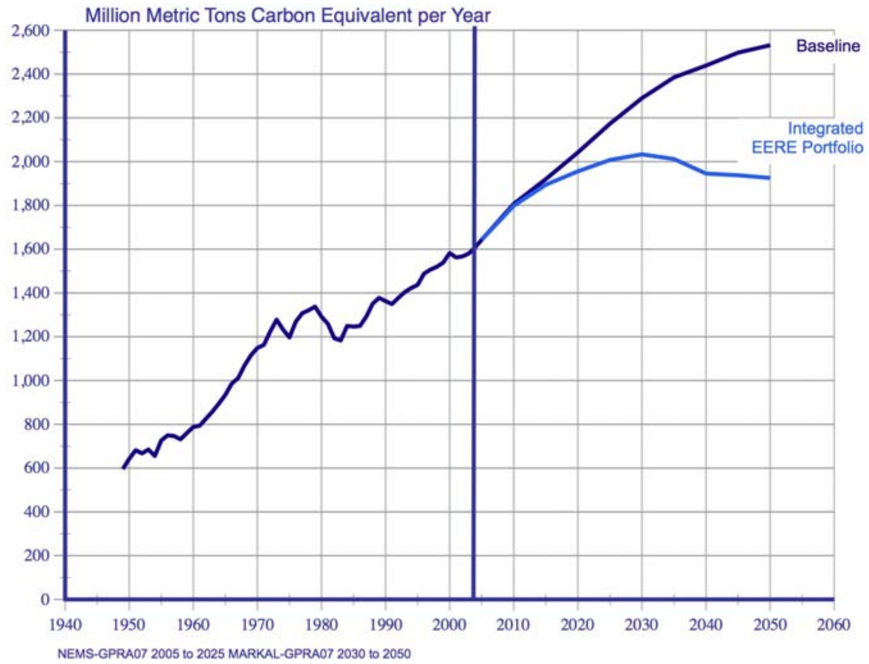
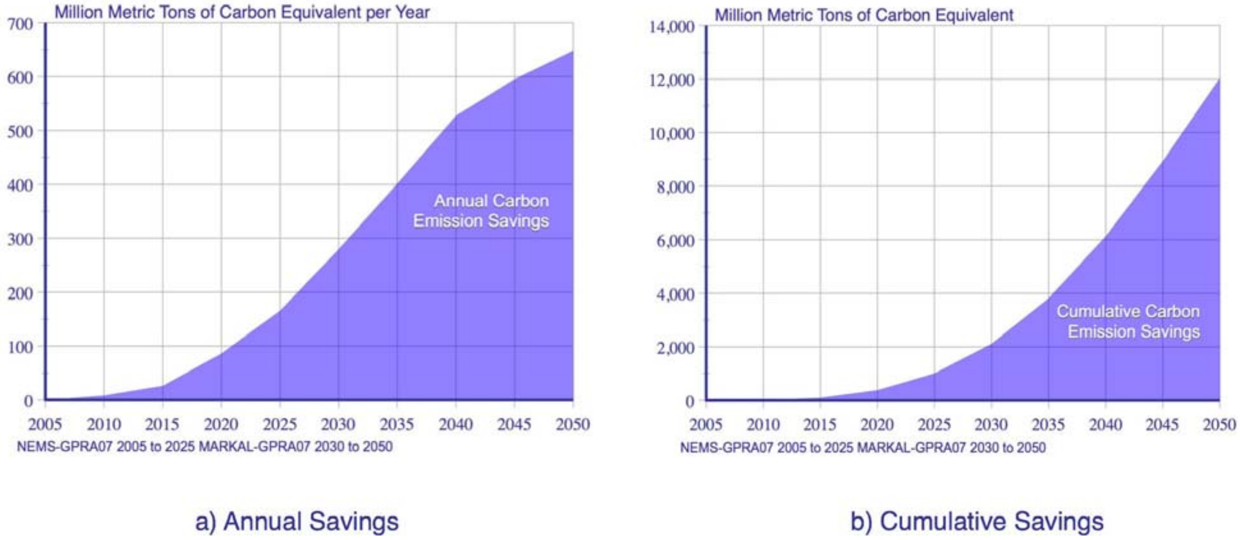


Figure 1.6. U.S. Carbon Emissions, 1980-2003, and Projections to 2050: Baseline and Portfolio Cases

Data Source: 1980-2000, Energy Information Administration, *Annual Energy Review 2004*, DOE/EIA-0384 (2004) (Washington, D.C., August 2005), Table 12.2, Web site http://www.eia.doe.gov/emeu/aer/contents.html.



a) Annual Savings

b) Cumulative Savings

Figure 1.7. U.S. Carbon Emissions, 1980-2003, and Projections to 2050: Baseline and Portfolio Cases

Security Benefits: The largest relative impact of the EERE portfolio is on reducing the Nation's reliance on oil. The portfolio is expected to reduce annual oil consumption by 1.7

mbpd from the 2025 baseline of 25 million barrels per day (mbpd), or about 28% of expected growth in oil demand between 2005 and 2025 (**Figure 1.8 and Figure 1.9a**).

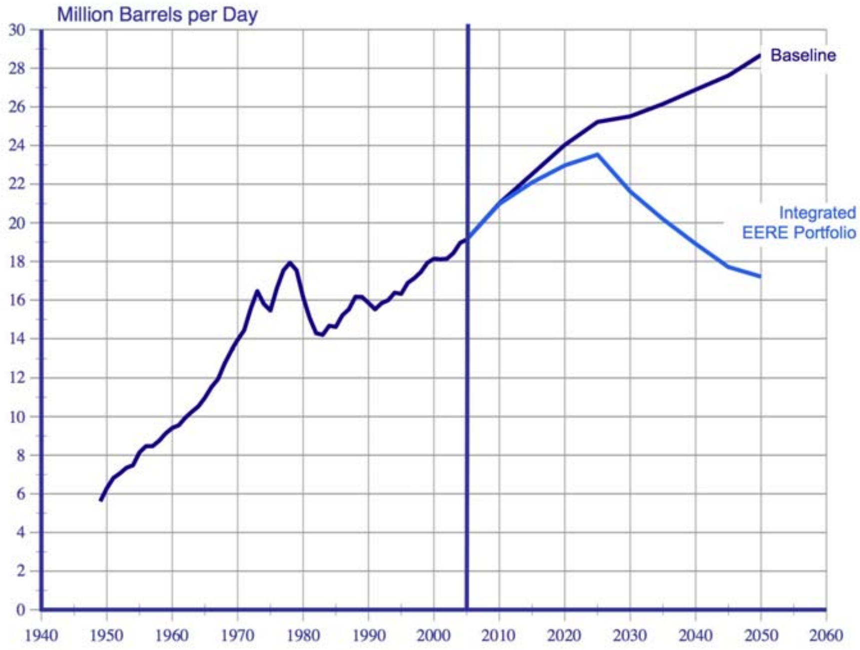
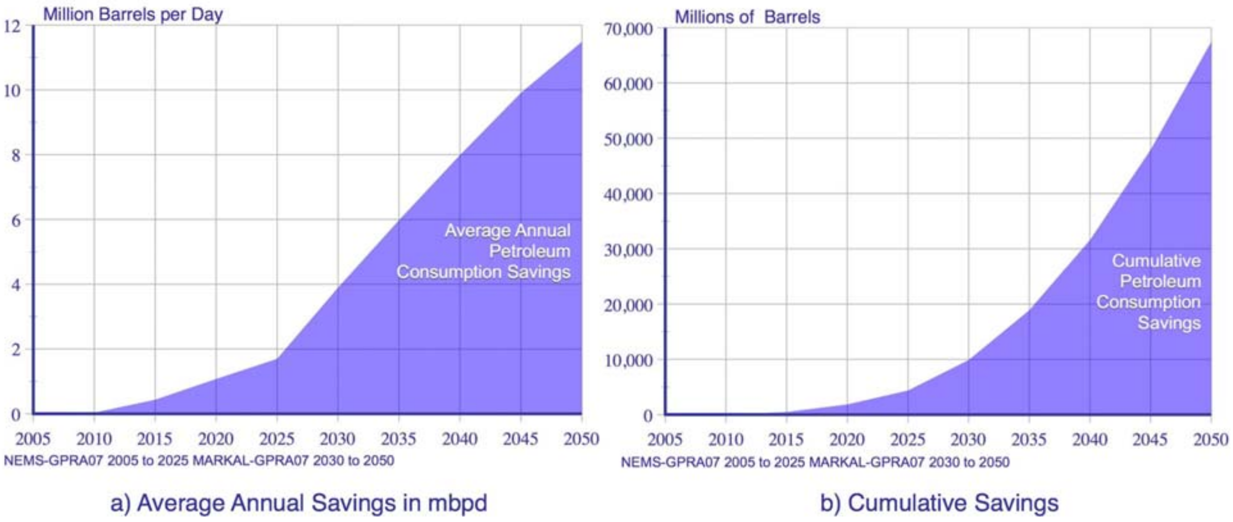


Figure 1.8. U.S. Oil Consumption, 1949-2004, and Projections to 2050: Baseline and Portfolio Cases

Data Source: 1980-2000, Energy Information Administration, *Annual Energy Review 2004*, DOE/EIA-0384 (2004) (Washington, D.C., August 2005), Table 1.3, Web site http://www.eia.doe.gov/emeu/aer/contents.html. Data were converted from quads per year to mbpd using conversion factor of 5.8 million Btus per barrel of crude oil.



a) Average Annual Savings in mbpd

b) Cumulative Savings

Figure 1.9. U.S. Oil Savings Projections to 2050: Baseline and Portfolio Cases

The portfolio is expected to reduce oil consumption by 11.5 mbpd from the 2050 baseline of 29 mbpd (about 120% of expected growth in oil demand between 2005 and 2050). This results in significantly declining oil consumption starting in 2030. Under the Portfolio Case, U.S. demand for oil would drop to levels not seen since the late 1970s. Over the period of 2008 to 2025, EERE's portfolio of technologies is projected to save a total 4.3 billion barrels of oil. From 2008 to 2050, cumulative oil savings would reach 67 billion barrels.

The oil savings projected under the Portfolio Case are nearly equivalent to reductions specifically in the projected demand for foreign oil. This is because almost all of the new U.S. demand for petroleum is projected to be met by foreign oil imports (see **Figure 1.10**).

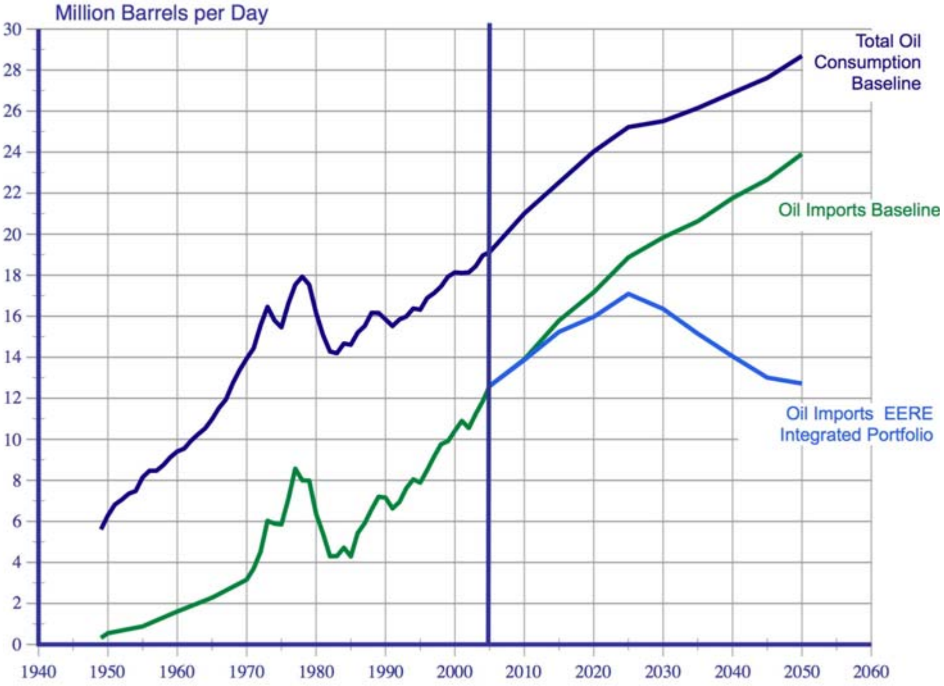


Figure 1.10. Foreign Oil Consumption, 1949-2004, and Projections to 2050: Baseline and Portfolio Cases

In the baseline projection, oil imports increase to 19 mbpd in 2025—equal to the total U.S. demand for oil in 2005. EERE's portfolio of technologies reduces foreign oil demand by 1.8 mpbd in 2025 (about 30% of expected growth in foreign oil imports in the baseline from 2005 to 2025). By 2050, projections for oil imports increase to 24 mbpd. EERE's programs would provide significant reductions in oil imports by 2050—cutting U.S. oil imports in half and eliminating all of the new growth in oil import demand for the period of 2005 to 2050.

While EERE's portfolio has elements that increase (as well as decrease) natural gas consumption; on balance, EERE's portfolio is expected to reduce annual natural gas consumption by about 0.8 quadrillion Btu from the baseline of 31 quadrillion Btu in 2025 and by 2.8 quadrillion Btu from the baseline of 38 quadrillion Btu in 2050 (**Figure 1.11 and**

Figure 12a). Over the period of 2008 to 2025, EERE's portfolio of technologies provides 9 quads of cumulative savings of natural gas (**Figure 1.12b**).

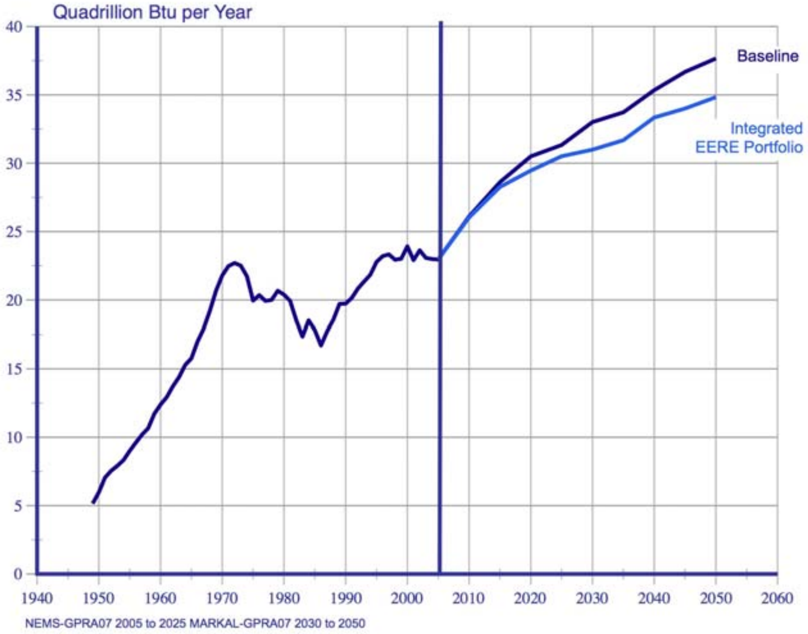
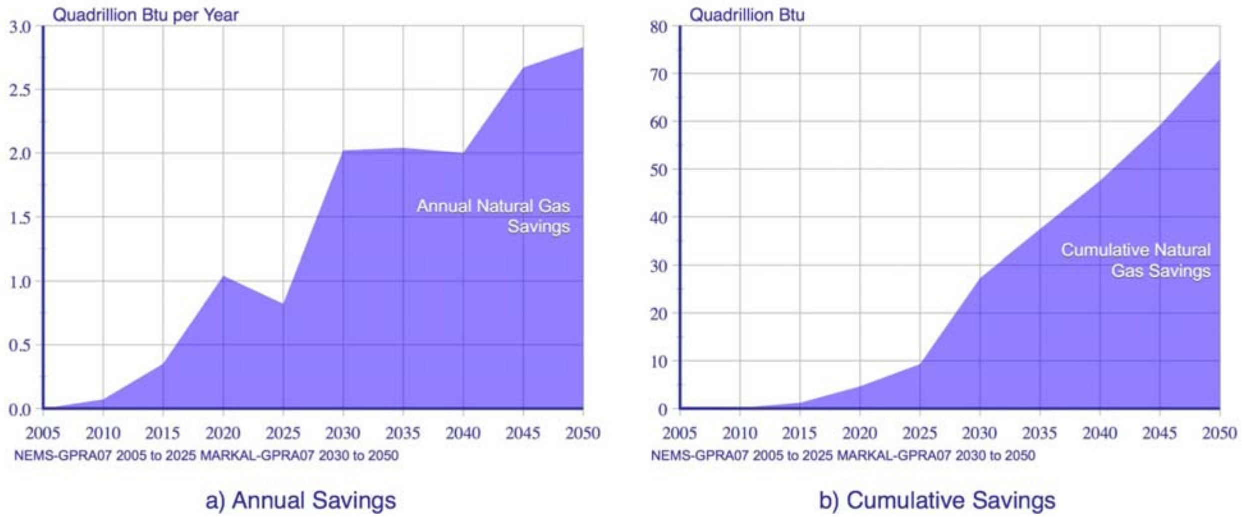


Figure 1.11. U.S. Natural Gas Consumption, 1949-2004, and Projections to 2050: Baseline and Portfolio Cases

Data Source: 1949-2004, Energy Information Administration, *Annual Energy Review 2004*, DOE/EIA-0384 (2004) (Washington, D.C., August 2005), Table 1.3, Web site http://www.eia.doe.gov/emeu/aer/contents.html.



a) Annual Savings

b) Cumulative Savings

Figure 1.12. U.S. Natural Gas Savings, Projections to 2050: Baseline and Portfolio Cases

Cumulative savings of natural gas through 2050 is 73 quads. While EERE does not estimate the portion of natural gas savings attributed to imported natural gas supplies, supplies from countries other than the United States and Canada may be the marginal sources of natural gas for meeting any future growth in demand.

EERE's technology programs also contribute to the security of the Nation's electricity supply by reducing central conventional power plant capacity additions (**Figure 1.13**). As shown in **Figure 1.14**, renewable energy capacity additions (central and distributed) are projected to grow by an additional 73 GW, compared with the Baseline Case in 2025; and 332 GW, compared with the Baseline Case in 2050.

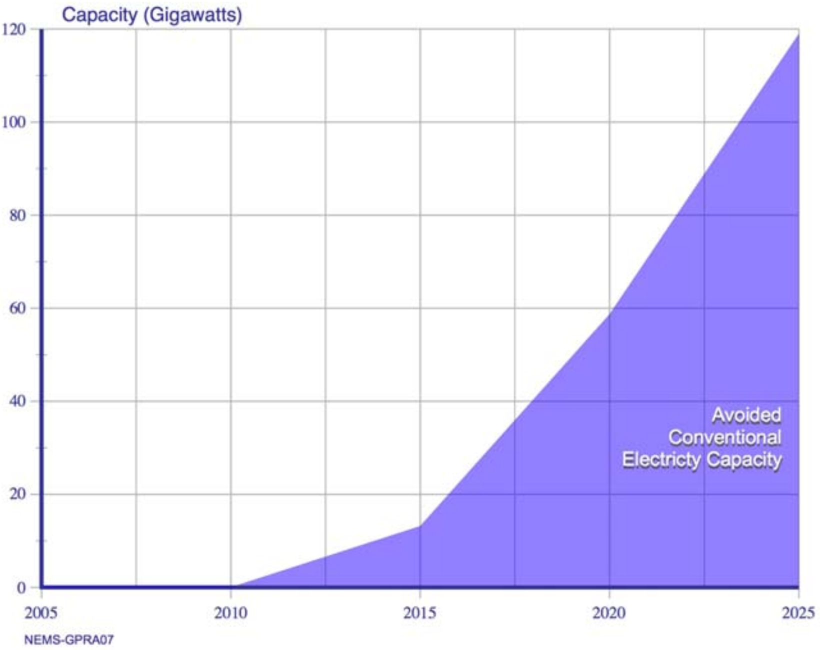


Figure 1.13. Avoided Conventional Central Generating Capacity Projections to 2025

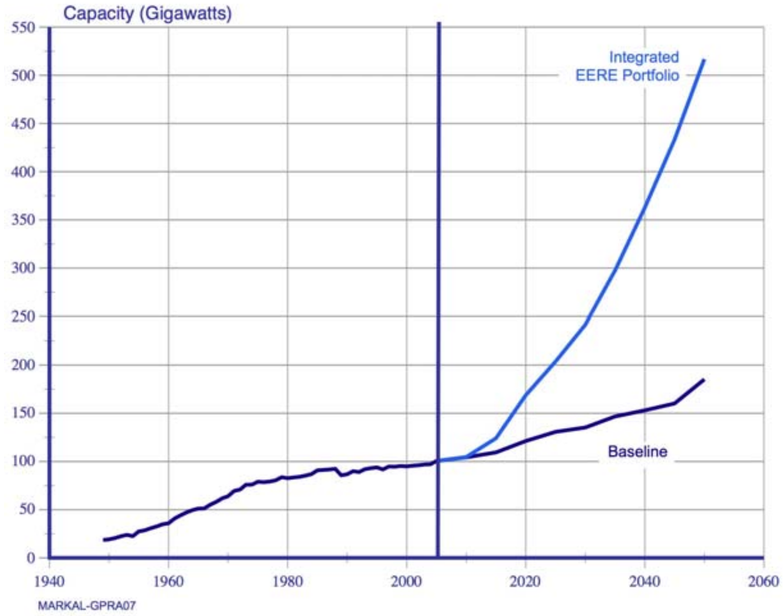
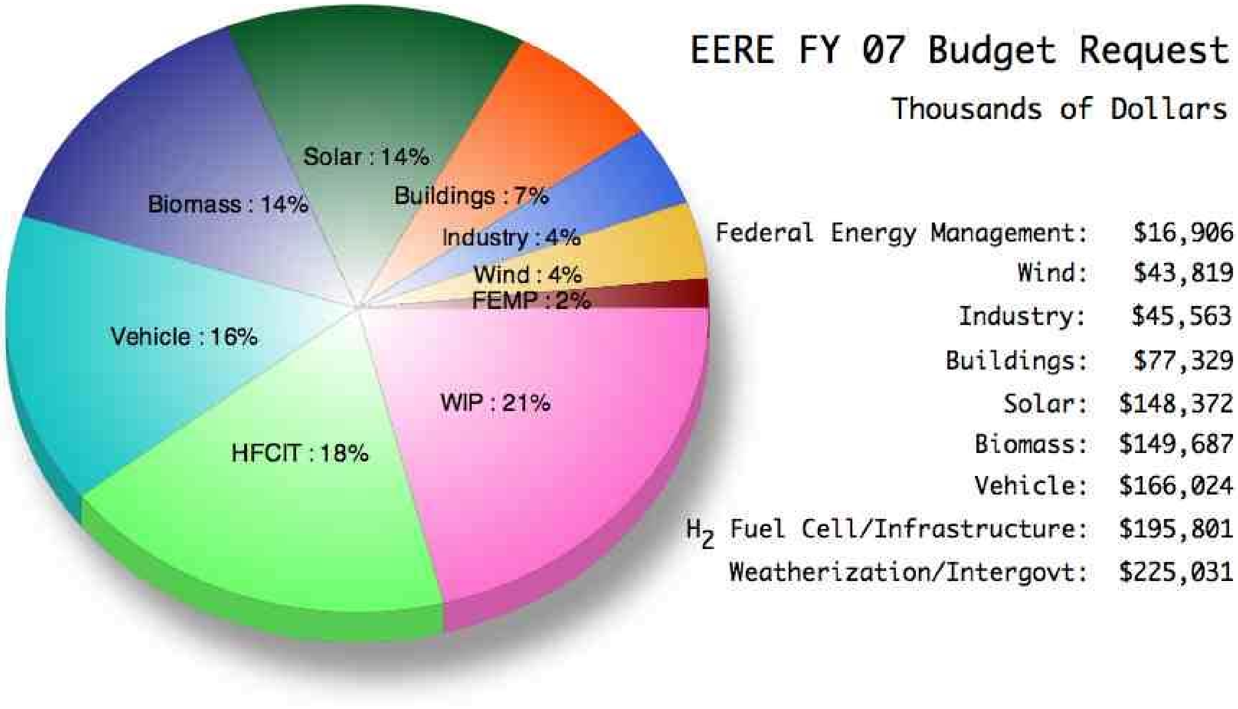


Figure 1.14. U.S. Renewable Energy Capacity, 1949-2004, and Projections to 2050: Baseline and Portfolio Cases

Data Source: 1948-2004, Energy Information Administration, *Annual Energy Review 2004*, DOE/EIA-0384 (2004) (Washington, D.C., August 2005), Table 8.11a, Web site http://www.eia.doe.gov/emeu/aer/contents.html.

Program Benefits

The remainder of this chapter is devoted to program-specific information, including program budget requests and benefits (see **Chapters 2 and 3** for more specific program-level analysis). **Figure 1.15** displays the EERE program budget requests for FY 2007. The largest program budget is $225 million for the Weatherization and Intergovernmental Program (WIP), which includes $164 million for Low-Income Weatherization Assistance.



Federal Energy Management:	$16,906
Wind:	$43,819
Industry:	$45,563
Buildings:	$77,329
Solar:	$148,372
Biomass:	$149,687
Vehicle:	$166,024
H_2 Fuel Cell/Infrastructure:	$195,801
Weatherization/Intergovt:	$225,031

Figure 1.15. EERE Program FY 2007 Budget Requests

Source: Budget request from *FY 2005 Budget-in-Brief*, U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, http://www1.eere.energy.gov/ba/pba/budget_07.html

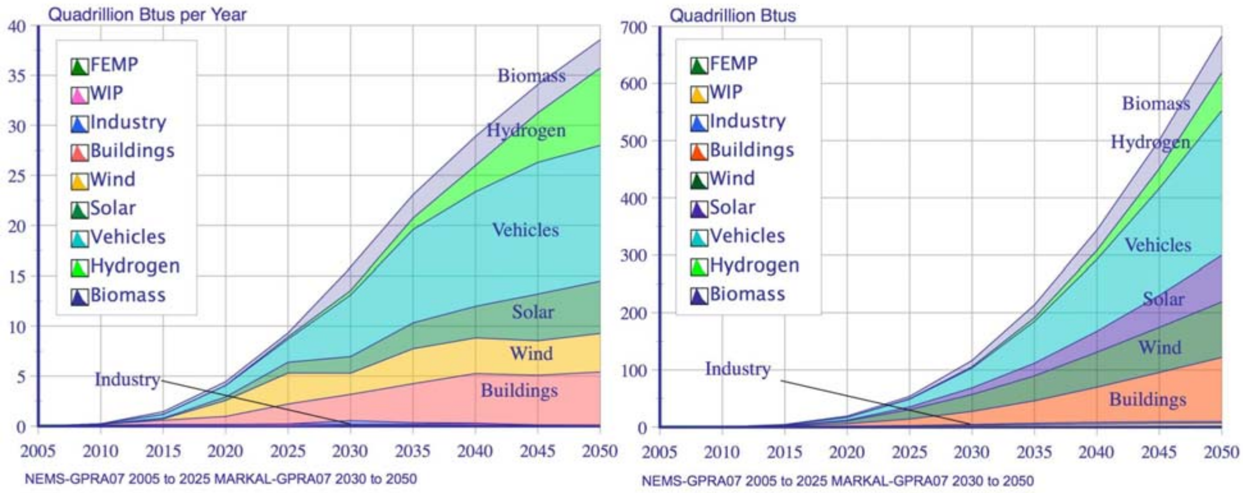
Individual program benefits are not—as indicated in the earlier discussion on primary nonrenewable energy savings—in sum, representative of the total benefits of the integrated EERE technology portfolio. That is because individual programs can compete with or be synergistic with other programs in the portfolio—and the individual program benefits presented here represent how each program's technologies can compete by themselves, without the presence of any other programs in the EERE portfolio. Still, the individual program benefits presented here serve as a proxy for understanding the relative strengths of each program's technology.

The picture that emerges from the individual program benefits presented here is one of robustness. Different technologies are positioned to dominate in the near, mid- and long term.

Some technologies are best-suited to improving energy security by reducing our dependence on foreign oil. In addition, different programs emerge as important contributors to consumer energy savings versus those that emerge as important contributors to total energy system net cost savings.

While incomplete, the results indicate both the range and approximate level of benefits available to the Nation from funding the efficiency and renewable investments in EERE's portfolio of programs. They indicate a potential for making better use of existing technologies and for accelerating technological advances to make significant changes in our energy markets, which can drive the Nation to a period of level energy consumption.

> **Energy Displacement: Figures 1.16 a and b** show the time profile of each program's savings (both annual and cumulative). The relative cumulative impact of the individual program cases is shown in **Figure 17** for three different time frames (2015, 2025, and 2050). The Industry, WIP, and FEMP programs have their greatest influence in the near term (through 2015). The Building Technologies Program has the largest impact in the near term, followed closely by the Vehicle Technologies Program, the Biomass Program, and Weatherization. In the midterm (through 2025), the Wind Technologies Program shows the greatest relative impact on energy savings. In the long term, advanced transportation technologies (from Hydrogen, Vehicles, and Biomass) become the dominant potential impacts. In the meantime, solar technologies show continuous growth in relative impact throughout the period of 2008 through 2050. By 2050, Vehicles, Buildings, Wind, Solar, Hydrogen, and Biomass (in descending order) each have significant potential impacts on energy displacement.



a) Annual Savings

b) Cumulative Savings

Figure 1.16 Individual Program Goal Cases Nonrenewable Energy Savings: Annual and Cumulative

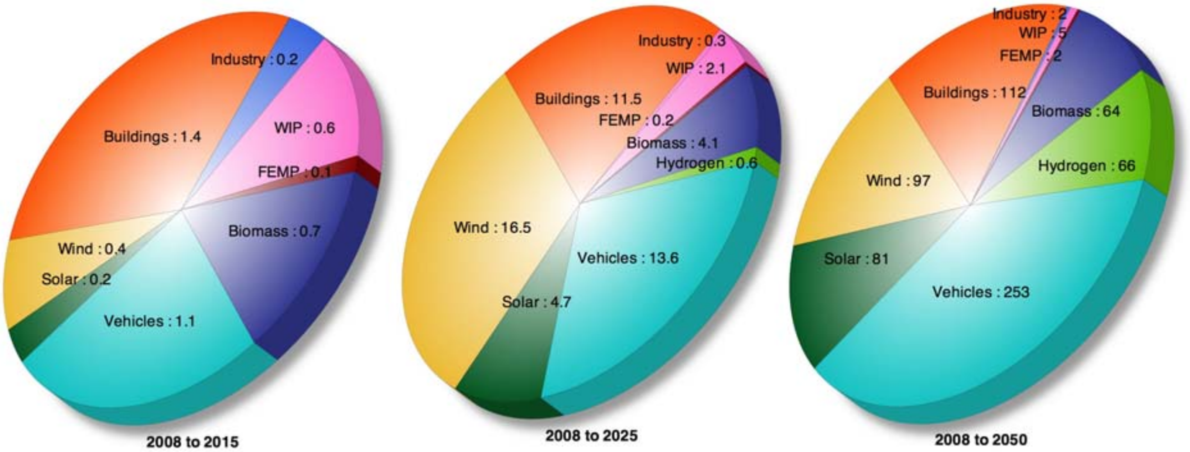
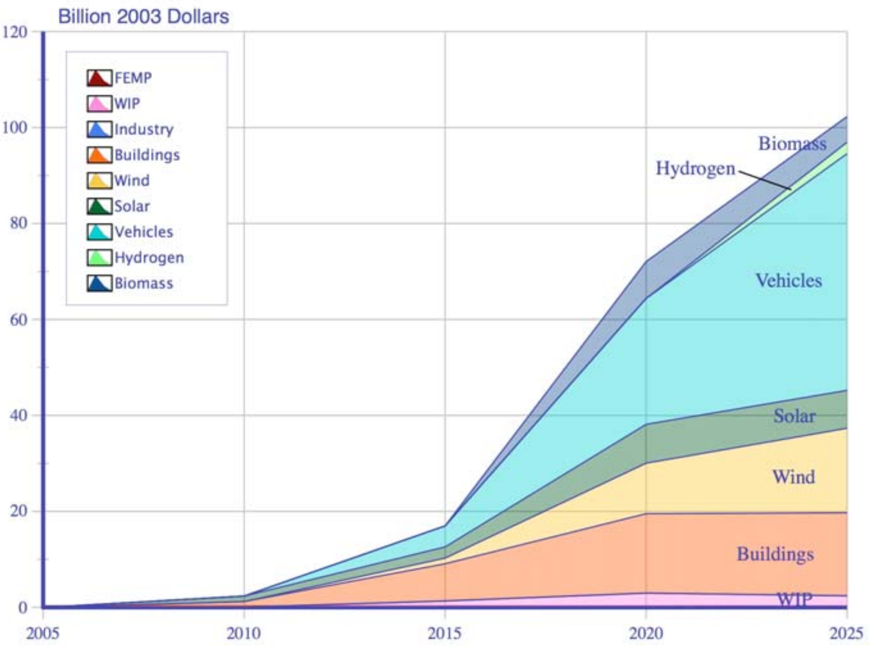


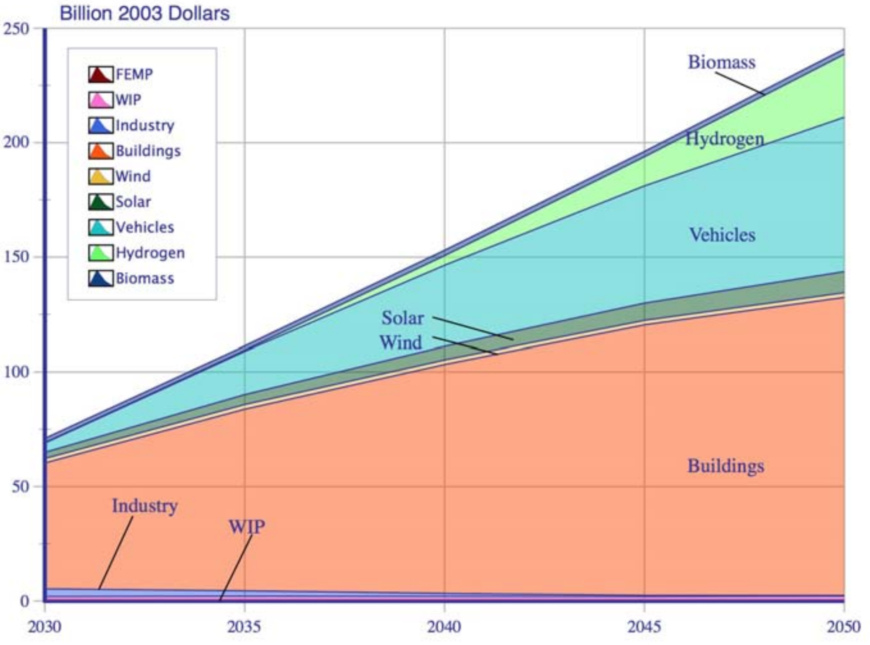
Figure 1.17. Cumulative Individual Program Goal Cases Nonrenewable Energy Savings for 2015, 2025, 2050 (Quadrillion Btu)

Economic Benefits: Figure 1.18 shows the time profile of the individual program impacts on consumer energy spending through 2025. As with energy displacement, energy-expenditure savings are dominated in the near term by the Building Technologies Program, followed closely by savings impacts from the Vehicle Technologies Program. By 2025, the largest individual program savings are associated with the Vehicles Program. Buildings, Wind, Solar, and Biomass are also positioned to have significant impacts. The Hydrogen Program is just beginning to show potential impact. **Figure 1.19** shows the time profile of the individual program impacts on total energy system cost. Here, the relative strengths of the different programs play out very differently. Total energy cost, as opposed to consumer spending, is most heavily influenced by energy efficiency technologies. Thus, in the near- and midterm, the Buildings Program dominates the savings. In the long term, energy savings from the Vehicles Program and the Buildings Program dominate.



NEMS-GPRA07 2005 to 2025

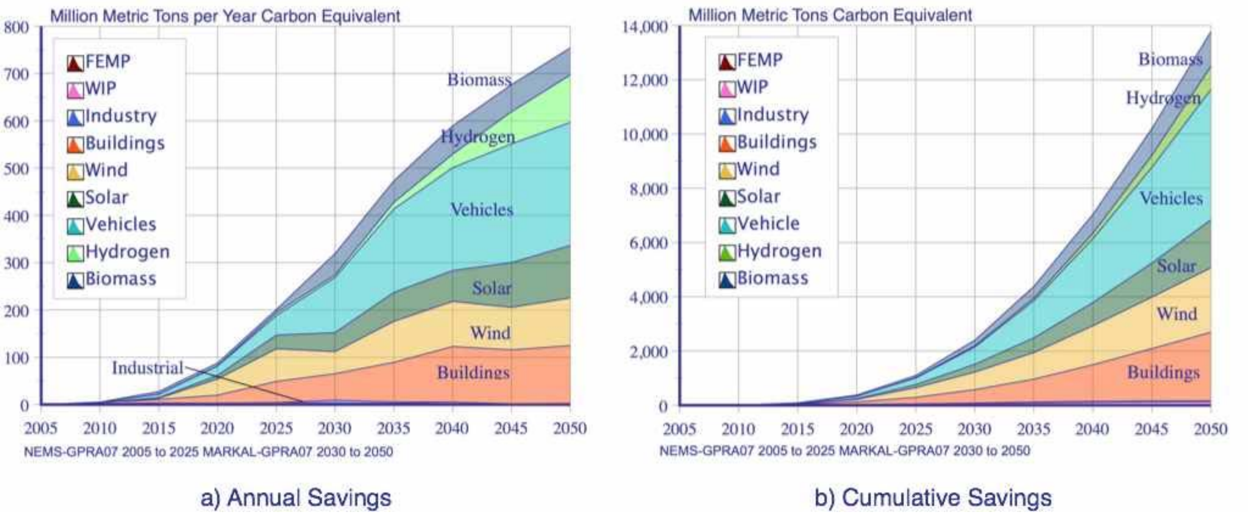
Figure 1.18. Annual Individual Program Goal Cases Consumer Energy-Expenditure Savings: Projections to 2025



MARKAL-GPRA07 2005 to 2050

Figure 1.19. Annual Program Goal Cases Energy-System Net Cost Savings: Projections to 2050

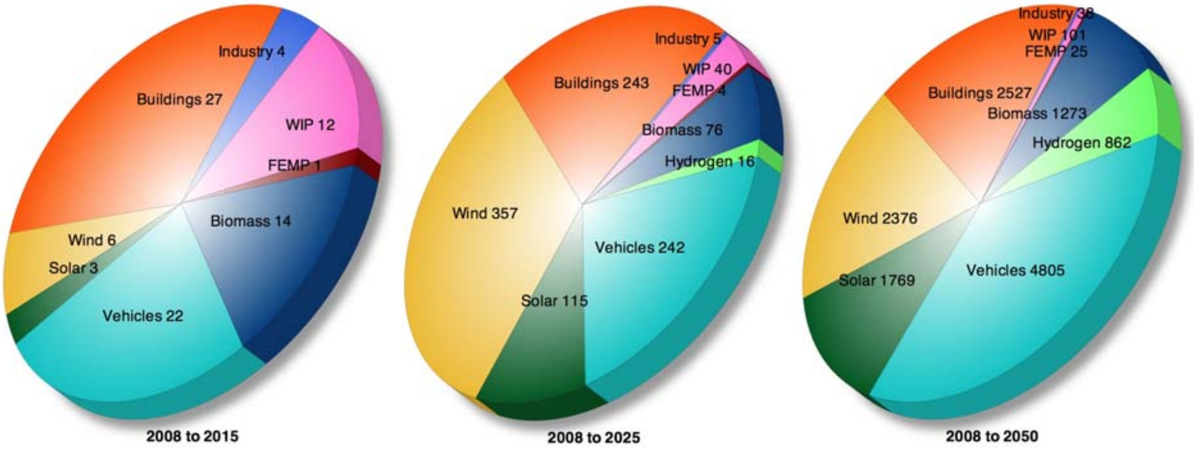
Environmental Benefits: The time profiles and relative impacts of each of the programs on carbon emissions follows very closely the trends described for total nonrenewable energy savings (see **Figures 1.20 and 1.21**).



a) Annual Savings

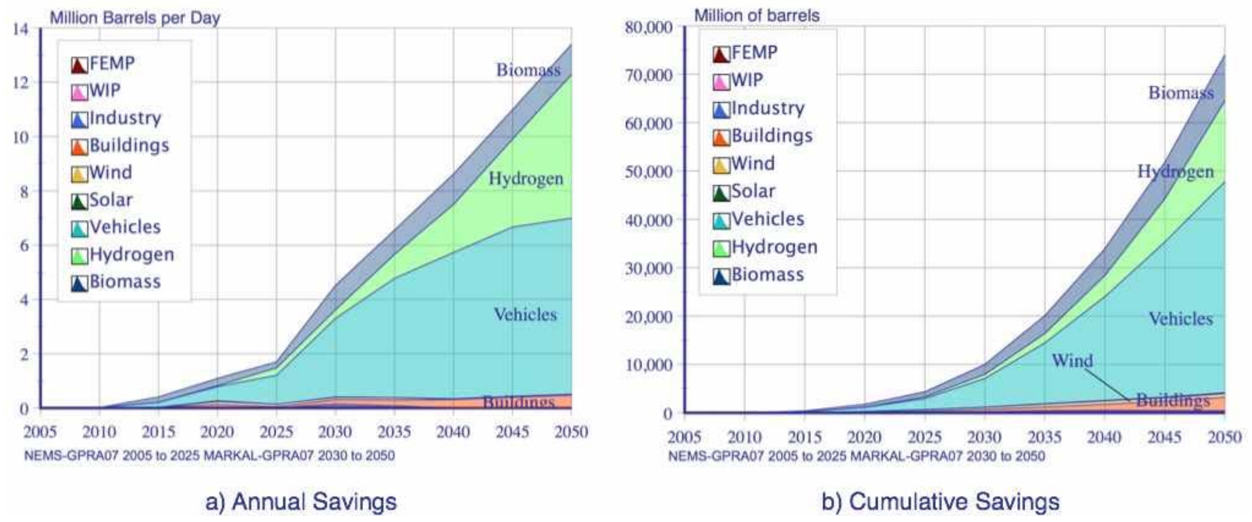
b) Cumulative Savings

Figure 1.20. Individual Program Goal Cases Carbon Emissions Avoided: Annual and Cumulative



Figures 1.21. Cumulative Individual Program Goal Cases Carbon Emissions Avoided, 2015, 2025, 2050 (Million Metric Tons Carbon Equivalent)

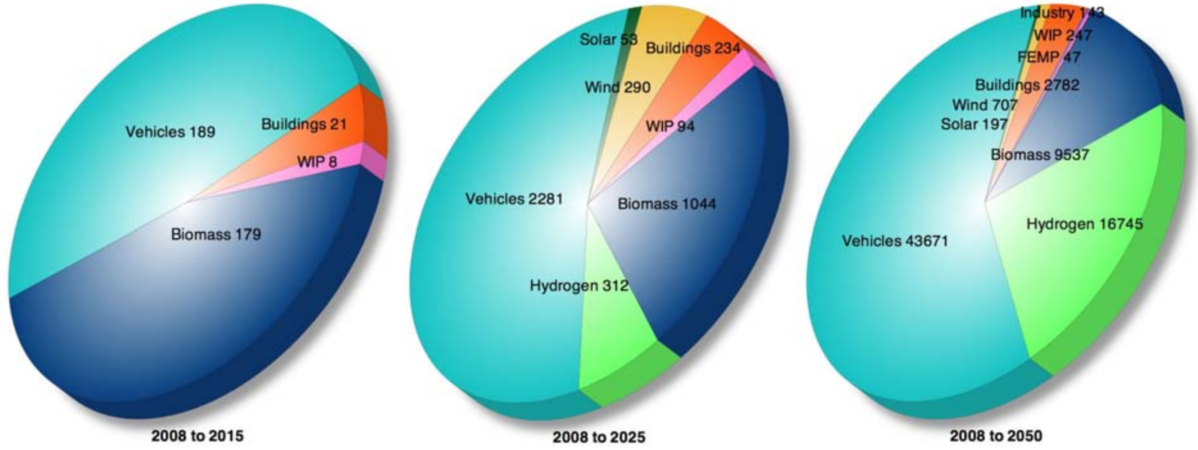
Energy Security Benefits: Oil savings are dominated by the three main transportation related technologies—Vehicles, Hydrogen, and Biomass (see **Figures 22 and 23**). In the near term, the Vehicles and Biomass programs are equally positioned to dominate oil savings in the portfolio. In the long term, Hydrogen steps forward as the third major technology positioned to contribute to oil savings.



a) Annual Savings

b) Cumulative Savings

Figure 1.22 Individual Program Goal Cases Oil Savings (mbpd)



Figures 1.23: Cumulative Individual Program Goal Cases Oil Savings (Millions of Barrels)

CHAPTER 2

MIDTERM BENEFITS ANALYSIS OF EERE'S PROGRAMS

Introduction

The anticipated outputs from the Office of Energy Efficiency and Renewable Energy (EERE) Research, Development, Demonstration, and Deployment (RD3) programs are represented in NEMS-GPRA07 in the Individual Program Goal Cases and Portfolio Cases to estimate the midterm (to 2025) benefits for each program and for EERE's overall portfolio. This chapter describes the NEMS-GPRA07 analyses for each program. The appendices provide additional information on the inputs provided by each program.

Table 2.1 shows a breakdown by program of the two types of analytical tools employed in its benefits analyses—specialized "off-line" tools and NEMS-GPRA07. A description of the Energy Information Administration's (EIA) National Energy Modeling System (NEMS) model is provided in **Box 2.1** at the end of this chapter.[1] Off-line tools are those used to develop input for NEMS and, in some cases, to estimate benefits for program activities outside of the scope of NEMS. Descriptions of the off-line tools are provided in the related program appendices.

Table 2.1. Program Benefits Modeling by Primary Type of Model Used and Activity Area

Program	Activity Area	Off-Line Tool	NEMS-GPRA07
Biomass	Ethanol from Corn Fiber and Residual Starch		✓
	Cellulosic Ethanol		✓
Building Technologies	Technology R&D	✓	✓
	Regulatory Actions	✓	✓
	Market Enhancement	✓	
FEMP	FEMP	✓	
Hydrogen, Fuel Cells, and Infrastructure Technologies	Fuel Cells		✓
	Production and Delivery	✓	
Industrial Technologies	Industrial programs	✓	
Solar Energy Technologies	Photovoltaic Systems	✓	✓
	Concentrated Solar Power		✓
Vehicle Technologies	Light Vehicle Hybrid and Diesel		✓
	Light-weight Materials for LDVs		✓
	Heavy Vehicles	✓	
Weatherization and Intergovernmental	Weatherization	✓	
	Domestic Intergovernmental	✓	
Wind and Hydropower Technologies	Wind		✓

Required off-line analysis using specialized off-line tools can range from simple verification of program goals to an initial calculation of energy savings, depending on the treatment of the target market in NEMS-GPRA07 and the nature of the program. The activity areas listed in **Table 2.1**

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[1] For more detailed information about NEMS, see http://www.eia.doe.gov/bookshelf/docs.html for individual reports documenting the NEMS modules.

are groupings of activities within each program that share either technology or market features—they do not represent actual program-management categories.

Biomass Program

The goal of the Biomass Program is the development of biomass refineries (biorefineries), which produce multiple products, including at least one energy product. Energy products include ethanol, other fuels, and electricity. Non-energy products include chemicals and materials. 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 biorefineries that produce ethanol fuel as a major output along with specialized bioproducts.[2]

Corn-based ethanol: The primary thrusts of the R&D related to corn-based ethanol production are the use of corn kernel fiber and residual starch in dry mills that will increase ethanol yields per bushel of corn, and the development of bio-based chemical coproducts. These goals are represented within the NEMS-GPRA07 framework through modifications in the corn ethanol yields, and per unit O&M and capital costs. The production of bio-based chemicals is treated as a revenue credit for the ethanol. The Biomass Program assumes that these same improvements would occur without the EERE R&D, but would be delayed by seven years. The program's goal is to begin to deploy the technology in 2012 and assumes a seven-year phase-in for implementation. Therefore, 2019 is the first year of deployment in the Base Case.

There were also several modifications made to the NEMS-GPRA07 representation of corn ethanol production with NEMS-GPRA07. The NEMS supply curves from the *AEO2005* were expanded to allow up to 10 billion gallons of production by assuming the same slope as in the AEO's feedstock corn prices and raising the last step of production. In addition, the base ethanol yields and credit for distillers' dry grains (DDG), an animal feed material that is the coproduct of dry mills, were increased from those in the *AEO2005* and are closer to those in the just-released AEO2006.[3] Note that, because NEMS-GPRA07 is based on the *AEO2005* reference case, the Baseline Case does not include new policies from EPACT that are reflected in *AEO2006*, such as the implementation of a renewable fuel standard that mandates increased use of ethanol up to a level of 7.4 billion gallons per year in 2012.

Cellulosic ethanol from biorefineries dedicated to the production of ethanol and lignin-derived electricity: EERE is sponsoring research aimed at reducing the cost of producing ethanol from cellulosic biomass.[4] The cellulosic biorefineries modeled in this analysis are ones that focus on producing ethanol and lignin-derived electricity.[5] The program goal, as alluded to

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[2] Future analyses could include additional fuels that the program may identify in the longer term. In addition, the research undertaken to improve the harvesting of agricultural residue feedstocks has not been included in the GPRA analysis.

[3] Unfortunately, the timing of AEO's release does not afford our program analysts and energy modelers the time to run our GPRA benefits analyses with the most recent AEO.

[4] Cellulose and hemicellulose 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.

[5] In the future, when designs of alternative biorefinery configurations (e.g., those producing ethanol, electricity, and bio-based chemicals) are available, the benefits analysis will include such concepts as well.

in the President's Advanced Energy Initiative,[6] is to achieve a production cost of $1.07 per gallon of ethanol by 2012, with cost reductions in subsequent years. In NEMS-GPRA07, the commercialization date was set to 2015 to allow for three years from pilot to start-up of a full commercial facility. Cellulosic production capacity is assumed to be able to expand at a rate of 500 million gallons, or by 25% per year (whichever is greater), consistent with growth constraints based on historical data of the highest existing corn ethanol industry and gasoline-refinery capacity expansion rates.

In NEMS-GPRA07, the capital costs, non-fuel operating costs, and conversion efficiencies for cellulosic ethanol were modified to reflect the program targets for the Individual Program Goal Case. The biomass feedstock curves in NEMS-GPRA07 are used to determine the feedstock price by region and year. In the Baseline, cellulosic ethanol production is assumed to penetrate after the NEMS time horizon to 2025.

The refinery model within NEMS-GPRA07 evaluates the use of ethanol as a blending agent for gasoline, taking into account its chemical properties as well as its energy value. As ethanol becomes less expensive due to advanced technologies, more ethanol is used. In both the Baseline and Individual Program Goal Cases, corn ethanol reaches its peak of 10 billion gallons per year by 2025. Cellulosic ethanol grows from its introduction in 2015 to 7.3 billion gallons in 2025. The refinery model also produces E85, for which production levels are dependent on the relative attractiveness of its use primarily in flex-fuel vehicles.

The Biomass Program benefits shown in **Table 2.2** are the reductions in energy use and carbon emissions in the Individual Program Goal Case compared with the Baseline Case.[7]

Table 2.2. FY07 Annual Benefits Estimates for Biomass Program (NEMS-GPRA07)

Benefits	**2010**	**2015**	**2020**	**2025**
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	ns	0.27	0.36	0.39
Economic				
Energy-Expenditure Savings (billion 2003 dollars/yr)	ns	ns	7.7	5.4
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	ns	6	6	7
Security				
Oil Savings (million barrels per day)	ns	0.20	0.27	0.22
Natural Gas Savings (quadrillion Btu/yr)	ns	-0.14	-0.10	ns
Avoided Additions to Central Conventional Power (cumulative gigawatts)	ns	ns	ns	ns
Other Program Metrics				
Incremental Ethanol Production (billion gallons/yr)	0.00	5.2	7.8	7.3

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[6] For more details on the Advanced Energy Initiative, see http://www.whitehouse.gov/stateoftheunion/2006/energy/index.html

[7] 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.

More information about the assumptions underlying the Biomass Program's benefits analysis can be found in **Appendix C**.[8]

Building Technologies Program

The activities of the Building Technologies Program can be classified into three general types: technology R&D, regulatory actions, and market enhancement. The modeling approach and applicable end uses for the activities that comprise the Building Technologies Program are shown in **Table 2.3**. Analysts model the technology R&D activities by modifying costs and efficiencies of the equipment and shell-technology slates. Market-enhancement activities and some regulatory activities (such as buildings codes) are modeled using penetration rates and energy-savings estimates.

Table 2.3. Modeling Approach for Building Technologies Program Activities

	Sector		End-Use					Modeling Approach		
Building Technology Project List	Resd	Comm	Heat	Cool	Water Heating	Lighting	Other	Energy Savings and Penetration Rates	Equipment Technology Costs and Efficiencies	Shell Technology Costs and Efficiencies
Residential Buildings Integration										
Research and Development (Building America)	✓		✓	✓	✓	✓	✓			✓
Residential Building Energy Codes	✓		✓	✓				✓		
Commercial Buildings Integration										
Commercial Research and Development		✓	✓	✓						✓
Commercial Building Energy Codes		✓	✓	✓		✓		✓		
Analysis Tools and Design Strategies		✓	✓	✓						✓
Refrigeration/Space Conditioning R&D										
Thermotunneling Based Cooling	✓	✓	✓	✓					✓	
HyPak-MA		✓		✓					✓	
Integrated Heat Pump	✓		✓	✓	✓				✓	
Building Envelope R&D										
Electrochromic Windows		✓	✓	✓		✓				✓
Superwindows	✓		✓	✓				✓		✓
Low-E Market Accpetance	✓	✓	✓	✓				✓		
Advanced Wall Systems	✓		✓	✓						✓
Next Generation Attic Systems	✓		✓	✓						✓
Next Generation Envelope Materials	✓		✓	✓						✓
Lighting Research and Development										
Lighting Controls		✓				✓		✓		
Solid State Lighting	✓	✓				✓			✓	
Appliances and Emerging Technologies										
SSL Market Acceptance	✓	✓							✓	
Standards										
HID lamps		✓				✓			✓	
Electric Motors, 1-200 HP		✓					✓	✓		
Distribution Transformers								✓		
Rebuild America		✓						✓		
Energy Star										
Compact Fluorescents	✓					✓		✓		
Windows	✓		✓	✓				✓		
Refrigerators	✓						✓	✓		
Dishwashers	✓						✓	✓		
Clotheswashers	✓						✓	✓		
Room AC	✓			✓				✓		
Home Performance	✓		✓	✓				✓		

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[8] More information about the relevant NEMS modules may be found at http://tonto.eia.doe.gov/FTPROOT/modeldoc/m059(2005)-1.pdf (Petroleum Market Module, volume 1), http://tonto.eia.doe.gov/FTPROOT/modeldoc/m059(2005)-2.pdf (Petroleum Market Module, volume 2), http://tonto.eia.doe.gov/FTPROOT/modeldoc/m070(2005).pdf (Renewable Fuels Module) and http://tonto.eia.doe.gov/FTPROOT/modeldoc/m069(2005).pdf (Transportation Sector Demand Module).

Technology R&D: The technology R&D activities seek to develop new or improved technologies that are more energy efficient and more cost-effective than the alternatives currently available. The projected benefits for these are measured by modifying the technology slates from those that are available in the Baseline Case to reflect the program goals. Building technologies in NEMS-GPRA07 are represented by end use. For most end uses, there are conversion technologies (e.g., furnaces and water heaters) that use different fuels and that have several different levels of energy efficiency. The Baseline Case incorporates EIA's estimation of future technology improvement. The rate of technology improvement is modified in the Individual Program Goal Case.

Residential shell technologies (such as windows or insulation) for new buildings are represented by several combinations or "packages" of technologies with different levels of improvements. Each package is characterized by a capital cost, and heating and cooling load reductions. The commercial-sector shell measures are represented by window and insulation technologies that can be selected individually. EIA developed the residential methodology for the *AEO2001*, while OnLocation developed the commercial methodology for EERE.

The residential and commercial sectors are each represented by several building types within nine Census divisions. NEMS-GPRA07 computes the end-use technology choice for each of these building types and geographic regions, based on the relative economics and estimations of consumer behavior for the technologies. The latter is important to replicate current technology market shares.

In a few cases where NEMS-GPRA07 has insufficient detail for explicit technology representation, analysts computed market penetration using off-line tools, and the results were implemented with NEMS-GPRA07 through efficiency factors.

Regulatory activities: Regulatory activities include setting new appliance standards—based on the legislatively mandated schedule—and encouraging state adoption of more stringent building codes. Modeling appliance standards is straightforward. In the year that the program expects the new standard to be implemented, all technologies that are less efficient than the standard are removed from the market and unavailable for consumer choice. The resulting energy savings depend on the difference in the level of efficiency of the standard compared to the technology that had been selected in the Baseline Case. The exception are distribution transformers that are not explicitly represented in the model, so off-line estimates of electricity savings are used to decrease the transmission and distribution losses.

Market enhancement: Building-code development is primarily a regulatory activity, although it also involves outreach to encourage the various states to adopt new and stricter standards. Analysts make a spreadsheet computation of average savings using off-line estimates for the fraction of buildings within areas that adopt more stringent codes, as well as the heating, cooling, and lighting load reductions associated with the new levels of codes. For residential buildings, the savings are based on increased compliance with existing codes, accelerated adoption of the 2000 edition of the International Energy Conservation Code, and the future development of more stringent building codes. For commercial buildings, savings are based on increased stringency from the combined impact of the latest forthcoming ASHRAE code and the next-generation code assumed to be published in 2007. These analyses were performed at the State level to reflect the current variation in building codes and climate factors. The resulting savings were then represented in NEMS-GPRA07 through modification of the building shell efficiencies.

Energy Star aims to accelerate the market penetration of existing high efficiency technologies by providing greater information to consumers about their benefits and life-cycle operating savings. This is equivalent to lowering consumers' hurdle rates for investment in energy-efficient appliances. Therefore, analysts represented the Energy Star activities by modifying the NEMS-GPRA07 consumer-behavior coefficients, indicating how consumers trade first-cost expenditures for annual energy savings. The program goals for market penetration were used to determine the degree of change of these parameters. For most Energy Star appliances, the program goal is to reach a 20% market share for the more efficient Energy Star appliances.[9]

The Building Technologies Program results in energy savings primarily in four end-use categories: space heating, space cooling, water heating, and lighting. **Table 2.4** demonstrates the level of delivered energy savings (excluding losses from electricity generation) from each category. In 2025, space heating and lighting end uses have the highest delivered energy savings in residential buildings; while the lighting energy-use reduction is the largest in commercial buildings.

Table 2.4. Building Technologies Program Delivered Energy Savings by End Use

Energy Savings by End-Use (Quads)	Residential Sector				Commercial Sector			
	2010	2015	2020	2025	2010	2015	2020	2025
Space Heating	0.02	0.13	0.22	0.33	0.00	0.02	0.04	0.08
Space Cooling	0.00	0.03	0.06	0.11	0.00	0.02	0.04	0.11
Water Heating	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lighting	0.01	0.02	0.05	0.17	0.00	0.02	0.05	0.21
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	0.04	0.18	0.32	0.60	0.01	0.06	0.13	0.40

The Building Technologies Program benefits (**Table 2.5**) are estimated within the integrated NEMS-GPRA07, so that the electricity-generation primary energy savings are directly computed. In addition, the estimates include any feedbacks in the buildings or other sectors resulting from changes in energy prices that result from the reduced energy consumption.

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[9] Energy Star is a cooperative effort between DOE and the Environmental Protection Agency. There is a division of responsibilities with respect to specific technologies, and EERE claims benefits for the penetration of the technologies for which it is responsible. Nevertheless, some of the general campaigns and marketing strategies are joint efforts between the agencies, and attribution of the benefits to DOE or EPA is difficult.

Table 2.5. FY07 Annual Benefits Estimates for Building Technologies Program (NEMS-GPRA07)

Benefits	2010	2015	2020	2025
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	0.10	0.41	0.81	1.99
Economic				
Energy-Expenditure Savings (billion 2003 dollars/yr)	1.2	7.7	16.5	17.3
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	2	8	17	45
Security				
Oil Savings (million barrels per day)	ns	0.02	0.09	0.04
Natural Gas Savings (quadrillion Btu/yr)	0.05	0.25	0.23	0.48
Avoided Additions to Central Conventional Power (gigawatts)	ns	9	26	62
Other Program Metrics				
Total Electricity Capacity Avoided (cumulative gigawatts)	ns	13	32	76

More detail about the assumptions underlying the Building Technologies Program's benefits analysis can be found in **Appendix G.**[10]

Federal Energy Management Program

The Federal Energy Management Program (FEMP) is an implementation program to increase the energy efficiency of Federal Government buildings, which account for about 5% of U.S. commercial-building energy consumption. FEMP activities support the installation of a variety of existing technologies, rather than focusing on the development of specific technologies, as do many other EERE programs. Because it encompasses a broad technological scope—while, at the same time, targets a specific market segment—FEMP is difficult to model in an integrated framework such as NEMS-GPRA07. However, there is also less uncertainty associated with achieved energy savings, because the program tracks changes in Federal energy consumption.

Delivered energy savings (estimated off-line) are used as inputs for the integrated modeling. These projected savings are subtracted from the Baseline Case for commercial-building energy consumption. Analysts use the model to compute the other benefits metrics of primary energy savings, carbon emission reductions, and energy-expenditure savings (**Table 2.6**).

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[10] More details about the relevant NEMS modules may be found at:
http://tonto.eia.doe.gov/FTPROOT/modeldoc/m067(2005).pdf (Residential Sector Demand Module) and
http://tonto.eia.doe.gov/FTPROOT/modeldoc/m066(2005).pdf (Commercial Sector Demand Module).

Table 2.6. FY07 Annual Benefits Estimates for FEMP (NEMS-GPRA07)

Benefits	2010	2015	2020	2025
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	0.01	0.01	0.02	0.02
Economic				
Energy-Expenditure Savings (billion 2003 dollars/yr)	0.1	0.1	0.1	0.2
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	0.2	0.2	0.3	0.4
Security				
Oil Savings (million barrels per day)	ns	ns	ns	ns
Natural Gas Savings (quadrillion Btu/yr)	ns	0.01	0.01	0.01
Avoided Additions to Central Conventional Power (cumulative gigawatts)	ns	ns	ns	ns

More detail on the Federal Energy Management Program's benefits analysis can be found in **Appendix I**.[11]

Hydrogen, Fuel Cells, and Infrastructure Technologies Program

The Hydrogen, Fuel Cells, and Infrastructure Technologies Program is targeted toward the introduction of fuel cells for both stationary and vehicular applications, as well as the production and delivery of hydrogen at a reasonable price. NEMS-GPRA07 does not have a representation of hydrogen-supply options.[12] Therefore, we employ a simplifying assumption that all hydrogen produced through 2025 would be derived from natural gas. The hydrogen conversion process is assumed to be 75% efficient and yield a hydrogen price of $2 per gallon of gasoline equivalent (excluding taxes) when the natural gas price is $5 per MMBtu.

The stationary fuel cell research is focused on distributed proton-exchange membrane (PEM) fuel cells. The program goals for their capital costs and efficiencies were taken from the multiyear program plan (MYPP). The MYPP provides goals through 2010, and no further improvements were assumed. This conservative assumption most likely understates the benefits of these fuel cells. Analysts converted program technology goals into installed costs for combined heat and power systems in residential and commercial buildings.

The fuel cell vehicles were modeled along with the Vehicle Technologies Individual Program Goal Case. The success of fuel cell vehicles is predicated on some of the vehicular improvements being developed under the Vehicle Technologies Program, so the fuel cell vehicles could not be treated in isolation. Analysts modified the gasoline and hydrogen fuel cell vehicle costs and efficiencies to reflect the program goals (see the Vehicle Technologies Program description for more detail about the modeling of vehicle choice). In addition, hydrogen was assumed to be available for vehicle refueling at 10% of vehicle refueling stations by 2020 and available at 25 percent of refueling stations by 2025. The benefits associated with fuel cell vehicles were derived by comparing the number of fuel cell vehicles projected in the case in which both Hydrogen and Vehicle Technologies were evaluated to the number of fuel cell vehicles projected

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[11] More details about the relevant NEMS module may be found at http://tonto.eia.doe.gov/FTPROOT/modeldoc/m066(2005).pdf (Commercial Sector Demand Module).

[12] Hydrogen is represented within the refinery model of NEMS-H2, but for internal use only.

in the case with Vehicle Technologies only. Analysts computed energy savings, oil savings, and carbon emission reductions, based on the relative fuel and carbon emissions per mile of the incremental fuel cell vehicles relative to those in the Baseline. This approach leads to greater savings than would a simple difference between the Baseline and Individual Program Goal Cases, while still yielding smaller savings than would be derived by comparing a fuel cell vehicles case with the Baseline Case. **Table 2.7** presents the overall benefits.

Table 2.7. FY07 Annual Benefits Estimates for Hydrogen, Fuel Cells, and Infrastructure Technologies Program (NEMS-GPRA07)

Benefits	2010	2015	2020	2025
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	ns	ns	0.02	0.22
Economic				
Energy-Expenditure Savings (billion 2003 dollars/yr)	ns	ns	ns	2.4
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	ns	ns	ns	6
Security				
Oil Savings (million barrels per day)	ns	ns	0.03	0.28
Natural Gas Savings (quadrillion Btu/yr)	ns	ns	-0.03	-0.33
Avoided Additions to Central Conventional Power (gigawatts)	ns	ns	ns	ns
Other Program Metrics				
Program-Specific Electric Capacity Additions (Cumulative gigawatts)	ns	ns	ns	ns

More details about the HFCIT Program's benefits analysis can be found in **Appendix B**.[13]

Industrial Technologies Program

The Industrial Technologies Program seeks to increase energy efficiency in the energy-intensive basic materials processing industries, as well as some key technologies that are common across most industries. The heterogeneity of the program makes it difficult to represent the program activities explicitly through technologies in the NEMS-GPRA07 framework. Therefore, analysts perform an off-line analysis using detailed spreadsheet models, and use the resulting energy savings by fuel type to provide inputs into the integrated model. Analysts then run the fully integrated NEMS-GPRA07 to compute the benefits metrics of primary energy savings, carbon emission reductions, and energy-expenditure savings that are associated with the fuel-consumption reductions.

At the time of publication of the Congressional Budget request, out-year funding profiles for a number of programs within DOE's FY 2007 Congressional Budget Request were not yet complete. In such instances, EERE assumed "steady-state" funding trajectories to calculate benefits estimates, pending further information. Now that "target" funding allocations have been finalized, the estimates shown here for the Industrial Technologies Program reflect DOE's decision to conclude this program after FY 2008. The benefits decline after 2010, due to the

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[13] More details about the relevant NEMS modules can be found at http://tonto.eia.doe.gov/FTPROOT/modeldoc/m070(2005).pdf (Transportation Sector Demand Module), http://tonto.eia.doe.gov/FTPROOT/modeldoc/m067(2005).pdf (Residential Sector Demand Module), and http://tonto.eia.doe.gov/FTPROOT/modeldoc/m066(2005).pdf (Commercial Sector Demand Module).

cessation of EERE R&D and the assumption that the program accelerates the adoption of efficient technologies—but that the private sector will eventually adopt at a later time even in the absence of the program.

Table 2.8. FY07 Annual Benefits Estimates for Industrial Technologies Program (NEMS-GPRA07)

Benefits	2010	2015	2020	2025
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	0.03	0.03	ns	ns
Economic				
Energy-Expenditure Savings (billion 2003 dollars/yr)	0.4	0.2	ns	ns
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	0.7	0.5	ns	ns
Security				
Oil Savings (million barrels per day)	ns	ns	ns	ns
Natural Gas Savings (quadrillion Btu/yr)	0.01	0.01	ns	ns

More details about the Industrial Technologies Program's benefits analysis can be found in **Appendix H**.[14]

Solar Energy Technologies Program

The Solar Energy Technologies Program develops two electric-solar technologies. Photovoltaics (PVs) are being improved for both distributed and central electricity generation applications, and the program is working to accelerate PV adoption through the Solar America Initiative. The concentrated solar power (CSP) R&D activity develops better technology for large-scale central electricity generation facilities that concentrate solar energy to produce electricity through a thermal process.

Photovoltaic Systems: Several changes were made to the representation of distributed PV systems in the Baseline. The size of the typical distributed PV installation was increased to 4 kW per home (from 2 kW) and to 100 kW per commercial building (from 25 kW) to reflect literature on recent installations. The California renewable energy credit program, which provides a PV credit of $4,000/kW in 2003 (declining by $400/kW per year), was included for the Pacific region. The recently passed Federal tax credit was not included, because the legislation occurred after this analysis was performed.

In addition, the adoption rates of distributed technologies in commercial buildings were modified to reflect market data gathered by the EERE on consumer adoption of energy efficiency projects as a function of payback time (**Figure 2.1**).[15] The NEMS-GPRA07 framework uses a cash-flow model to evaluate the distributed energy (DE) technologies—combined heat and power (CHP) and photovoltaic (PV) systems—within the building sectors. For commercial buildings, debt and interest payments are computed over a loan period of 15 years, along with associated taxes and

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[14] Details about the relevant NEMS module can be found at: http://tonto.eia.doe.gov/FTPROOT/modeldoc/m064(2005).pdf (Industrial Demand Sector Module).

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

tax benefits and assuming a 25% down payment. Annual fixed maintenance costs also are included. The value of the electricity produced is then subtracted from these costs to determine the cash flow. The number of years until positive cash flow is reached determines the market share in new buildings. The annual market share for existing buildings is assumed to be a fraction of the share for new.

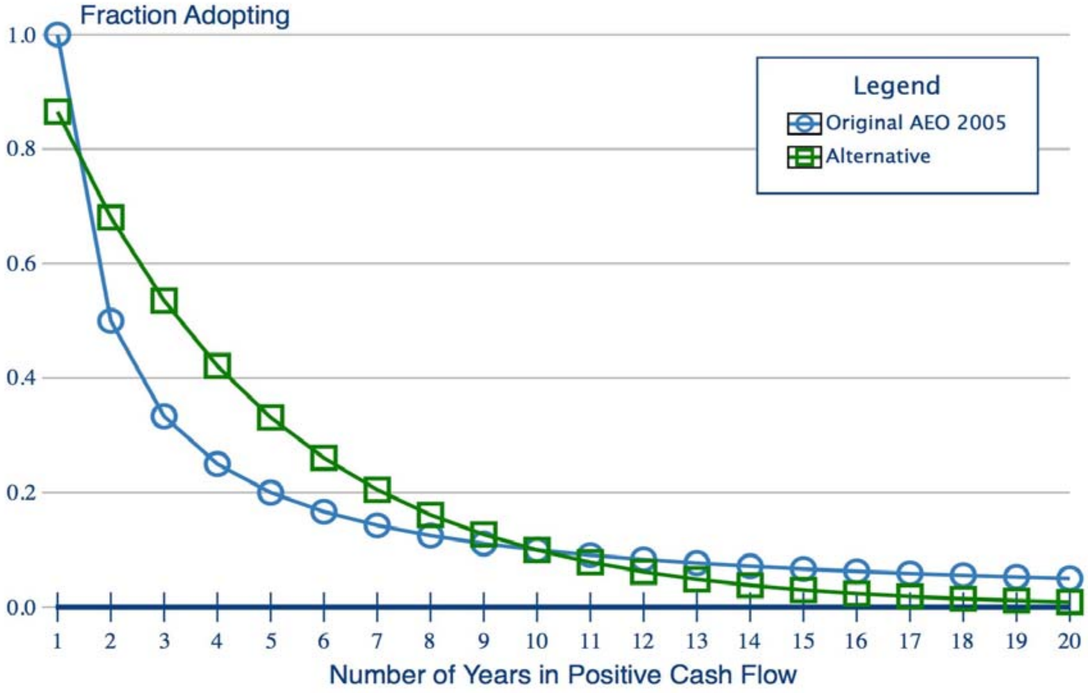

Figure 2.1. Commercial-Sector DG Adoption Rates

Under both the EIA and program assumptions, market share in new buildings decreases sharply as the number of years required to achieve positive cash flows increases. This reflects the high rates of return generally expected for energy-related projects by commercial-building owners. These shares apply to the fraction of commercial buildings assumed to be eligible for an installation of PV systems. The fraction of eligible buildings was increased from 30% to 60% for homes and to 55% for commercial buildings. These adoption-rate changes were made in the Baseline Case as well as the Individual Program Goal Case. In addition, the average-size building for commercial PV installations was modified from being four times the average size (as in the *AEO2005*) to being only twice as large. At this size, the PV-produced electricity is roughly equivalent to the annual electricity demand of the building.

The *AEO2005* Reference Case includes significant PV technological advancement. The GPRA07 Baseline was developed assuming that private industry would continue to improve first-generation PV (crystalline silicon) technology, but would not invest significantly on its own in second- or third-generation PV (thin-film, etc.) technologies in the absence of continued EERE programs. For the Individual Program Goal Case, the capital and O&M costs were modified to reflect the program's goals. The regional capacity factors in the Baseline Case were similar to those in the program's goals, so they were left unchanged.

In addition to competing on an economic basis with other electricity-generation technologies, PV may be constructed for its environmental benefits. For example, the Solar Program's Solar America Initiative goals were incorporated as planned distributed-PV capacity additions in NEMS-GPRA07.

Table 2.9. NEMS-GPRA07 Projected Solar Capacity (GW)

Solar Generation Technologies

	2010	2015	2020	2025
GPRA Base				
Solar CSP	0.5	0.5	0.5	0.5
Central PV	0.1	0.2	0.3	0.4
Distributed PV	0.5	0.5	0.5	1.3
Total	1.1	1.2	1.3	2.2
Solar Individual Program Goal Case				
Solar CSP	0.5	0.5	0.5	3.2
Central PV	0.1	0.2	0.3	0.4
Distributed PV	1.4	5.6	30.4	65.2
Total	2.0	6.3	31.2	68.9
Incremental Capacity				
Solar CSP	0.0	0.0	0.0	2.7
Central PV	0.0	0.0	0.0	0.0
Distributed PV	0.8	5.0	29.8	63.9
Total	0.8	5.0	29.8	66.6
Incremental Generation (BkWh)				
Solar CSP	0	0	0.0	18
Central PV	0	0	0.0	0.0
Distributed PV	2	10	60	129
Total	2	10	60	147

Concentrated Solar Power: The improved concentrated solar power (CSP) technology was represented by declining capital costs over time and higher capacity factors. The capital costs goals are higher than those used in the Baseline but represent systems with significantly more storage and, therefore, higher electrical output. A set of capacity factors by time periods within a year were computed by analysts to optimize the timing of solar output for each region within the bounds of the storage potential. The capacity factors and capital costs vary by region, due to differences in solar insolation and resulting storage costs.

Primary energy, oil, and carbon emissions savings result from PV and CSP generation. These savings depend on which types of generating plants were built and operated in the Baseline Case. Over time, the mix of fuels and efficiencies of power generation vary; and, therefore, the energy savings will as well. Energy-expenditure savings are measured as the reduction in consumer expenditures for electricity and other fuels. Lower-cost renewable generation options reduce the price of electricity directly and reduce the pressure on natural gas supply, both of which benefit end-use consumers. Overall benefits of the Solar Energy Technologies Program are shown in **Table 2.10**.

Table 2.10. FY07 Annual Benefits Estimates for Solar Energy Technologies Program (NEMS-GPRA07)

Benefits	2010	2015	2020	2025
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	ns	0.06	0.35	1.07
Economic				
Energy-Expenditure Savings (billion 2003 dollars/yr)	1.1	2.3	8.1	7.9
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	ns	1	8	29
Security				
Oil Savings (million barrels per day)	ns	ns	0.03	ns
Natural Gas Savings (quadrillion Btu/yr)	ns	0.05	0.09	Ns
Avoided Additions to Central Conventional Power (gigawatts)	ns	3	20	54
Other Program Metrics				
Program-Specific Incremental Generation (gigawatt-hours/yr)	2	10	60	147
Program-Specific Electric Capacity Additions (cumulative gigawatts)	1	5	30	67

More details about the Solar Energy Technologies Program's benefits analysis can be found in **Appendix D**.[16]

Vehicle Technologies Program

The Vehicle Technologies Program consists of research on light-duty vehicle hybrid and diesel technologies, heavy-vehicle engine/drivetrain and parasitic loss-reduction technologies, and lightweight materials for engines and vehicles. The program includes research in advanced petroleum and renewable fuels, the benefits of which are not modeled. In addition, Clean Cities, a deployment program to stimulate greater use of alternative fuels and efficient vehicles, is included within the Vehicle Technologies Program.

Light-duty vehicle hybrid and diesel technologies: This research aims to improve engine technologies in light-duty vehicles, which include passenger cars and light-duty trucks. NEMS-GPRA07 is used to compute benefits estimates for these activities through a process that estimates the penetration (sales) of the various technologies in the market for light-duty vehicles over time. The amount that each technology penetrates into the market determines the stock of these vehicles and the vehicle miles traveled (VMT) associated with each technology.

In the NEMS-GPRA07 integrating model, the light-duty vehicle (LDV) market consists of six car classes—mini-compact, subcompact, compact, midsize, large, two-seater—and six light-duty truck classes—small and large pickup, small and large van, small and large sport utility vehicle (SUV)—in nine Census divisions. For each vehicle type and class and for each region, a number of LDV technologies compete against each other in the market for vehicle sales. These include conventional gasoline, advanced combustion diesel, gasoline hybrids, diesel hybrids, gasoline

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[16] Details about the relevant NEMS modules are available at: http://tonto.eia.doe.gov/FTPROOT/modeldoc/m067(2005).pdf (Residential Sector Demand Module), http://tonto.eia.doe.gov/FTPROOT/modeldoc/m066(2005).pdf (Commercial Sector Demand Module), http://tonto.eia.doe.gov/FTPROOT/modeldoc/m068(2004).pdf (Electricity Market Module), and http://tonto.eia.doe.gov/FTPROOT/modeldoc/m069(2005).pdf (Renewable Fuels Module).

fuel cell, hydrogen fuel cell, electric, natural gas, and alcohol. The plug-in HEV (PHEV) activity was added in FY06, but the capability to model the market acceptance of this new vehicle (which uses both electricity and a liquid fuel) has not yet been developed.

Each vehicle technology is represented by a number of characteristics that can change over the forecast time horizon and that influence the technology's acceptance in the marketplace and its sales. These characteristics include the vehicle cost, the fuel cost per mile (a combination of the fuel price and the vehicle efficiency), the vehicle range, the operating and maintenance cost, the acceleration, the luggage space, the fuel availability, and the make and model availability. The NEMS-GPRA07 model also includes "calibration" coefficients to calibrate the model to historical sales data. The associated characteristics for all the alternative technologies are specified as relative to those for the conventional gasoline vehicle.

The model estimates the sales-penetration share of each technology in all of the vehicles, classes, and regions in each year of the forecast. The various characteristics of the technologies determine the technology's value to consumers and its acceptance in the marketplace, but each characteristic has a differing degree of influence. The vehicle cost is generally the most influential of the characteristics, certainly having a much stronger influence than luggage space, for example. The values of all the characteristics are combined together to create an overall value. The technologies are competed against each other, based on the overall values, using a nested logit formulation. In a logit formulation, the relative size of the overall value for each technology determines the relative penetration share for that technology. Technologies that have higher values are given greater sales shares, resulting in a distribution of consumer preferences rather than the technology with the highest value receiving 100% of the market.

In the FY 2007 benefits analysis, the Baseline Case for transportation programs includes some additional penetration of hybrids above the level in the *AEO2005* Reference Case—sales of hybrids are roughly 11% by 2025, compared to only 6% in the *AEO2005*. This reflects the program's view that the *AEO2005* hybrid penetration is too low, due to the roughly constant hybrid vehicle efficiencies and costs over time. For the Baseline Case, the hybrid cost differentials relative to conventional gasoline vehicles were reduced so that they were approximately halfway between the *AEO2005* Reference Case and the Individual Program Goal Case. The model calibration coefficient was also phased out over 20 years to represent a gradual increase in consumer acceptance of hybrids. The effect of the higher hybrid sales in the Baseline is to reduce the incremental benefits credited to the Vehicle Technologies Program.

The Individual Program Goal Case uses the program technology characteristics, along with a variety of other assumptions relating to behavioral responses, in the underlying logit formulation of the NEMS-GPRA07 model. These include modeling an increase in the consumer acceptance of HEVs relative to gasoline internal-combustion engines[17] more rapidly than in the Baseline, and reworking the manner in which the make and model availability coefficients are used.

Lightweight materials for engines and vehicles: The lightweight materials developed under this R&D activity are used in both light and heavy vehicles and are represented in the NEMS-

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[17] Modelers, based on the expert judgment of the benefits analysis team, decrease the "calibration coefficients" over time to zero - faster in the Individual Program Goal Case than in the Base Case.

GPRA07 model. For light-duty vehicles, the effect of these materials for hybrids and advanced diesel is included in the projection of vehicle attributes described above, and is not modeled separately. However, for light-duty conventional vehicles, the effect of these materials is modeled using the Manufacturers' Technology Choice (MTC) submodule within NEMS-GPRA07, where an economic decision is made based on the costs and efficiency of the technology. The costs and efficiencies are provided as attributes for an advanced conventional vehicle and transformed for use in existing lightweight technology slots in the MTC. For heavy vehicles, the effect of these materials is included in the projections of penetrations and efficiencies.

Clean Cities: This deployment subprogram is represented through an increase in alternative-fuel vehicles and an increase in dedicated ethanol (E85) vehicles and fuel use. For the increase in alternative-fuel vehicles, analysts used off-line analysis to determine the cumulative number of expected vehicles participating in Clean Cities. These were converted to annual vehicle sales and used as inputs into NEMS-GPRA07. The largest share of vehicles are compressed natural gas, ethanol, and liquefied petroleum gas—electric and methanol vehicle shares are small. For the portion of the program that encourages greater ethanol use, analysts determined the change in the fraction of vehicles using E85 over time and an increasing fraction of E85 use per vehicle. These were converted to overall fractions of E85 use and were then used as inputs to NEMS-GPRA07.

Heavy-vehicle engine/drivetrain and parasitic loss reduction technologies: Heavy vehicles are those that have a gross weight (the weight when fully loaded) of 10,000 pounds or more. This program researches multiple technologies including engines/drivetrains, parasitics/accessories, aerodynamics, and hybrids. The benefits of this R&D activity are derived from penetration rates estimated by the Heavy Truck Energy Balance and TRUCK 2.0 models (developed for the Vehicle Technologies Program), using efficiency and technology cost assumptions. The penetration rates and efficiencies are then used in the NEMS-GPRA07 freight model to increase the efficiency of new vehicles. NEMS-GPRA07 performs the stock accounting for the fleet and determines the overall change in consumption.

Using the integrated NEMS-GPRA07 model, the overall sales share for gasoline light-duty vehicles in 2025 falls from 77% in the Baseline Case to 37% in the Individual Program Goal Case (**Figure 2.2**). This decrease in share is due to the penetration of the alternative technologies. The overall share in 2025 for advanced combustion diesel increases from 5% to 18%; for gasoline hybrids, from 10% to 24%; and, for diesel hybrids, from 1% to 16%.

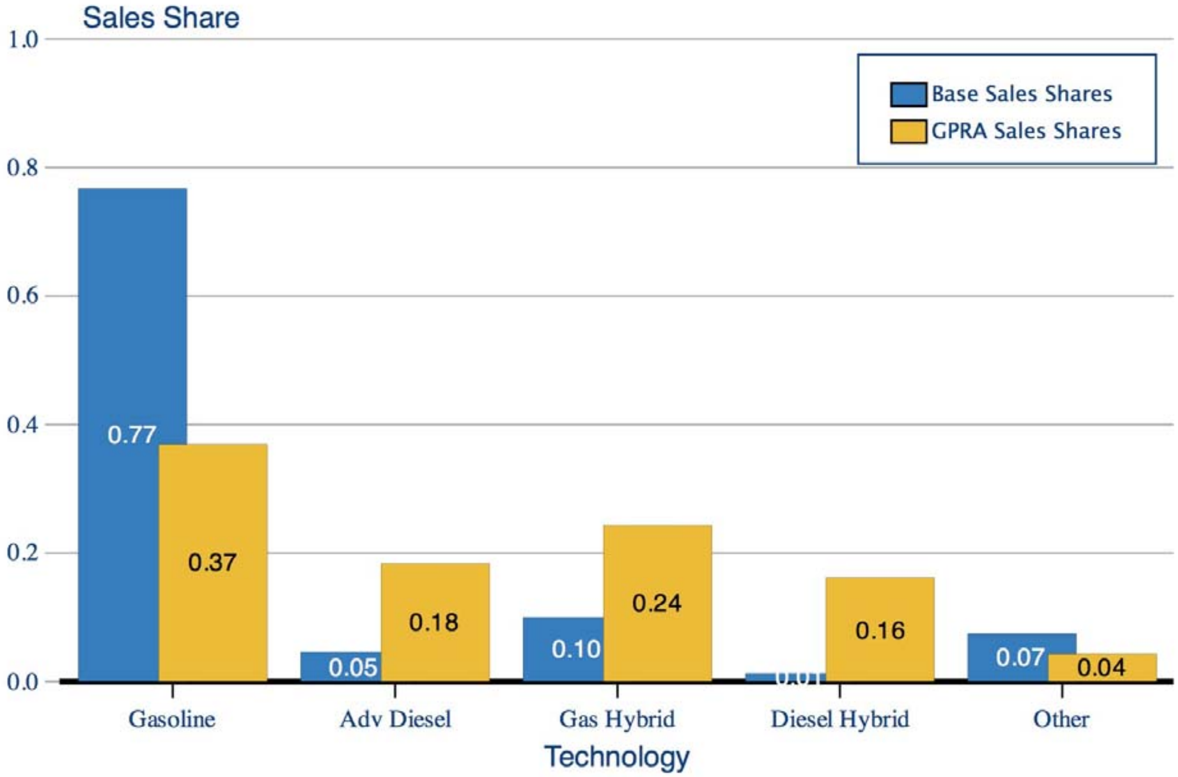

Figure 2.2 Vehicle Technology Sales Share in 2025

These larger vehicle sales shares for advanced technology vehicles in 2025, however, translate into much smaller shares of overall vehicle stocks and overall shares of vehicle miles traveled (VMT) for each technology. The stock shares depend on the share of sales over time, which only gradually increases for the alternative-technology vehicles, and the rate of vehicle replacement and growth. The total VMT for gasoline vehicles falls from 3,311 billion miles in 2025 to 2,563 (just more than 60 percent of the VMT) between the two cases (**Figure 2.3**). The total VMT for advanced-combustion diesel increases from 165 to 378 billion miles (9%); for diesel hybrids, from 25 to 291 billion miles (almost 7%); and, for gasoline hybrids, from 266 to 769 billion miles (18%).

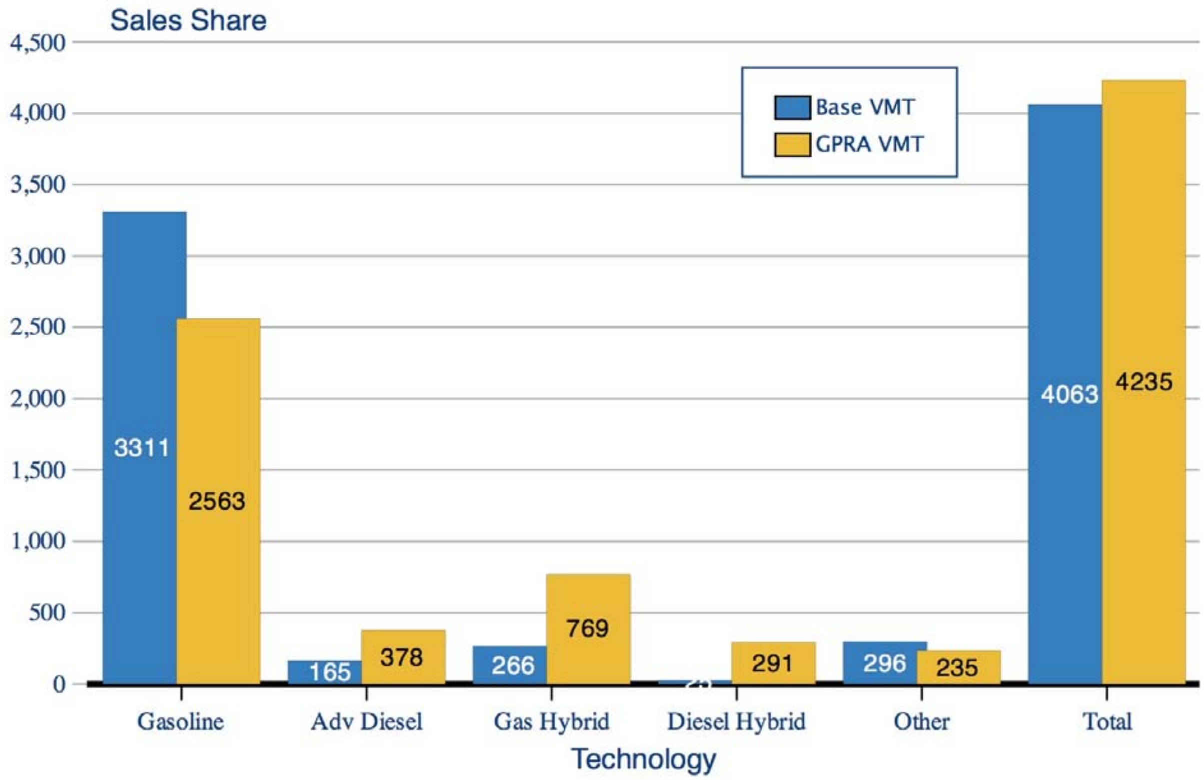

Figure 2.3 Vehicle Miles Traveled in 2025

The miles per gallon (MPG) for advanced-combustion diesel and for hybrid vehicles is much greater than the MPG for conventional gasoline vehicles. In addition, the conventional gasoline vehicles are more efficient, due to adoption of lower-cost lightweight materials. As a consequence of the advanced-technology vehicles substitution for the conventional gasoline vehicles and improved conventional vehicles, there is a considerable amount of fuel savings.

In these integrated NEMS-GPRA07 model runs, the savings are typically somewhat less than what they would be if they were estimated in a transportation-only model, because of feedback effects that come through the integration with other sectors. The primary feedback effect occurs through lower fuel prices. In this case, reduced gasoline demand causes lower gasoline prices, which leads to an increase in travel and less-efficient vehicle purchases than would otherwise have occurred absent the price change. The rebound of gasoline consumption reduces the program savings. At the same time, energy-expenditure savings are greater. The small decreases in price apply to the total amount of fuel consumed and contribute significant additional expenditure savings. In addition, the "rebound" effect is also influenced by the fact that vehicles are more efficient, thereby reducing the cost to drive, causing more miles to be driven. The total effect is that light-duty VMT in 2025 is roughly 4% higher in the Individual Program Goal Case than in the Baseline. **Table 2.11** presents the total program benefits, including those of heavy trucks and Clean Cities.

Table 2.11. FY07 Benefits Estimates for Vehicle Technologies Program (NEMS-GPRA07)[18]

Benefits	2010	2015	2020	2025
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	0.04	0.38	1.15	2.32
Economic				
Energy-Expenditure Savings (billion 2003 dollars/yr)	ns	4.4	26.2	49.3
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	1	7	20	41
Security				
Oil Savings (million barrels per day)	0.02	0.18	0.52	1.07
Natural Gas Savings (quadrillion Btu/yr)	ns	ns	0.18	0.15
Avoided Additions to Central Conventional Power (cumulative gigawatts)	ns	ns	ns	ns

More details about the Vehicle Technologies Program's benefits analysis can be found in **Appendix F**.[19]

Weatherization and Intergovernmental Program

The Weatherization and Intergovernmental Program (WIP) encompasses several market-enhancement activities, rather than R&D. The major components include: International, Native American Renewable Initiative (also referred to as Tribal Energy), the Renewable Energy Production Incentive (REPI), Weatherization (Assistance), and State Energy Program Grants. The FY 2007 benefits estimate methodologies vary by activity. The International activities are currently outside the scope of the integrated modeling framework.

Weatherization and State Energy Program Grants are implementation programs that lead to greater adoption of energy efficiency. The projected energy savings are based on the program's evaluations of past experience for these programs. Weatherization is aimed primarily at achieving heating and cooling energy reductions in homes of low-income households. To determine the annual energy savings, the number of homes projected to be weatherized is combined with the expected savings per household. The State Energy Program provides financial assistance to States and encompasses a number of types of activities including codes and standards, energy audits, retrofits, labeling, workshops and training, incentives, loans and grants, and technical assistance. Energy savings are estimated for each of these activities based on evaluations of prior-year efforts. The Weatherization and SEP energy savings are represented in NEMS-GPRA07 by reducing energy consumption in the residential and commercial sectors, based on the program goals.

The Native American renewable initiative offers assistance for renewable energy feasibility studies and shares the cost of renewable energy projects on tribal lands. The goal is the electrification of currently nonelectrified occupied housing and the offsetting of more

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[18] Note that in the Vehicle Technologies Individual Program Goal Case, the advanced ethanol production technologies 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.

[19] Details about the relevant NEMS modules are available at: http://tonto.eia.doe.gov/FTPROOT/modeldoc/m070(2005).pdf (Transportation Sector Module).

expensively provided electricity on tribal lands. Analysts made projections of central station wind and biomass capacity that would be stimulated by the program, as well as home-installed PV systems, based on the program's goals. The wind and biomass capacities were added as "planned additions"[20] within the NEMS-GPRA electricity sector. The additional PV capacity is counted in the benefits for added program capacity, but is not included in the modeling as displacing conventional generation and fuel consumption, because the systems provide electrifications to those who would not have it otherwise.

REPI provides payments to publicly owned utilities, such as municipal utilities or rural electric cooperatives, for electricity generation from renewable energy sources. These payments are the public power equivalent of the production tax credit for investor-owned renewable generators. Analysts projected the amount of new renewable generation that is likely to be stimulated by future REPI payments based on the requested budget levels and historical patterns of payments. Almost all the new generation is expected to be wind, based on the eligibility criteria and past experience. Some of the wind capacity added as planned builds to represent WIP displaces economic wind builds in NEMS-GPRA07, so the incremental is less than that calculated off-line. Overall benefits for WIP are shown in **Table 2.12**.

Table 2.12. FY07 Annual Benefits Estimates for Weatherization and Intergovernmental Program (NEMS-GPRA07)

Benefits	2010	2015	2020	2025
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	0.06	0.13	0.15	0.20
Economic				
Energy-Expenditure Savings (billion 2003 dollars/yr)	ns	1.2	2.9	2.3
Environmental				
Carbon Savings (million metric tons carbon equivalent/yr)	1	3	3	4
Security				
Oil Savings (million barrels per day)	ns	0.01	0.04	0.01
Natural Gas Savings (quadrillion Btu/yr)	0.02	0.07	0.07	0.11
Avoided Additions to Central Conventional Power (gigawatts)	ns	2	1	2
Other Program Metrics				
Program-Specific Incremental Generation (gigawatt-hours/yr)	1	11	7	17
Program-Specific Electric Capacity Additions (cumulative gigawatts)	1	4	3	5

More details on the Weatherization and Intergovernmental Program's benefits analysis can be found in **Appendix J**.[21]

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[20] In NEMS, there are two ways that generation capacity is added to the energy system. "Builds" are capacity additions that the model endogenously calculates based on energy supply and demand. "Planned additions" are specific plants that are included in the model's capacity expansion plan based on modeler knowledge. These can represent capacity under construction at the time the forecast is made, capacity that is anticipated to meet local requirements (such as State renewable portfolio standards or State incentives), or capacity that may be built for site- or institution-specific reasons that are not reflected in the model's endogenous decision framework. The planned additions will displace capacity that the model would have otherwise built. Because there are supply curves for biomass and wind resources, the planned builds may, in part, offset endogenous builds of these resources.

[21] More details on the relevant NEMS module are available at: http://tonto.eia.doe.gov/FTPROOT/modeldoc/m067(2005).pdf (Residential Sector Demand Module), http://tonto.eia.doe.gov/FTPROOT/modeldoc/m066(2005).pdf (Commercial Sector Demand Module), and http://tonto.eia.doe.gov/FTPROOT/modeldoc/m068(2004).pdf (Electricity Market Model).

Wind Technologies Program

The wind component of the Wind Technologies Program seeks to reduce the cost—and improve the performance—of wind generation. The FY 2007 benefits are based primarily on projecting the market share for wind technologies, based on their economic characteristics.

Representation of Wind: The NEMS-GPRA07 electricity-sector module performs an economic analysis of alternative technologies in each of 13 regions. Within each region, new capacity is selected based on its relative capital and operating costs, its operating performance (i.e., availability), the regional load requirements, and existing capacity resources. NEMS-GPRA07 characterizes wind by three wind classes, each with its own capital costs and resource cost multipliers. The regional resource cost multipliers act to increase costs as more of a wind class is developed in a region, and development may move to the next most cost-effective wind class. NEMS-GPRA07 assumes that the capacity value of wind diminishes with greater wind capacity in a region. Finally, another constraint on the growth of wind-resource development is how quickly the wind industry can expand before costs increase due to manufacturing bottlenecks. As in the *AEO2005,* the Individual Program Goal Case[22] (see **Table 2.13**) assumes that a cost premium is imposed when new orders in a year are 20% higher than in the highest of the previous 10 years.

The baseline characterizations of wind capital costs and capacity factors were modified to reflect a more consistent view relative to the program goals. The Baseline costs were reduced over time so that, by 2050, the onshore cost remains below the offshore costs by a ratio equivalent to that of that ratio in the Individual Program Goal Case. In addition, the capacity factors were increased for all three wind classes. The effect of these changes is to increase onshore wind capacity in the Baseline relative to the *AEO2005*, which reduces the benefits attributed to the program, but presents a better representation of the impact of the program's R&D.

NEMS-GPRA07 also includes a representation of offshore wind that is not in the *AEO2005* version of the NEMS model. The offshore wind is represented as a distinct technology that competes with all other generation technologies. It is characterized in a manner similar to onshore wind, with three wind classes—but also has a distinction between shallow and deeper water (transitional) sites. The constraints on intermittent generation and rapid growth apply similarly to offshore as to onshore wind development. The offshore wind does not have the regional resource cost multipliers, because there is insufficient data on how they might apply. The Baseline technology characteristics assume that improvements would occur without EERE R&D, but at a slower pace of roughly 10 years later.

Analysts represented the Wind Program R&D activities by reducing the capital and O&M costs and increasing the performance of wind capacity to match the program cost goals.

Table 2.14 provides the estimates of primary energy, oil, and carbon emissions savings stemming from wind and hydropower displacing fossil-fueled generation sources. Analysts measure the energy-expenditure savings as the reduction in consumer expenditures for electricity

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[22] In the *AEO2005,* all generation technologies face similar premiums associated with rapid growth.

and other fuels. Lower-cost renewable generation options reduce the price of electricity directly and reduce the pressure on natural gas supply, both of which benefit end-use consumers.

Table 2.13. Wind Capacity (GW)

		2010	2015	2020	2025
AEO Base		8.9	9.3	10.5	11.3
GPRA Baseline					
Onshore	Class 6	4.0	4.8	8.1	8.8
	Class 5	4.4	7.8	15.7	20.7
	Class 4	0.5	0.6	0.7	2.9
	Subtotal	8.9	13.2	24.5	32.3
Offshore	Class 7	0.0	0.0	0.0	0.9
	Class 6	0.0	0.0	0.0	2.9
	Class 4&5	0.0	0.0	0.0	0.0
	Subtotal	0.0	0.0	0.0	3.8
Total	Total	8.9	13.2	24.5	36.2
Wind Individual Program Goal Case					
Onshore	Class 6	4.0	5.5	8.4	8.7
	Class 5	4.4	8.8	21.8	24.1
	Class 4	0.5	4.6	28.8	47.0
	Subtotal	8.9	18.9	59.0	79.8
Offshore	Class 7	0.0	0.0	0.9	3.5
	Class 6	0.0	0.1	17.7	47.4
	Class 4&5	0.0	0.0	0.0	5.2
	Subtotal	0.0	0.1	18.7	56.1
Total	Total	8.9	19.0	77.6	135.8
Incremental Capacity					
Onshore	Class 6	0.0	0.7	0.3	0.0
	Class 5	0.0	1.0	6.1	3.4
	Class 4	0.0	4.0	28.1	44.1
	Subtotal	0.0	5.7	34.5	47.5
Offshore	Class 7	0.0	0.0	0.9	2.6
	Class 6	0.0	0.1	17.7	44.5
	Class 4&5	0.0	0.0	0.0	5.2
	Subtotal	0.0	0.1	18.7	52.2
Total	Total	0.0	5.8	53.1	99.7

Table 2.14. FY07 Benefits Estimates for Wind Technologies Program (NEMS-GPRA07)

Benefits	**2010**	**2015**	**2020**	**2025**
Energy Displaced				
Primary Nonrenewable Energy Savings (quadrillion Btu/yr)	ns	0.14	1.60	3.10
Economic				
Energy-Expenditure Savings (billion 2003 dollars/year)	ns	1.2	10.5	17.6
Environmental				
Carbon Savings (million metric tons carbon equivalent/year)	ns	3	34	69
Security				
Oil Savings (million barrels per day)	ns	ns	0.11	0.09
Natural Gas Savings (quadrillion Btu/year)	ns	0.10	0.48	0.83
Avoided Additions to Central Conventional Power (gigawatts)	ns	1	14	17
Other Program Metrics				
Program-Specific Incremental Generation (gigawatt-hours/yr)	0	23	225	429
Program-Specific Electric Capacity Additions (cumulative gigawatts)	0	6	53	100

More information about the Wind Program's benefits analysis can be found in **Appendix E**.[23]

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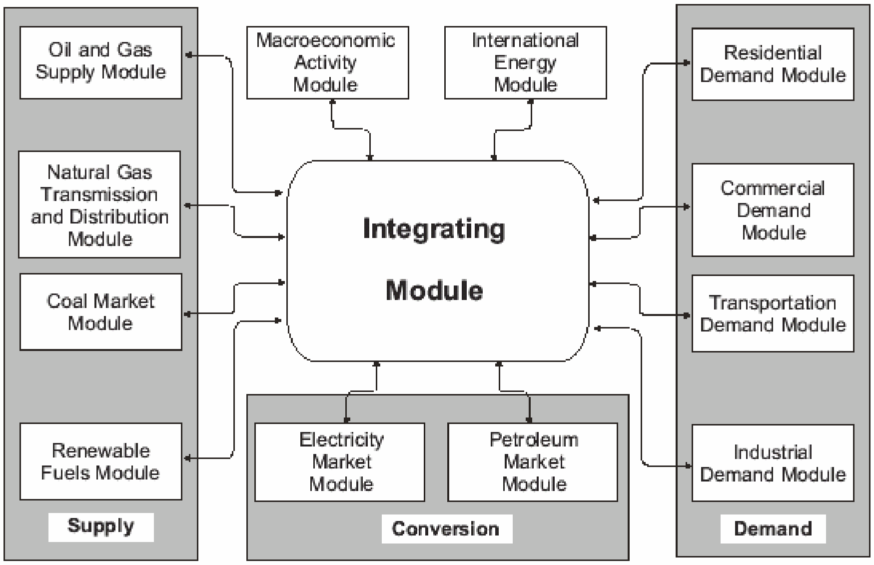
[23] Details about the relevant NEMS modules are available at: http://tonto.eia.doe.gov/FTPROOT/modeldoc/m068(2004).pdf (Electricity Market Module) and http://tonto.eia.doe.gov/FTPROOT/modeldoc/m069(2005).pdf (Renewable Fuels Module).

Box 2.1—EIA's National Energy Modeling System (NEMS)*

The National Energy Modeling System (NEMS) is an energy-economy modeling system of U.S. energy markets for the midterm period through 2025. NEMS projects the production, imports, conversion, consumption, and prices of energy, subject to assumptions on macroeconomic and financial factors, world energy markets, resource availability and costs, behavioral and technological choice criteria, cost and performance characteristics of energy technologies, and demographics. NEMS was designed and implemented by the Energy Information Administration (EIA) of the U.S. Department of Energy (DOE). As described in the GPRA Baseline section, the NEMS-GPRA07 version of the model used for the EERE GPRA analysis includes minor modifications to the standard EIA NEMS.

NEMS is designed as a modular system. Four end-use demand modules represent fuel consumption in the residential, commercial, transportation, and industrial sectors—subject to delivered fuel prices, macroeconomic influences, and technology characteristics. The primary fuel supply and conversion modules compute the levels of domestic production, imports, transportation costs, and fuel prices that are needed to meet domestic and export demands for energy—subject to resource base characteristics, industry infrastructure and technology, and world market conditions. The modules interact to solve for the economic supply and demand balance for each fuel. Because of the modular design, each sector can be represented with the methodology and the level of detail (including regional detail) that is appropriate for that sector.

A key feature of NEMS is the representation of technology and technology improvement over time. Five of the sectors—residential, commercial, transportation, electricity generation, and refining—include extensive treatment of individual technologies and their characteristics, such as the initial capital cost, operating cost, date of availability, efficiency, and other characteristics specific to the sector. Technological progress results in a gradual reduction in cost and is modeled as a function of time in these end-use sectors. In addition, the electricity sector accounts for technological optimism in the capital costs of first-of-a-kind generating technologies and for a decline in cost as experience with the technologies is gained both domestically and internationally. In each of these sectors, equipment choices are made for individual technologies as new equipment is needed to meet growing demand for energy services or to replace retired equipment. In the other sectors—industrial, oil and gas supply, and coal supply—the treatment of technologies is more limited, due to a lack of data on individual technologies. In the industrial sector, only the combined heat and power and motor technologies are explicitly considered and characterized. Cost reductions resulting from technological progress in combined heat and power technologies are represented as a function of time as experience with the technologies grows. Technological progress is not explicitly modeled for the industrial motor technologies. Other technologies in the energy-intensive industries are represented by technology bundles, with technology possibility curves representing efficiency improvement over time. In the oil and gas supply sector, technological progress is represented by econometrically estimated improvements in finding rates, success rates, and costs. Productivity improvements over time represent technological progress in coal production.



* Most of this description is taken from *The National Energy Modeling System: An Overview 2003*, DOE/EIA-0581(2003), March 2003. The document is available at http://tonto.eia.doe.gov/FTPROOT/forecasting/05812003.pdf .

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.

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[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

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[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**

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[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.

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[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.**

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[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**.

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[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

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[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

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[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.**

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[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

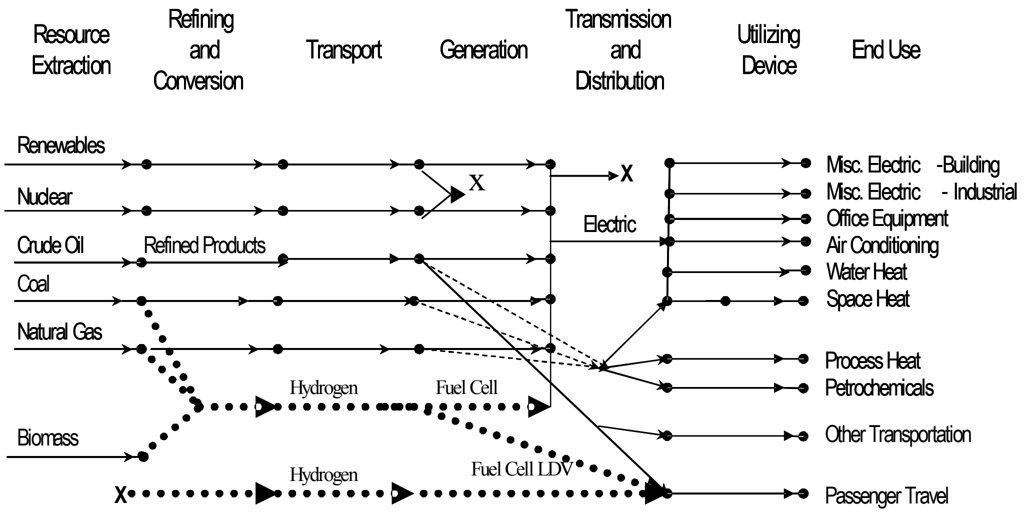
The U.S. MARKAL model is a technology-driven linear optimization model of the U.S. energy system that runs in five-year intervals over a 50-year projection period. MARKAL provides a framework to evaluate all resource and technology options within the context of the entire energy/materials system, and 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



Appendix A – GPRA07 Benefits Estimates: NEMS-GPRA07 and MARKAL-GPRA07 Baseline Cases

Overview

The Office of Energy Efficiency and Renewable Energy (EERE) programs use integrated energy models to analyze the benefits expected from successful implementation of individual programs and the EERE portfolio as a whole. The use of integrated models provides a consistent economic framework and incorporates the interactive effects among the various programs. Feedback and interactive effects result from (1) changes in energy prices resulting from lower energy consumption, (2) the interaction between supply programs affecting the mix of generation sources and the end-use sector programs affecting the demand for electricity, and (3) additional savings from reduced energy production and delivery.

A modified version of the National Energy Modeling System (NEMS)[1] was one of the models used for this benefits analysis. NEMS is an integrated energy model of the U.S. energy system that was developed by the Energy Information Administration (EIA) for forecasting and policy analysis purposes. NEMS provides projection capability to the year 2025[2] and so is used for the midterm benefits analysis. The latest version of NEMS available at the time of the benefits analysis was used as the starting point. This is a slightly updated version from *Annual Energy Outlook 2005* (AEO2005) that was setup by EIA at the request of the DOE R&D offices for use in GPRA scenarios[3]. Several modifications were subsequently made to the model by EERE to enhance its ability to represent the EERE programs. The modified version of the model is referred to as NEMS-GPRA07.

For projections beyond 2025, a modified version of the MARKAL (MARket Allocation) model was employed, referred to here as MARKAL-GPRA07. To the extent possible, the same input data and assumptions were used in MARKAL-GPRA07 as were used to generate the *AEO2005* Reference Case. MARKAL-GPRA07 was “benchmarked” to NEMS-GPRA07. While the models have some similarities, there are basic structural differences and parameter differences that will yield slightly different model results, even under the same reference conditions.

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[1] *The National Energy Modeling System: An Overview 2003,* March 2003, DOE/EIA-0581(2003).

[2] For the AEO2006, NEMS projects to the year 2030.

[3] The request for the slightly modified Base Case was made under an initiative to coordinate and integrate the GPRA analyses undertaken by the various offices within DOE’s Office of Energy, Science, and Environment. Formally, the request was transmitted to EIA through the Office of Fossil Energy and the National Energy Technology Laboratory’s NEMS modelers.

This appendix describes the changes made to the NEMS and MARKAL models' baselines to derive the NEMS-GPRA07 and MARKAL-GPRA07 baselines, the rationale for those changes, and the resulting energy and economic projections for each model's forecast horizon. While the first section of this appendix nominally pertains to NEMS, it is relevant to MARKAL as well, because MARKAL is benchmarked to NEMS—and because the fundamental baseline changes affect both models. The second section of the appendix pertains only to the MARKAL baseline. The MARKAL section focuses on the energy and economy assumptions and projections beyond 2025.

NEMS Baseline Case Assumptions and Projections

GPRA 2007 Baseline

The first step in the benefits analysis process is to establish an appropriate Baseline Case. The EERE Baseline Case is a projection intended to represent the future U.S. energy system without the effect of EERE Programs. This Baseline Case assures that program benefits are estimated, based on the same initial forecasts for economic growth, energy prices, and levels of energy demand. It also assures that these initial assumptions are consistent with each other; e.g., that the level of electricity demand expected under the economic growth assumptions could be met at the electricity price assumed. It provides a basis for assessing how well renewable and efficiency technologies might be able to compete against future, rather than current, conventional energy technologies (e.g., more efficient central power generation). Finally, it helps ensure that underlying improvements in efficiency and renewable energy are not counted as part of the benefits of the EERE programs.

The most recent Annual Energy Outlook Reference Case is used as the starting point for developing the base case.[4] The Energy Information Administration (EIA) *Annual Energy Outlook* (AEO) Reference Case provides an independent representation of the likely evolution of energy markets. This forecast reflects expected changes in the demand for energy (e.g., to reflect the availability of new appliances), technology improvements that might improve the efficiency of energy use, and changes in energy resource production costs, including renewable energy. Energy market policies that are current at the time of the AEO's publication are included in the Base Case.[5] This approach ensures that EERE's benefits estimates do not include expected impacts of such policies. Neither the EIA Reference Case nor the EERE Base Case includes any changes in future energy policies.

Removal of EERE programs. Several adjustments are made to remove EERE programs from the EIA Reference Case. For example, EIA's estimate of rooftop photovoltaic installations

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[4] As described above, the updated NEMS produces similar reference case projections as the *Annual Energy Outlook 2005* with Projections to 2025, January 2005, DOE/EIA-0383 (2005). See http://www.eia.doe.gov/oiaf/archive/aeo05/pdf/0383(2005).pdf. The Energy Information Administration's recently released Annual Energy Outlook 2006 indicates significantly higher oil and fuels prices for much of the forecast horizon than does the previous forecast (AEO 2005) on which this benefits analysis is based. All else equal, higher fuels prices would be expected to increase the market penetration of renewable energy and energy efficiency measures undertaken irrespective of DOE programs, as these technologies become more price competitive. As such, some of the nonrenewable energy savings, cost savings, and emissions reductions attributable to DOE programs might be reduced.

[5] At the publication date of *AEO 2005*, EPACT 2005 had not passed, nor had the extension of the production tax credit incentive for renewable energy generation.

resulting from the Million Solar Roofs Initiative was removed for the EERE Baseline. The improvement in distributed photovoltaic system costs was reduced. The most efficient shell improvement packages for new residential buildings were removed as well, although the impact was minimal, because they received very small market share in the AEO. Cellulosic ethanol production was assumed to not become available until after 2025 without EERE's R&D efforts.

Table A-1. Summary of Baseline Changes from the AEO2005

	AEO2005	**GPRA07 Baseline Case**
Removal of EERE Programs		
Solar America	0.3 GW installed 2007 to 2025	Removed
Photovoltaic system costs	Significant improvement	Slower rate of improvement
Residential high efficiency shell packages	Small penetration	Removed
Cellulosic ethanol production	Commercially available by 2015	Not commercially available by 2025
Greater Technology Improvement in Base		
Solid-State Lighting	Very small improvement	Much greater improvement
Onshore Wind Performance	33% to 44% capacity factors, depending on wind class and year	35% to 53% capacity factors, depending on wind class and year
Onshore Wind Capital Costs	1% reduction over 20 years	12% to 15% reduction (depending on wind class) over 20 years
Conventional Corn ethanol production	Yield of 2.65 gallons per bushel	Yield of 2.80 gallons per bushel
Corn ethanol production with starch	Not included	Available in 2011
Hybrid Electric Vehicles	Sales share at 6% by 2025	Sales share at 1% by 2025
Energy Market Updates		
PV system size	2 kW residential, 25 kW commercial	4 kW residential, 100 kW commercial
PV maximum market share	30% for both residential and commercial	60% for residential and 55% for commercial
California PV subsidy	Not included	Included for residential systems
Corn ethanol maximum production	5.7 billion gallons	10.0 billion gallons
Structural Changes		
Offshore wind	No offshore wind technology	Offshore wind
Commercial shell efficiency	Index	Technology representation
Commercial DG algorithms		Market share and stock accounting modified

Greater Technology Improvement in the Baseline

There are a few EERE technologies that are either not represented in the *AEO2005* or their improvement is less than anticipated by the program in the absence of EERE programs. These technology assumptions were also modified for the GPRA07 Baseline.

- In commercial lighting, solid-state lighting characteristics were assumed to improve more than the very minimal improvement in the AEO2005.
- Offshore wind technology characteristics were added, and the onshore wind characteristics were modified. The onshore capital costs were assumed to decline more rapidly over time. In addition the capacity factors for each wind class were assumed to

be higher than in the *AEO2005*, although lower than the program goals. Both of these changes for onshore wind raise the projected market penetration of wind in the Baseline and shrink the benefits attributed to the EERE R&D.

- The representation of hybrid electric vehicles was modified to lower their costs over time and to gradually increase the consumer preference for hybrids. Corn ethanol with residual starch conversion was added to the EERE base that is not in the AEO. This leads to increases in ethanol yields and decreases in unit costs over time. In addition the supply curves were extended to allow up to 10 billion gallons of corn ethanol production. As a result of these changes, the EERE base has more ethanol production that the AEO.

Energy Market Updates

A few other modifications were made to reflect EERE program assumptions or updated information about energy markets. These changes affect both the Baseline and the Benefits Cases. The size of typical PV systems was increased to 4 kW in residential and 100 kW in commercial buildings to reflect recent PV installation experience and trends. The maximum market for PV systems was increased from 30% to 55% in the commercial sector and to 60% for residential PVs. Similarly, the maximum market share for gas-fired distributed generation technologies was increased from 30% to 50% in the commercial sector. California PV credits were incorporated in the Pacific region.

Structural Changes

In a few cases, we made structural changes to improve the model's representation of markets important to EERE technologies.

- Offshore wind was added as another technology option with resources available in the coastal regions and the regions around the Great Lakes.
- The shell indices in the commercial module were replaced with a technology choice algorithm necessary for later representation of EERE shell technologies. In addition, alterations to the distributed generation algorithm in the building modules were made to reflect market adoption data gathered by Lawrence Berkeley National Laboratory, to account for buildings that have already installed a DG technology in prior years, and to allow greater than an annual 0.5% adoption in existing buildings.

A summary of these modifications is provided in **Table A-4**. Greater detail can be found in the individual program appendices.

GPRA07 Baseline

In the Baseline projections, oil prices are projected to fall and then gradually increase through 2025, as shown in **Figure A-1**. Natural gas prices follow a similar pattern. Coal prices, on the other hand, are projected to be relatively constant in real terms, with a very slight decline. Electricity prices are projected to experience a decrease through 2010 and then increase gradually.

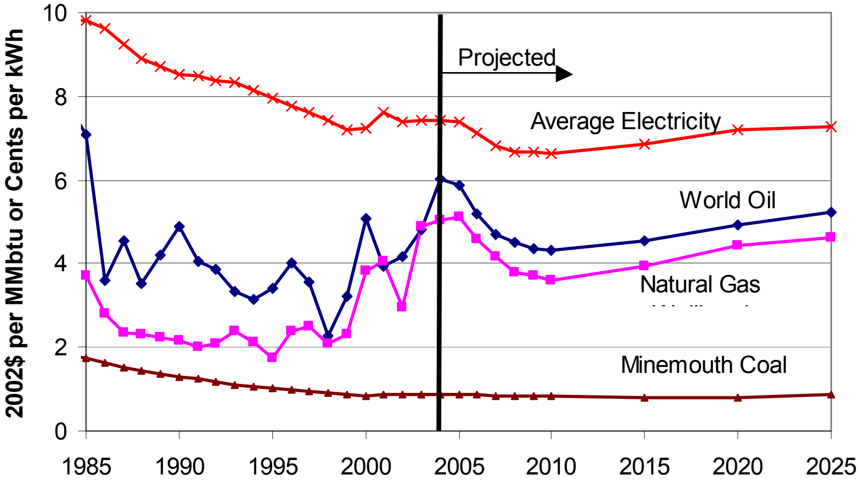

Figure A-1. Projected Energy Prices

The resulting Baseline Case projects a 30% increase in conventional energy demand from 2005 to 2025.[6] Energy efficiency and renewable energy improvements, however, contribute toward a 28% reduction in conventional energy intensity (energy used per dollar of GPD produced) over the same period (**Figure 2**).[7] Between 2005 and 2025, renewable energy technology improvements result in increases in renewable electric generation in central and distributed applications of roughly 180 billion kWh, which is an almost 50 % increase in nonhydroelectric generation.

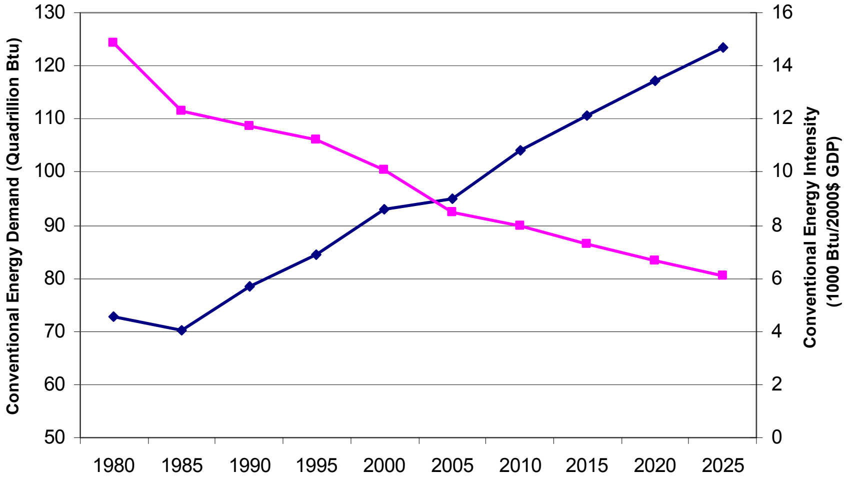

Figure A-2. U.S. Conventional Energy Demand and Energy Intensity

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[6] Very similar to the *AEO2005*.

[7] Energy intensity changes result from a mix of structural changes in the economy (e.g., growing service sector) and efficiency improvements. Two recent EERE-sponsored studies provide additional background on understanding the sources of changes to our energy intensity: Ortiz and Sollinger, *Shaping Our Future by Reducing Energy Intensity in the U.S. Economy; Volume 1: Proceedings of the Conference* (2003, Rand Corporation); and Bernstein, Fonkych, Loeb, and Loughran, "State-Level Changes in Energy Intensity and their National Implications" (2003, Rand Corporation).

NEMS-GPRA07 Baseline Tables A-1 Through A-6

Table A-1. Total Energy Supply and Disposition Summary
(Quadrillion Btu per Year, Unless Otherwise Noted)

	2010	2015	2020	2025
Production				
Crude Oil & Lease Condensate	12.74	11.63	10.99	10.00
Natural Gas Plant Liquids	2.65	2.66	2.78	2.79
Dry Natural Gas	20.90	21.23	22.36	22.29
Coal	25.12	25.54	26.86	29.48
Nuclear Power	8.46	8.59	8.64	8.64
Renewable Energy 1/	6.81	7.23	8.11	9.14
Other 2/	1.02	0.83	0.83	1.28
Total	77.72	77.70	80.56	83.61
Imports				
Crude Oil 3/	24.69	29.00	32.49	35.08
Petroleum Products 4/	6.01	6.23	6.61	7.53
Natural Gas	5.77	8.02	8.82	9.68
Other Imports 5/	0.92	1.07	1.15	1.23
Total	37.39	44.32	49.07	53.51
Exports				
Petroleum 6/	2.15	2.21	2.26	2.32
Natural Gas	0.65	0.81	0.86	0.83
Coal	1.06	0.88	0.89	0.67
Total	3.86	3.89	4.01	3.81
Discrepancy 7/	0.02	-0.11	-0.06	-0.10
Consumption				
Petroleum Products 8/	44.85	48.05	51.29	54.23
Natural Gas	26.10	28.61	30.50	31.33
Coal	24.98	25.68	27.10	30.04
Nuclear Power	8.46	8.59	8.64	8.64
Renewable Energy 1/	6.82	7.23	8.11	9.14
Other 9/	0.03	0.08	0.05	0.04
Total	111.23	118.24	125.68	133.42
Net Imports - Petroleum	28.55	33.02	36.84	40.28
Prices (2003 dollars per unit)				
World Oil Price ($ per bbl) 10/	25.00	26.75	28.50	30.31
Gas Wellhead Price ($ / Mcf) 11/	3.68	4.17	4.55	4.75
Coal Minemouth Price ($ / ton)	17.32	16.85	17.13	18.60
Electricity (cents / Kwh)	6.63	6.94	7.20	7.26

1/ Includes grid-connected electricity from conventional hydroelectric; wood and wood waste; landfill gas; municipal solid waste; other biomass; wind; photovoltaic and solar thermal sources; non-electric energy from renewable sources, such as active and passive solar systems, and wood; and both the ethanol and gasoline components of E85, but not the ethanol components of blends less than 85 percent. Excludes electricity imports using renewable sources and nonmarketed renewable energy.

2/ Includes liquid hydrogen, methanol, supplemental natural gas, and some domestic inputs to refineries.

3/ Includes imports of crude oil for the Strategic Petroleum Reserve.

4/ Includes imports of finished petroleum products, unfinished oils, alcohols, ethers, and blending components.

5/ Includes coal, coal coke (net), and electricity (net).

6/ Includes crude oil and petroleum products.

7/ Balancing item. Includes unaccounted for supply, losses, gains, net storage withdrawals, heat loss when natural gas is converted to liquid fuel, and heat loss when coal is converted to liquid fuel.

8/ Includes natural gas plant liquids, crude oil consumed as a fuel, and nonpetroleum-based liquids for blending, such as ethanol.

9/ Includes net electricity imports, methanol, and liquid hydrogen.

10/ Average refiner acquisition cost for imported crude oil.

11/ Represents lower 48 onshore and offshore supplies.

Table A-2. Energy Consumption by Sector and Source
(Quadrillion Btu per Year, Unless Otherwise Noted)

	2010	2015	2020	2025
Energy Consumption				
Residential				
Distillate Fuel	0.89	0.87	0.82	0.77
Kerosene	0.09	0.09	0.09	0.09
Liquefied Petroleum Gas	0.57	0.61	0.64	0.67
Petroleum Subtotal	1.56	1.57	1.56	1.52
Natural Gas	5.68	5.90	6.05	6.16
Coal	0.01	0.01	0.01	0.01
Renewable Energy 1/	0.40	0.39	0.39	0.38
Electricity	5.02	5.40	5.79	6.18
Delivered Energy	12.66	13.28	13.79	14.25
Electricity Related Losses	10.79	11.29	11.83	12.46
Total	23.45	24.57	25.62	26.71
Commercial				
Distillate Fuel	0.61	0.65	0.70	0.75
Residual Fuel	0.07	0.07	0.08	0.08
Kerosene	0.03	0.03	0.03	0.03
Liquefied Petroleum Gas	0.10	0.10	0.11	0.11
Motor Gasoline 2/	0.04	0.04	0.04	0.04
Petroleum Subtotal	0.85	0.90	0.95	1.00
Natural Gas	3.47	3.69	3.96	4.27
Coal	0.10	0.10	0.10	0.10
Renewable Energy 3/	0.09	0.09	0.09	0.09
Electricity	4.99	5.62	6.29	7.07
Delivered Energy	9.50	10.39	11.38	12.52
Electricity Related Losses	10.74	11.74	12.87	14.25
Total	20.23	22.13	24.25	26.77
Industrial 4/				
Distillate Fuel	1.04	1.08	1.14	1.19
Liquefied Petroleum Gas	2.30	2.44	2.59	2.73
Petrochemical Feedstocks	1.48	1.52	1.55	1.56
Residual Fuel	0.34	0.38	0.38	0.37
Motor Gasoline 2/	0.31	0.33	0.35	0.37
Other Petroleum 5/	4.68	4.69	5.01	5.20
Petroleum Subtotal	10.16	10.44	11.02	11.43
Natural Gas	8.12	8.50	8.91	9.43
Lease and Plant Fuel 6/	1.20	1.22	1.32	1.30
Natural Gas Subtotal	9.32	9.73	10.22	10.73
Metallurgical Coal	0.55	0.48	0.42	0.37
Steam Coal	1.42	1.42	1.42	1.42
Net Coal Coke Imports	0.06	0.05	0.05	0.05
Coal Subtotal	2.03	1.95	1.89	1.83
Renewable Energy 7/	2.07	2.19	2.34	2.49
Electricity	3.78	3.98	4.19	4.40
Delivered Energy	27.36	28.28	29.67	30.89
Electricity Related Losses	8.13	8.31	8.58	8.87
Total	35.49	36.59	38.24	39.75

1/ Includes wood used for residential heating.

2/ Includes ethanol (blends of 10 percent or less) and ethers blended into gasoline.

3/ Includes commercial sector consumption of wood and wood waste, landfill gas, municipal solid waste, and other biomass for combined heat and power.

4/ Includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.

5/ Includes petroleum coke, asphalt, road oil, lubricants, still gas, and miscellaneous petroleum products.

6/ Represents natural gas used in the field gathering and processing plant machinery.

7/ Includes consumption of energy from hydroelectric, wood and wood waste, municipal solid waste, and other biomass.

Table A-2. Energy Consumption by Sector and Source (Continued)

	2010	2015	2020	2025
Transportation				
Distillate Fuel 8/	6.95	7.66	8.33	9.02
Jet Fuel 9/	4.04	4.45	4.74	4.89
Motor Gasoline 2/	19.16	20.81	22.28	23.98
Residual Fuel	0.56	0.57	0.58	0.58
Liquefied Petroleum Gas	0.06	0.07	0.08	0.09
Other Petroleum 10/	0.26	0.27	0.29	0.31
Petroleum Subtotal	31.02	33.83	36.30	38.87
Pipeline Fuel Natural Gas	0.70	0.73	0.82	0.84
Compressed Natural Gas	0.06	0.08	0.10	0.12
Renewable Energy (E85) 11/	0.00	0.00	0.00	0.00
Liquid Hydrogen	0.00	0.00	0.00	0.00
Electricity	0.09	0.10	0.11	0.12
Delivered Energy	31.87	34.74	37.34	39.95
Electricity Related Losses	0.19	0.21	0.22	0.24
Total	32.06	34.95	37.56	40.19
Electric Power 14/				
Distillate Fuel	0.40	0.40	0.48	0.45
Residual Fuel	0.86	0.92	0.98	0.96
Petroleum Subtotal	1.26	1.32	1.46	1.41
Natural Gas	6.87	8.47	9.35	9.22
Steam Coal	22.84	23.63	25.10	28.11
Nuclear Power	8.46	8.59	8.64	8.64
Renewable Energy/Other 15/	4.26	4.56	5.29	6.17
Electricity Imports	0.03	0.08	0.05	0.04
Total	43.72	46.64	49.88	53.58
Total Energy Consumption				
Distillate Fuel	9.89	10.66	11.47	12.18
Kerosene	0.14	0.14	0.14	0.13
Jet Fuel 9/	4.04	4.45	4.74	4.89
Liquefied Petroleum Gas	3.04	3.22	3.42	3.60
Motor Gasoline 2/	19.51	21.18	22.67	24.39
Petrochemical Feedstocks	1.48	1.52	1.55	1.56
Residual Fuel	1.84	1.94	2.01	1.99
Other Petroleum 12/	4.92	4.94	5.29	5.49
Petroleum Subtotal	44.85	48.05	51.29	54.23
Natural Gas	24.20	26.65	28.36	29.20
Lease and Plant Fuel 6/	1.20	1.22	1.32	1.30
Pipeline Natural Gas	0.70	0.73	0.82	0.84
Natural Gas Subtotal	26.10	28.61	30.50	31.33
Metallurgical Coal	0.55	0.48	0.42	0.37
Steam Coal	24.37	25.15	26.62	29.63
Net Coal Coke Imports	0.06	0.05	0.05	0.05
Coal Subtotal	24.98	25.68	27.10	30.04
Nuclear Power	8.46	8.59	8.64	8.64
Renewable Energy 16/	6.82	7.23	8.11	9.14
Liquid Hydrogen	0.00	0.00	0.00	0.00
Electricity Imports	0.03	0.08	0.05	0.04
Total	111.23	118.24	125.68	133.42

2/ Includes ethanol (blends of 10 percent or less) and ethers blended into gasoline.

6/ Represents natural gas used in the field gathering and processing plant machinery.

8/ Diesel fuel containing 500 parts per million (ppm) or 15 ppm sulfur.

9/ Includes only kerosene type.

10/ Includes aviation gasoline and lubricants.

11/ E85 refers to a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable). To address cold starting issues, the percentage of ethanol actually varies seasonally. The annual average ethanol content of 74 percent is used for this forecast.

12/ Includes unfinished oils, natural gasoline, motor gasoline blending components, aviation gasoline, lubricants, still gas, asphalt, road oil, petroleum coke, and miscellaneous petroleum products.

13/ Includes electricity generated for sale to the grid and for own use from renewable sources, and non-electric energy from renewable sources. Excludes nonmarketed renewable energy consumption for geothermal heat pumps, buildings photovoltaic systems, and solar thermal hot water heaters.

14/ Includes consumption of energy by electricity-only and combined heat and power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public. Includes small power producers and exempt wholesale generators.

15/ Includes conventional hydroelectric, geothermal, wood and wood waste, municipal solid waste, other biomass, petroleum coke, wind, photovoltaic and solar thermal sources. Excludes net electricity imports.

16/ Includes hydroelectric, geothermal, wood and wood waste, municipal solid waste, other biomass, wind, photovoltaic and solar thermal sources. Includes ethanol components of E85; excludes ethanol blends (10 percent or less) in motor gasoline. Excludes net electricity imports and nonmarketed renewable energy consumption for geothermal

Table A-3. Energy Prices by Sector and Source
(2003 Dollars per Million Btu, Unless Otherwise Noted)

	2010	2015	2020	2025
Residential	14.38	15.00	15.66	16.09
Primary Energy 1/	8.38	8.75	9.20	9.60
Petroleum Products 2/	10.41	10.76	11.34	11.94
Distillate Fuel	8.24	8.48	8.84	9.12
Liquefied Petroleum Gas	14.23	14.44	14.98	15.62
Natural Gas	7.84	8.23	8.66	9.04
Electricity	23.03	23.66	24.16	24.16
Commercial	13.83	14.85	15.63	16.00
Primary Energy 1/	6.84	7.21	7.54	7.79
Petroleum Products 2/	7.11	7.28	7.56	7.84
Distillate Fuel	6.26	6.48	6.77	7.06
Residual Fuel	4.26	4.52	4.80	5.08
Natural Gas	6.91	7.34	7.68	7.92
Electricity	20.01	21.22	22.06	22.23
Industrial 3/	6.87	7.25	7.74	8.08
Primary Energy	5.55	5.83	6.24	6.60
Petroleum Products 2/	7.23	7.42	7.81	8.34
Distillate Fuel	6.75	7.18	7.40	7.73
Liquefied Petroleum Gas	9.99	10.23	10.64	11.33
Residual Fuel	3.87	4.10	4.33	4.62
Natural Gas 4/	4.41	4.83	5.25	5.43
Metallurgical Coal	1.82	1.76	1.75	1.68
Steam Coal	1.56	1.55	1.56	1.62
Electricity	13.91	14.65	15.52	15.67
Transportation	10.90	10.94	11.15	11.44
Primary Energy	10.88	10.92	11.12	11.41
Petroleum Products 2/	10.88	10.92	11.13	11.41
Distillate Fuel 5/	10.71	10.69	10.70	10.84
Jet Fuel 6/	6.23	6.29	6.56	6.93
Motor Gasoline 7/	12.25	12.26	12.50	12.78
Residual Fuel	3.74	4.01	4.28	4.56
Liquefied Petroleum Gas 8/	15.23	15.28	15.59	16.19
Natural Gas 9/	8.59	9.11	9.44	9.66
Ethanol (E85) 10/	16.86	16.90	17.14	16.88
Electricity	18.92	19.66	20.04	19.92

1/ Weighted average price includes fuels below as well as coal.

2/ This quantity is the weighted average for all petroleum products, not just those listed below.

3/ Includes energy for combined heat and power plants, except those whose primary business is to sell electricity, or electricity and heat, to the public.

4/ Excludes use for lease and plant fuel.

5/ Diesel fuel containing 500 parts per million (ppm) or 15 ppm sulfur. Price includes Federal and State taxes while excluding county and local taxes.

6/ Kerosene-type jet fuel. Price includes Federal and State taxes while excluding county and local taxes.

7/ Sales weighted-average price for all grades. Includes Federal, State, and local taxes.

8/ Includes Federal and State taxes while excluding county and local taxes.

9/ Compressed natural gas used as a vehicle fuel. Price includes estimated motor vehicle fuel taxes.

10/ E85 refers to a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable). To address cold starting issues, the percentage of ethanol actually varies seasonally. The annual average ethanol content of 74 percent is used for this forecast.

Table A-3. Energy Prices by Sector and Source (Continued)

	2010	2015	2020	2025
Average End-Use Energy	10.55	10.95	11.41	11.77
Primary Energy	8.59	8.83	9.16	9.51
Electricity	19.44	20.35	21.12	21.26
Electric Power 11/				
Fossil Fuel Average	2.07	2.28	2.43	2.43
Petroleum Products	4.55	4.77	5.12	5.43
Distillate Fuel	5.34	5.52	5.96	6.34
Residual Fuel	4.19	4.44	4.71	5.00
Natural Gas	4.32	4.81	5.20	5.38
Steam Coal	1.25	1.23	1.24	1.32
Average Price to All Users 12/				
Petroleum Products 2/	9.87	10.00	10.27	10.64
Distillate Fuel	9.49	9.70	9.80	10.03
Jet Fuel	6.23	6.29	6.56	6.93
Liquefied Petroleum Gas	10.97	11.21	11.65	12.32
Motor Gasoline 7/	12.24	12.25	12.49	12.77
Residual Fuel	3.99	4.25	4.52	4.80
Natural Gas	5.56	5.94	6.32	6.56
Coal	1.27	1.25	1.26	1.33
Ethanol (E85) 10/	16.86	16.90	17.14	16.88
Electricity	19.44	20.35	21.12	21.26
Non-Renewable Energy Expenditures by Sector (billion 2003 dollars)				
Residential	176.3	193.3	209.8	223.2
Commercial	130.1	153.0	176.6	199.0
Industrial	140.1	152.6	169.9	185.1
Transportation	339.7	372.2	407.2	447.2
Total Non-Renewable Expenditures	786.2	871.1	963.5	1054.4
Transportation Renewable Expenditures	0.0	0.0	0.1	0.1
Total Expenditures	786.3	871.2	963.5	1054.5

2/ This quantity is the weighted average for all petroleum products, not just those listed below.

7/ Sales weighted-average price for all grades. Includes Federal, State, and local taxes.

10/ E85 refers to a blend of 85 percent ethanol (renewable) and 15 percent motor gasoline (nonrenewable). To address cold starting issues, the percentage of ethanol actually varies seasonally. The annual average ethanol content of 74 percent is used for this forecast.

11/ Includes electricity-only and combined heat and power plants whose primary business is to sell electricity, or electricity and heat, to the public.

12/ Weighted averages of end-use fuel prices are derived from the prices shown in each sector and the corresponding sectoral consumption.

Table A-4. Electricity Supply, Disposition, Prices, and Emissions
(Billion Kilowatthours, Unless Otherwise Noted)

	2010	2015	2020	2025
Generation by Fuel Type				
Electric Power Sector 1/				
Power Only 2/				
Coal	2171	2248	2418	2786
Petroleum	111	117	128	123
Natural Gas 3/	635	844	1000	1000
Nuclear Power	810	823	827	827
Pumped Storage/Other	-9	-9	-9	-9
Renewable Sources 4/	386	408	462	527
Distributed Generation (Natural Gas)	0	0	1	3
Total	4106	4432	4828	5258
Combined Heat and Power 5/				
Coal	33	33	33	33
Petroleum	6	7	8	7
Natural Gas	187	201	193	183
Renewable Sources	4	4	4	4
Total	230	245	238	227
Total Net Generation	4336	4676	5067	5486
Less Direct Use	66	65	65	65
Net Available to the Grid	4270	4611	5001	5420
Commercial and Industrial Generation 6/				
Coal	21	21	21	21
Petroleum	9	10	12	12
Natural Gas	101	121	150	186
Other Gaseous Fuels 7/	4	5	5	5
Renewable Sources 4/	43	45	49	54
Other 8/	10	10	10	10
Total	188	212	247	288
Less Direct Use	140	153	173	198
Total Sales to the Grid	48	59	74	90
Total Electricity Generation	4523	4888	5314	5774
Total Net Generation to the Grid	4318	4670	5076	5511

1/ Includes electricity-only and combined heat and power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public.

2/ Includes plants that only produce electricity.

3/ Includes electricity generation from fuel cells.

4/ Includes conventional hydroelectric, geothermal, wood, wood waste, municipal solid waste, landfill gas, other biomass, solar, and wind power.

5/ Includes combined heat and power plants whose primary business is to sell electricity and heat to the public (i.e., those that report NAICS code 22).

6/ Includes combined heat and power plants and electricity-only plants in the commercial and industrial sectors; and small on-site generating systems in the residential, commercial, and industrial sectors used primarily for own-use generation, but which may also sell some power to the grid.

7/ Other gaseous fuels include refinery and still gas.

8/ Other includes batteries, chemicals, hydrogen, pitch, purchased steam, sulfur, and miscellaneous technologies.

Table A-4. Electricity Supply, Disposition, Prices, and Emissions (Continued)

	2010	2015	2020	2025
Net Imports	10	22	16	11
Electricity Sales by Sector				
Residential	1470	1584	1696	1812
Commercial	1463	1646	1845	2072
Industrial	1107	1166	1229	1290
Transportation	26	29	32	35
Total	4067	4424	4801	5208
Direct Use	205	218	238	264
Total Consumption	4273	4643	5039	5472
End-Use Prices 9/ (2003 cents per kilowatthour)				
Residential	7.9	8.1	8.2	8.2
Commercial	6.8	7.2	7.5	7.6
Industrial	4.7	5.0	5.3	5.3
Transportation	6.5	6.7	6.8	6.8
All Sectors Average	6.6	6.9	7.2	7.3
Prices by Service Category 9/ (2003 cents per kilowatthour)				
Generation	4.1	4.5	4.7	4.8
Transmission	0.6	0.6	0.7	0.7
Distribution	2.0	1.9	1.8	1.8
Electric Power Sector Emissions 1/				
Sulfur Dioxide (million tons)	9.3	9.0	9.0	8.9
Nitrogen Oxide (million tons)	4.0	4.1	4.2	4.3
Mercury (tons)	54.4	55.2	55.7	55.5

1/ Includes electricity-only and combined heat and power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public.

9/ Prices represent average revenue per kilowatthour.

Table A-5. Electricity Generating Capacity
(Gigawatts)

	2010	2015	2020	2025
Electric Power Sector 2/				
Power Only 3/				
Coal Steam	305.1	310.3	331.6	383.1
Other Fossil Steam 4/	119.4	98.8	97.8	97.2
Combined Cycle	136.2	146.9	172.6	185.5
Combustion Turbine/Diesel	132.5	141.4	164.7	183.8
Nuclear Power 5/	100.6	102.2	102.7	102.7
Pumped Storage	20.9	20.9	20.9	20.9
Fuel Cells	0.0	0.0	0.0	0.0
Renewable Sources 6/	95.0	100.0	113.1	128.1
Distributed Generation (Natural Gas) 7/	0.4	1.0	2.7	6.2
Total	910.0	921.6	1006.0	1107.5
Combined Heat and Power 8/				
Coal Steam	5.1	5.0	5.0	5.0
Other Fossil Steam 4/	1.1	1.1	1.1	1.1
Combined Cycle	33.5	33.5	33.5	33.5
Combustion Turbine/Diesel	5.1	5.1	5.1	5.1
Renewable Sources 6/	0.3	0.3	0.3	0.3
Total	45.1	45.0	45.0	45.0
Cumulative Planned Additions 9/				
Coal Steam	1.8	1.8	1.8	1.8
Other Fossil Steam 4/	0.0	0.0	0.0	0.0
Combined Cycle	28.3	28.3	28.3	28.3
Combustion Turbine/Diesel	3.9	3.9	3.9	3.9
Nuclear Power	0.0	0.0	0.0	0.0
Pumped Storage	0.0	0.0	0.0	0.0
Fuel Cells	0.0	0.0	0.0	0.0
Renewable Sources 6/	2.7	2.8	2.9	3.0
Distributed Generation 7/	0.0	0.0	0.0	0.0
Total	36.7	36.8	36.9	37.0
Cumulative Unplanned Additions 9/				
Coal Steam	0.0	5.8	27.0	78.5
Other Fossil Steam 4/	0.0	0.0	0.0	0.0
Combined Cycle	3.3	14.6	40.3	53.2
Combustion Turbine/Diesel	5.8	19.1	44.7	65.2
Nuclear Power	0.0	0.0	0.0	0.0
Pumped Storage	0.0	0.0	0.0	0.0
Fuel Cells	0.0	0.0	0.0	0.0
Renewable Sources 6/	0.1	5.0	18.0	33.0
Distributed Generation 7/	0.4	1.0	2.7	6.2
Total	9.7	45.6	132.7	236.1
Cumulative Electric Power Sector Additions	46.3	82.3	169.6	273.0
Cumulative Retirements 10/				
Coal Steam	1.9	2.5	2.5	2.5
Other Fossil Steam 4/	9.3	29.8	30.8	31.4
Combined Cycle	0.1	0.7	0.7	0.7
Combustion Turbine/Diesel	1.9	6.3	8.6	9.9
Nuclear Power	0.0	0.0	0.0	0.0
Pumped Storage	0.0	0.0	0.0	0.0
Fuel Cells	0.0	0.0	0.0	0.0
Renewable Sources 6/	0.1	0.1	0.1	0.1
Total	13.3	39.4	42.7	44.6
Total Electric Power Sector Capacity	955.1	966.6	1051.0	1152.5

Table 5. Electricity Generating Capacity (Continued)

	2010	2015	2020	2025
Commercial and Industrial Generators 11/				
Coal	4.1	4.1	4.1	4.1
Petroleum	1.5	1.5	1.6	1.7
Natural Gas	17.5	20.2	24.1	29.0
Other Gaseous Fuels	1.5	1.6	1.6	1.7
Renewable Sources 6/	7.0	7.4	8.0	9.4
Other	0.7	0.7	0.7	0.7
Total	32.3	35.5	40.3	46.6
Cumulative Capacity Additions 9/	5.1	8.3	13.0	19.3

1/ Net summer capacity is the steady hourly output that generating equipment is expected to supply to

Table 6. Renewable Energy Generating Capacity and Generation
(Gigawatts, Unless Otherwise Noted)

	2010	2015	2020	2025
Electric Power Sector 1/				
Net Summer Capacity				
Conventional Hydropower	0.8	0.9	0.8	0.6
Geothermal 2/	5.2	4.6	4.4	4.1
Municipal Solid Waste 3/	11.3	13.3	14.9	16.1
Wood and Other Biomass 4/	11.3	13.3	14.9	16.1
Solar Thermal	0.0	0.0	0.0	0.0
Solar Photovoltaic 5/	0.0	0.0	0.0	0.0
Wind	17.3	18.8	20.1	20.8
Total	0.0	0.0	0.0	0.0
Generation (billion kilowatthours)				
Conventional Hydropower	2.0	1.8	1.8	2.1
Geothermal 2/	0.6	0.8	0.9	1.0
Municipal Solid Waste 3/	0.5	0.5	0.6	0.6
Wood and Other Biomass 4/	1.0	1.0	1.1	1.1
Dedicated Plants	1.1	1.4	1.5	1.6
Cofiring	0.6	0.5	0.5	0.9
Solar Thermal	0.0	0.0	0.0	0.0
Solar Photovoltaic	0.0	0.0	0.0	0.0
Wind	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	0.0
End Use Sector				
Net Summer Capacity				
Combined Heat and Power				
Municipal Solid Waste	4.7	5.1	5.5	5.8
Biomass	0.8	0.8	0.9	0.9
Total	5.3	5.4	5.7	6.0
Other End-Use Generators 6/				
Conventional Hydropower 7/	23.0	24.7	26.3	27.8
Geothermal	0.0	0.0	0.0	0.0
Solar Photovoltaic 5/	0.0	0.0	0.0	0.0
Total	0.0	0.0	0.0	0.0
Generation (billion kwh)				
Combined Heat and Power				
Municipal Solid Waste	0.6	0.6	0.7	0.6
Biomass	23.0	24.7	26.3	27.8
Total	0.0	0.0	0.0	0.0
Other End-Use Generators 6/	0.0	0.0	0.0	0.0
Conventional Hydropower 7/	0.0	0.0	0.0	0.0
Geothermal	25.0	26.8	28.5	30.3
Solar Photovoltaic	0.6	0.6	0.6	0.7
Total	0.0	0.0	0.0	0.0

1/ Includes electricity-only and combined heat and power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public.

2/ Includes hydrothermal resources only (hot water and steam).

3/ Includes landfill gas.

4/ Includes projections for energy crops after 2010.

5/ Does not include off-grid photovoltaics (PV). EIA estimates that another 76 megawatts of remote electricity generation PV applications were in service in 1999, plus an additional 205 megawatts in communications, transportation, and assorted other non-grid-connected applications.

6/ Includes small on-site generating systems in the residential, commercial, and industrial sectors used primarily for own-use generation, but which may also sell some power to the grid.

7/ Represents own-use industrial hydroelectric power.

MARKAL Baseline Case Assumptions and Projections

Economic and Demographic Assumptions

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.[8] 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 low-cost assumptions.[9]

In the reference case, GDP is projected to increase at an average annual rate of 3% from 2005 to 2025, and then slow to an average annual rate of 2.2% from 2025 to 2050. The population growth rate is projected to decline from an average annual rate of 0.8% between 2005 and 2025 to 0.5% from 2025 to 2050. The reference case macroeconomic assumptions are shown in **Table A-7.**

Table A-7. Reference Case Macroeconomic and Demographic Assumptions

											Annual Growth Rates		
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'05-'25	25-'50	'05-'50
GDP (Bill. 2001$)	$11,490	$13,398	$15,581	$18,057	$20,779	$23,625	$26,534	$29,584	$32,651	$35,961	3.0%	2.2%	2.6%
Population (Million)	296.8	310.1	323.5	337.0	350.6	362.6	373.3	381.8	387.7	393.1	0.8%	0.5%	0.6%
Total Households (Million)	115.0	122.0	129.1	135.8	142.5	145.0	149.3	152.7	155.1	157.2	1.1%	0.4%	0.7%
Commercial Floorspace (Bill. sq ft)	74.7	81.2	88.4	96.2	104.8	112.9	120.8	128.7	136.3	144.1	1.7%	1.3%	1.5%
Industrial Production (2000=100)	96	108	120	133	148	167	185	205	225	245	2.2%	2.0%	2.1%
Light Duty Vehicle Miles Traveled (Bill. VMT)	2,667	3,017	3,354	3,680	4,053	4,377	4,680	4,929	5,106	5,272	2.1%	1.1%	1.5%

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[8] The Energy Information Administration's recently released *Annual Energy Outlook 2006* (Early Release) indicates significantly higher oil and fuels prices for much of the forecast horizon than does the previous forecast (*AEO 2005*), on which this benefits analysis is based. *All else equal*, higher fuels prices would be expected to increase the market penetration of renewable energy and energy efficiency measures undertaken irrespective of DOE programs, as these technologies become more price competitive. As such, some of the nonrenewable energy savings, cost savings, and emissions reductions attributable to DOE programs might be reduced.

[9] *The Long-Term Budget Outlook,* Congressional Budget Office, December 2003.
The 2005 Annual Report of the Board of Trustees of the Federal Old Age and Survivors Insurance and the Federal Disability Insurance Trust Funds, March 2005.

Assumptions on Energy Prices

Table A-8 shows projected energy prices for the reference case. Real natural gas prices are projected to drop between 2005 and 2010, and then increase at nearly 1.7% per year from 2010 to 2025 before increasing amounts of arctic gas and LNG imports limit the average annual increase to 0.8% from 2025 to 2050. Real crude oil prices are also projected to decrease between 2000 and 2005, increase at average annual rates of 1.3% between 2010 and 2025, and 1% per year thereafter.

Average real mine mouth coal prices are projected to continue to decline by about 1% a year between 2005 and 2015, due to increasing productivity gains and a continued shift to less labor intensive Western coal production. However, coal prices are projected to increase at an average rate of 1% per year after 2015, due to increased demands, gradually increasing mine depths, and a saturation of labor productivity gains.

Table A-8. Reference Case Energy Prices

											Annual Growth Rates		
2003 $s	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'05-'25	25-'50	'05-'50
World Oil Price ($/bbl)	$33.65	$24.73	$26.42	$28.11	$29.94	$31.89	$33.91	$34.75	$36.51	$38.40	-0.6%	1.0%	0.3%
Natural Gas Wellhead Price ($/Mcf)	$5.10	$3.63	$4.31	$4.52	$4.66	$4.41	$4.63	$4.87	$5.12	$5.68	-0.4%	0.8%	0.2%
Coal Minemouth Price ($/short ton)	$18.49	$17.17	$16.72	$17.22	$18.17	$19.45	$20.95	$22.57	$23.49	$24.00	-0.1%	1.1%	0.6%

Primary Energy Consumption

As a result of slightly increasing energy prices relative to technology improvements and shifts within the economy, energy demand is projected to increase more slowly than GDP. As shown in **Table A-9**, total primary energy use is projected to increase at a rate of 1.3% per year from 2005 to 2025, and at an average annual rate of 0.5% between 2025 and 2050. By 2050, total primary energy consumption is projected to reach just under 150 quadrillion Btus (quads). Overall, the energy consumption to GDP ratio is projected to decline by 1.7% per year from 2005 to 2050, while total carbon emissions increase by 1.1% per year over the same period.

Table A-9. Primary Energy Consumption, Energy Intensity, and Carbon Emissions

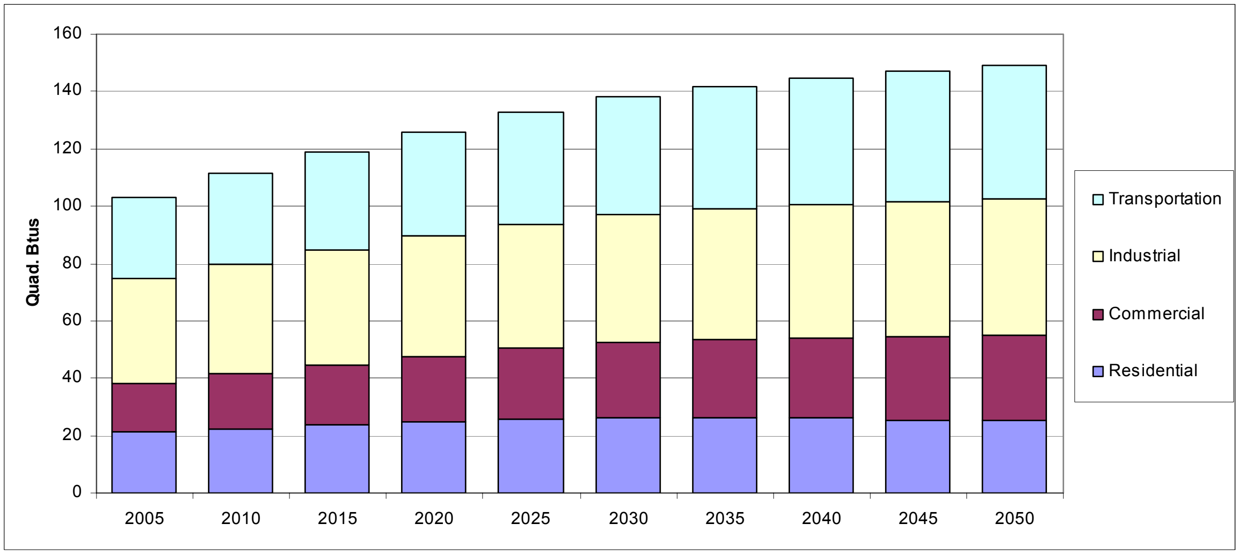
											Annual Growth Rates		
	2005	2010	2015	2020	2025	2030	2035	2040	2045	2050	'05-'25	25-'50	'05-'50
Petroleum	40.6	44.5	47.2	49.5	52.1	54.0	55.4	56.9	58.5	60.7	1.3%	0.6%	0.9%
Natural Gas	23.4	27.4	29.1	31.1	32.7	33.0	33.7	35.3	36.7	37.7	1.7%	0.6%	1.1%
Coal	24.0	23.9	26.1	28.1	30.2	33.0	35.3	35.5	35.9	35.1	1.2%	0.6%	0.8%
Nuclear	8.4	8.4	8.6	8.6	8.6	8.6	6.6	6.0	4.2	2.7	0.1%	-4.5%	-2.5%
Renewables	7.2	7.7	8.3	9.1	9.8	10.2	11.2	11.6	12.4	13.4	1.5%	1.3%	1.4%
Total Primary Energy	**103.6**	**111.8**	**119.3**	**126.4**	**133.5**	**138.8**	**142.3**	**145.3**	**147.7**	**149.7**	**1.3%**	**0.5%**	**0.8%**
Energy/GDP (Thos. Btu/ '01$ GDP)	9.0	8.3	7.7	7.0	6.4	5.9	5.4	4.9	4.5	4.2	-1.7%	-1.7%	-1.7%
Carbon Emissions (MMT)	1,657	1,835	1,983	2,130	2,274	2,347	2,454	2,549	2,634	2,714	1.6%	0.7%	1.1%

Crude oil's share of total energy consumption is projected to increase from 39% in 2005 to nearly 41% in 2050. The natural gas share is projected to grow from 23% to 25% over the same period. Coal generation is projected to increase slightly from a 23% share in 2005 to nearly 24% in 2050. Almost all existing nuclear generation capacity is assumed to retire between 2025 and

2050.[10] However, 29 GW of new nuclear capacity is projected to be added between 2025 and 2050. The share of renewable energy is also projected to increase from 7% and 9% throughout the projection period.

End-Use Energy Demand

The sectoral breakout of energy use, shown in **Figure A-3**, demonstrates that commercial buildings and transportation energy demand is projected to increase most rapidly, at 1.2% and 1.1% per year respectively, from 2005 to 2050; while residential and industrial energy demand increases most slowly, at 0.4% and 0.6% per year, respectively. The growth rates in energy consumption are a function of the opposing trends of increasing end-use energy-service demand and improvements in the efficiency of technologies that satisfy this demand, as well as macroeconomic shifts toward less energy-intensive industries. This phenomenon is best illustrated by examining the energy intensity of the economy. **Figure A-4** shows the relative energy intensity for different end-use and conversion sectors and the economy as a whole.



Note: consumption totals include electric generation and distribution losses

Figure A-3. Energy Consumption by Sector

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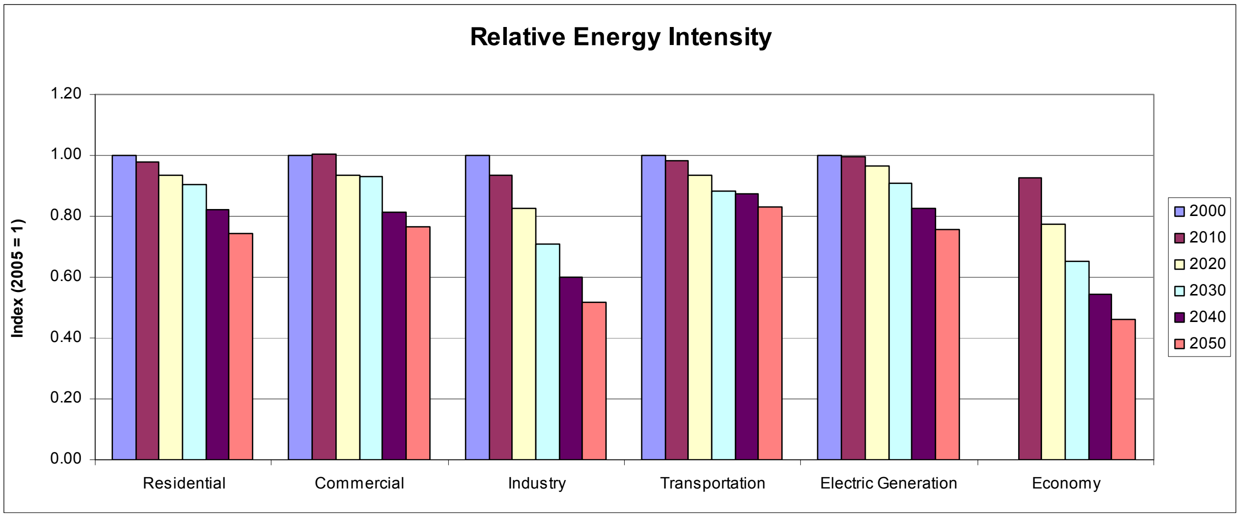
[10] The nuclear generation retirement schedule was derived by examining reactor-license expiration dates and applying one 20-year extension where applicable.



Note: Residential index is primary energy excluding misc. use per household; Commercial index is primary energy use excluding office equipment and misc. appliances per square foot; Industrial index is total primary energy per unit output; Transportation index is light duty vehicle primary energy per mile traveled; Electricity index is non-renewable average heat rate; and Economy index is total primary energy per unit GDP.

Figure A-4. Relative Energy Intensity by Sector

As shown in **Figure A-4**, our Reference Case projection indicates that the energy intensity of the economy (which we've defined as total primary energy consumption per $ of GDP) is projected to fall by more than half by 2050. This decrease reflects both a continued shift toward a service-based economy, as well as increases in energy technology efficiency. End-use efficiencies are projected to increase throughout the economy over the projection period as new, more efficient capital stocks are purchased to replace existing equipment and to meet new demand. The Reference Case technology database includes technologies that are expected to become available in the future, as well as those that are currently on the market. For example, more efficient electric heat pumps and light-duty vehicles are assumed to become available throughout the projection period. The technical and economic data associated with these technologies are derived from a variety of sources, but rely most heavily on the NEMS database.

The residential energy intensity index shows significant improvements in energy use per household. However, the residential index excludes "miscellaneous demands," the fastest growing segment of residential energy demand. The miscellaneous demand category includes electric devices such as home computers, TVs, microwave ovens, as well as devices such as gas lamps and swimming pool heaters. Because these service demands are growing faster than the sector as a whole, their energy use per household actually increases over time. Thus, the inclusion of miscellaneous demands in the calculation of residential energy intensity would obscure the efficiency gains being made in other residential service demands. While these miscellaneous demands are excluded from the chart, they are modeled within MARKAL.

The commercial energy intensity index shows significant improvements in energy use per square foot. However, as with the residential sector, this calculation excludes the fastest-growing demand categories; office equipment and miscellaneous commercial appliances. The inclusion of these demand categories would result in relatively constant commercial energy demand per square foot.

The industrial-sector efficiency index shows dramatic declines in energy intensity, due to a shift from energy-intensive industries to nonenergy-intensive manufacturing, as well as improvements in process efficiency. Between 2005 and 2050, nonenergy-intensive manufacturing output is expected to grow at twice the rate as energy-intensive industrial output. This shift in output exaggerates the decline in energy intensity. However, in the transportation sector, consumer preferences for more powerful engines, and a continued shift from passenger cars to SUVs, limit gains in overall efficiency.

In the power-generation sector, the efficiency of nonrenewable generation is expected to increase as older, less-efficient fossil steam units retire and new high efficiency gas combined cycle and IGCC capacity is built. Electric generation by type is shown in **Figure A-5**. Natural gas-fired generation is projected to increase its share of total generation from about 19% to 26% over the projection period. Coal-fired generation remains the largest source of electricity at 51% to 59% of total generation. Due to significant retirements of existing nuclear capacity, the share of nuclear generation falls from 20% to 4% of generation in the projection period. Renewable generation is relatively constant at 10% to 11% of total generation.

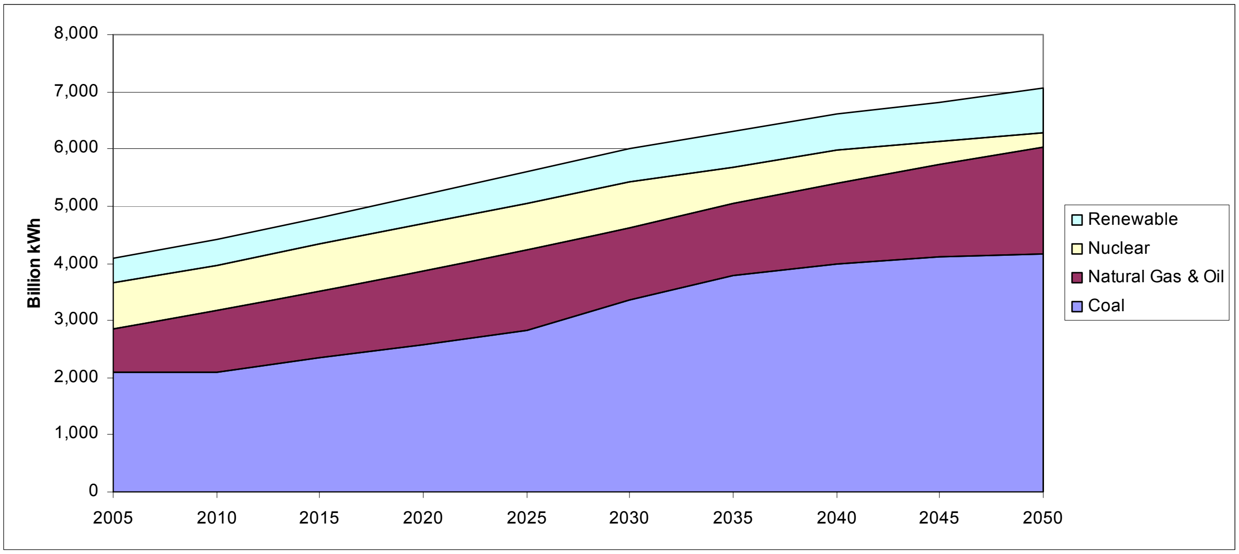


Figure A-5. Electricity Generation by Type: Reference Case

While both natural gas and coal-fired generation show increased efficiency, fossil fuel use for electric generation increases by 60% during the projection period. Such an increase in coal and natural gas demand for power generation is dependent on the availability of these resources. However, potential reduction in supply, such as changes in the outlook in natural gas supply, would necessitate a significant change in fuels used for electric generation.

Appendix B – GPRA07 Hydrogen, Fuel Cells, and Infrastructure Technologies (HFCIT) Program Documentation

1. Introduction

The target markets for the Office of Hydrogen, Fuel Cells, and Infrastructure Technologies (HFCIT) program include transportation (cars and light trucks) and stationary (particularly residential and commercial) applications. The two main markets will be discussed separately below.

1.1 Target Market: Fuel Cell Vehicle Market

The market for fuel cell vehicles (FCVs) includes all cars and light trucks sold for both personal and business use. Today, the size of this market is approximately 17 million vehicle sales per year. Total car and light-truck stock is about 220 million vehicles. EIA projects both sales and stock to grow to more than 20 million and 300 million respectively by 2025. Additional growth is expected post-2025, as explained in Chapter 3. The vehicle miles of travel are projected to grow from 3.28 trillion in 2020 to 5.63 trillion in 2050.

1.2 Key Factors in Shaping the Market Adoption of FCVs

Key factors associated with the adoption of new vehicle technologies include how the new vehicle technologies compare with the baseline vehicle technologies in terms of the following vehicle attributes:

- Vehicle Price
- Fuel Economy
- Range
- Maintenance Cost
- Acceleration
- Top Speed
- Luggage Space

Of these, vehicle price and fuel economy are the most important.

Nonvehicle attributes that are important factors in a consumer's decision to purchase new vehicle technologies include the following:

- Fuel Price
- Fuel Availability

1.3 Methodology and Calculations

The factors listed above include the factors used in the modeling of new vehicle technology penetration by the NEMS and MARKAL models. FCV attributes and other factors are discussed below.

1.3.1 FCV Attributes

FCV attributes were developed based on the HFCIT program goals, discussions with HFCIT program managers, Powertrain Systems Analysis Toolkit (PSAT) modeling, and payback analysis (Refs. 1-5). The PSAT model is a simulation model used by DOE to evaluate the fuel economy and performance of light vehicles using various technologies. (See Section 1.3.2 of Appendix F for a discussion of how the fuel economies of FCVs and other advanced technology vehicles are estimated in GPRA 07).

Payback analysis was used to estimate what the incremental price of FCVs would be when they become cost competitive with conventional vehicles, a goal of the program. (The incremental price equals the present value of the energy cost reduction achieved by FCVs over three years, assuming a hydrogen price of $1.50/gallon gasoline equivalent and 7.5% discount rate. See Section 1.3.3 of Appendix F for additional discussion of how the incremental prices of FCVs and other advanced technology vehicles are estimated in GPRA 07.) Other attributes were based on a review of past GPRA characterizations (e.g., Ref. 6).

Because the NEMS and MARKAL models require different levels of detail, two separate vehicle characterizations are provided. In both cases, most of the attributes are provided as ratios to the vehicle attributes of conventional vehicles. (For NEMS, the $ value of the price increments were provided.) The attributes are for new vehicles in the year listed. The conventional vehicles to which the FCVs are compared are the conventional vehicles of the AEO 2004 Reference Case extended to 2050 with modest increases in fuel economy. (See Appendix A for the description of the GPRA 07 Baseline.)

Table 1 contains the vehicle attributes for FCVs provided for input to the NEMS model. Attributes are provided for six car size classes and six light-truck classes. **Table 2** contains vehicle attributes for FCVs provided as input to the MARKAL model. MARKAL uses only vehicle price and fuel economy attributes. MARKAL does not disaggregate cars and light trucks into various classes.

1.3.2 Hydrogen Price

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 $0.65 per gallon of gasoline equivalent (gge)[1]—was assumed for hydrogen distribution costs based on published data from NREL.[2] We will be enhancing the representation of the distribution and fueling costs for hydrogen in future analysis as data becomes available. **Table 3** shows projected

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[1] One kilogram of hydrogen is roughly equivalent in energy content to 1 gallon of gasoline, and is often referred to as a gallon of gasoline equivalent (gge).

[2] 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.

hydrogen costs by cost component for the Hydrogen Program Case. Due to market factors affecting feedstock costs, the projected costs do not always match HFCIT Program goals.

1.3.3 Hydrogen Availability at Stations

An availability factor for hydrogen refueling stations is required by the NEMS model. The assumptions used are as follows: 1) hydrogen (H2) will not be available at any stations until sometime between 2015 and 2020; 2) in 2020, H2 will be available at 10% of all U.S. service stations and 3) H2 will be available at 25% of all U.S. service stations by 2025. These assumptions were provided by the HFCIT program.

1.3.4 FCV Market Penetration Methodology

Brief descriptions of how the NEMS and MARKAL models project new vehicle technology penetration using these vehicle attributes can be found in **Chapter 2** (NEMS) and **Chapter 3** (MARKAL).

1.4 Sources

1. "Hydrogen, Fuel Cells & Infrastructure Technologies Program: Multi-Year Research, Development and Demonstration Plan" (Draft), U.S. Department of Energy, Energy Efficiency and Renewable Energy (June 3, 2003).

2. PSAT (POWERTRAIN SYSTEM ANALYSIS TOOLKIT): see http://www.transportation.anl.gov/software/PSAT/

3. Phillip Sharer and Aymeric Rousseau, "PSAT Results for GREET and GPRA – FE Adjusted 081705.xls," August 17, 2005.

4. Rousseau, Aymeric, "Number Associated with Presentation," July 6, 2005.

5. Payback model developed by Jim Moore, TA Engineering (2003) and expanded by Margaret Singh, ANL (2005).

6. "Program Analysis Methodology: Office of Transportation Technologies, Quality Metrics 2003 Final Report," prepared by OTT Analytic Team, for Office of Transportation Technologies, U.S. Department of Energy (March 2002).

Table 1. FCV Attributes Input to NEMS
(All units are ratios to the conventional gasoline vehicles of the specific year, except for the incremental price which is in 2003$)

	2-SEATER		MINI-COMPACT		SUB-COMPACT		COMPACT	
Fuel Cell (H2)	**2022**	**2025**	**2022**	**2025**	**2022**	**2025**	**2022**	**2025**
Incremental Vehicle Price ($)	2392	1611	2311	1559	1964	1325	1991	1345
Range	0.90	0.96	0.90	0.96	0.90	0.96	0.90	0.96
Maintenance Cost	1.05	1.02	1.05	1.02	1.05	1.02	1.05	1.02
Acceleration	1.00	1.06	1.00	1.06	1.00	1.06	1.00	1.06
Top Speed	0.90	0.93	0.90	0.93	0.90	0.93	0.90	0.93
Luggage Space	0.80	0.86	0.80	0.86	0.80	0.86	0.80	0.86
Fuel Economy (a)	2.37	2.43	2.37	2.43	2.37	2.43	2.37	2.43

	MEDIUM CAR			LARGE CAR		
Fuel Cell (H2)	**2018**	**2023**	**2025**	**2018**	**2023**	**2025**
Incremental Vehicle Price ($)	2251	1661	1613	2415	1775	1722
Range	1.00	1.00	1.00	1.00	1.00	1.00
Maintenance Cost	1.05	1.00	0.97	1.05	1.00	0.97
Acceleration	1.00	1.00	1.04	1.00	1.00	1.04
Top Speed	0.85	0.9	0.92	0.85	0.9	0.92
Luggage Space	0.90	1.00	1.00	0.90	1.00	1.00
Fuel Economy (a)	2.28	2.38	2.42	2.28	2.38	2.42

(a) Gasoline gallon equivalent

Table 1 (continued).

	SMALL SUV		LARGE SUV			SMALL TRUCK		CARGO (Incl. 2b) TRUCK	
Fuel Cell (H2)	**2020**	**2025**	**2018**	**2023**	**2025**	**2020**	**2025**	**2024**	**2025**
Incremental Vehicle Price ($)	2626	1879	3281	2350	2242	2342	1685	2802	1861
Range	0.90	1.00	1.00	1.00	1.00	0.90	1.00	0.90	0.93
Maintenance Cost	1.10	1.00	1.05	1.00	0.97	1.10	1.00	1.05	1.04
Acceleration	1.00	1.10	1.10	1.10	1.10	1.00	1.10	1.00	1.00
Top Speed	0.90	0.95	0.90	0.95	0.95	0.90	0.95	0.90	0.90
Luggage Space	0.90	0.95	0.95	1.00	1.00	0.90	0.95	0.90	0.91
Fuel Economy (a)	2.37	2.35	2.36	2.36	2.35	2.16	2.16	2.16	2.16

	MINIVAN		LARGE VAN		
Fuel Cell (H2)	**2020**	**2025**	**2018**	**2023**	**2025**
Incremental Vehicle Price ($)	2535	1821	3178	2267	2158
Range	0.90	1.00	1.00	1.00	1.00
Maintenance Cost	1.10	1.00	1.05	1.00	0.97
Acceleration	1.00	1.10	1.10	1.10	1.10
Top Speed	0.90	0.95	0.90	0.95	0.95
Luggage Space	0.90	0.95	0.95	1.00	1.00
Fuel Economy (a)	2.37	2.35	2.36	2.36	2.35

(a) Gasoline gallon equivalent

Table 2. FCV Attributes for Input to MARKAL

Ratios to Conventional Vehicles

		2010	2020	2025	2030	2035	2050
CARS	MPG	2.12	2.32	2.42	2.54	2.67	2.95
	Incremental Price			1.061			1.036
LIGHT TRUCKS	MPG	2.21	2.30	2.29	2.27	2.26	2.73
	Incremental Price			1.063			1.036

Table 3. Hydrogen Production Costs by Technology and Component (2003 $/gge)

Central Coal - No Co-product

Unit Costs	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Capital Costs	0.65	0.65	0.65	0.65	0.65	0.65
O&M	0.23	0.23	0.23	0.23	0.23	0.23
Feedstock Costs	0.20	0.24	0.26	0.27	0.29	0.32
Plant Gate	**1.08**	**1.12**	**1.14**	**1.14**	**1.17**	**1.20**
Distribution, Storage & Tax	1.23	1.23	1.23	1.23	1.23	1.23
Total	**2.30**	**2.34**	**2.36**	**2.37**	**2.39**	**2.42**

Central Coal - with Elec Co-product

Unit Costs	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Capital Costs		1.11	1.11	1.11	1.11	1.11
O&M		-0.24	-0.23	-0.19	-0.20	-0.21
Feedstock Costs		0.31	0.34	0.34	0.38	0.41
Plant Gate		1.18	1.21	1.26	1.28	1.31
Distribution, Storage & Tax		1.23	1.23	1.23	1.23	1.23
Total		2.40	2.44	2.48	2.51	2.54

Remote Gas Reformer

Unit Costs	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Capital Costs	0.58	0.58	0.58	0.58	0.58	0.58
O&M	0.46	0.46	0.46	0.46	0.46	0.46
Feedstock Costs	0.94	0.91	0.94	0.97	1.02	1.13
Plant Gate	1.98	1.95	1.98	2.01	2.07	2.18
Distribution, Storage & Tax	0.46	0.46	0.46	0.46	0.46	0.46
Total	2.44	2.41	2.44	2.47	2.53	2.64

Central Gas Reformer

Unit Costs	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Capital Costs	0.21	0.21	0.21	0.21	0.21	0.21
O&M	0.10	0.10	0.10	0.10	0.10	0.10
Feedstock Costs	1.02	0.98	1.02	1.06	1.13	1.25
Plant Gate	1.33	1.29	1.33	1.37	1.44	1.56
Distribution, Storage & Tax	1.23	1.23	1.23	1.23	1.23	1.23
Total	2.56	2.52	2.56	2.59	2.66	2.79

Central Biomass

Unit Costs	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Capital Costs	0.42	0.42	0.42	0.41	0.41	0.41
O&M	0.26	0.26	0.26	0.26	0.26	0.26
Feedstock Costs	0.35	0.35	0.35	0.35	0.40	0.52
Plant Gate	1.04	1.04	1.04	1.03	1.08	1.20
Tax	1.23	1.23	1.23	1.23	1.23	1.23
Total	2.26	2.26	2.26	2.25	2.31	2.42

Distributed Ethanol

Unit Costs	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**
Capital Costs	0.44	0.44	0.44	0.44	0.44	0.44
O&M	0.50	0.50	0.50	0.50	0.50	0.50
Feedstock Costs	2.44	2.45	2.43	2.33	2.35	2.35
Plant Gate	3.39	3.39	3.38	3.28	3.29	3.30
Distribution, Storage & Tax	0.46	0.46	0.46	0.46	0.46	0.46
Total	3.85	3.85	3.84	3.74	3.75	3.76

Central Electrolytic H2 - Grid or Wind

Unit Costs	2025	2030	2035	2040	2045	2050
Capital Costs	0.23	0.23	0.23	0.23	0.23	0.23
O&M	0.10	0.10	0.10	0.10	0.10	0.10
Feedstock Costs	2.94	2.18	2.16	2.02	2.05	2.22
Plant Gate	3.28	2.52	2.50	2.36	2.39	2.56
Distribution & Storage*	1.23	1.23	1.23	1.23	1.23	1.23
Total	4.51	3.75	3.72	3.58	3.62	3.78

Distributed Electrolytic H2

Unit Costs	2025	2030	2035	2040	2045	2050
Capital Costs	0.66	0.66	0.66	0.66	0.66	0.66
O&M	0.50	0.50	0.50	0.50	0.50	0.50
Feedstock Costs	3.16	2.35	2.32	2.17	2.21	2.39
Plant Gate	4.33	3.51	3.49	3.34	3.37	3.55
Distribution, Storage & Tax	0.46	0.46	0.46	0.46	0.46	0.46
Total	4.79	3.97	3.95	3.80	3.83	4.01

2.1 Stationary Fuel Cell Market

Stationary fuel cells are one of a variety of distributed electricity-generation technologies. The particular market sectors in which stationary fuel cells are most applicable include residential and commercial applications.

2.2 Key Factors in Shaping the Market Adoption of Stationary Fuel Cells

Key factors associated with the market penetration of stationary fuel cells include the energy efficiency (electrical and combined heat and power), installed cost, and maintenance cost of the fuel cells relative to other distributed and traditional electricity-generation technologies.

2.3 Methodology and Calculations

2.3.1 Baseline Assumptions for Stationary Fuel Cells

There were no changes in the technology assumptions for distributed generation, including stationary fuel cells, from AEO 2004 to AEO2005. There remain a few definitional differences in how the HFCIT Program goals are stated and how the technology characterizations are used within NEMS. There also remains a difference in the view of current (or nearly current) technology that might reflect different trade-offs of efficiency and costs or may reflect differences in development. In either case, the same 2005 values should be used for the GPRA Baseline and Program cases so the Baseline was modified to reflect the Program view of 2005. As described below, the Program values were first adjusted to the same definitions as used in NEMS. By 2010, the Baseline returns to the AEO2005 values, with higher efficiencies and also higher costs than the values for 2005. Because of their relatively high costs, fuel cells are not cost-effective in the early years regardless of which source of data is used.

Residential 5kW PEMFC Baseline

AEO2005 Reference Case

Year	CHP System Efficiency	Electrical Efficiency	Installed Cost (2003 $/kW)	Maint. Cost (2003$/kW-yr)
2005	0.690	0.300	5500	264
2010	0.700	0.320	3800	184
2015	0.710	0.335	3000	168
2020	0.720	0.350	2200	152
2025	0.725	0.355	1750	140

GPRA07 Baseline

Year	CHP System Efficiency	Electrical Efficiency	Installed Cost (2003 $/kW)	Maint. Cost (2003$/kW-yr)
2005	0.675	0.288	2300	264
2010	0.700	0.320	3800	184
2015	0.710	0.335	3000	168
2020	0.720	0.350	2200	152
2025 to 2050	0.725	0.355	1750	140

Commercial 200kW Fuel Cell Baseline

AEO2005 Reference Case

Year	CHP System Efficiency	Electrical Efficiency	Installed Cost (2003 $/kW)	Maint. Cost (2003$/kW-yr)
2005	0.750	0.360	5200	232
2010	0.720	0.490	2500	128
2015	0.720	0.500	2150	124
2020	0.720	0.510	1800	120
2025	0.735	0.520	1450	112

GPRA07 Baseline

2005	0.675	0.288	1930	232
2010	0.720	0.490	2500	128
2015	0.720	0.500	2150	124
2020	0.720	0.510	1800	120
2025 to 2050	0.735	0.520	1450	112

2.3.2 Program Case Assumptions for Stationary Fuel Cells

Assumptions for distributed PEM fuel cells are based on the multiyear program plan (Ref.1). Capital costs and efficiencies were provided in the MYPP for the years 2005 and 2010. The costs are assumed to be in year 2003 dollars. No values were listed for maintenance costs, so the AEO2005 values are used The costs and efficiencies assumed for NEMS by 2025 were held constant through 2050 in MARKAL.

The program goal capital costs were increased to account for the installation cost that is assumed in the Baseline fuel cells costs from the NREL report. In addition, the efficiencies in the multiyear plan are expressed in lower heating values and were converted to higher heating value efficiencies for use in NEMS.

Residential 5kW PEMFC Program Case

HFCIT Goals from Multiyear Plan

Year	CHP System Efficiency*	Electrical Efficiency*	Equip. Cost (2003 $/kW)	Maint. Cost (2003$/kW-yr)
2005	0.75	0.32	1500	n/a
2010	0.80	0.35	1000	n/a

* based on LHV on input fuel

Model Inputs for HFCIT Goals

Year	CHP System Efficiency	Electrical Efficiency	Installed Cost (2003 $/kW)	Maint. Cost (2003$/kW-yr)
2005	0.675	0.288	2300	264
2010	0.720	0.315	1800	184
2015	0.720	0.315	1800	168
2020	0.720	0.315	1800	168
2025 to 2050	0.720	0.315	1800	168

Commercial 200kW Fuel Cell Program Case

HFCIT Goals from Multiyear Plan

Year	CHP System Efficiency*	Electrical Efficiency*	Equip. Cost (2003 $/kW)	Maint. Cost (2003$/kW-yr)
2005	0.75	0.32	1250	n/a
2010	0.80	0.40	750	n/a

* based on LHV on input fuel

Model Inputs for HFCIT Goals

Year	CHP System Efficiency	Electrical Efficiency	Installed Cost (2003 $/kW)	Maint. Cost (2003$/kW-yr)
2005	0.675	0.288	1930	232
2010	0.720	0.360	1430	128
2015	0.720	0.360	1430	128
2020	0.720	0.360	1430	128
2025 to 2050	0.720	0.360	1430	128

2.4 Sources

1. "Hydrogen, Fuel Cells & Infrastructure Technologies Program: Multi-Year Research, Development and Demonstration Plan" (Draft), U.S. Department of Energy, Energy Efficiency and Renewable Energy (June 3, 2003).

Appendix C – GPRA07 Biomass Technologies Program Documentation

Background

This appendix discusses the assumptions and methods employed in the biomass benefits analysis, which is part of the fiscal year 2007 GPRA benefits analysis for all of the Department of Energy's Energy Efficiency and Renewable Energy (EERE) research and deployment programs. The biomass benefits analysis focuses on the benefits of future achievements by the Biomass Program and excludes retrospective benefits, as well as benefits resulting from industry's own initiative and funding.

The major program focus is to enable integrated biorefineries that produce ethanol as the main output and, where possible, limited volumes of coproducts such as chemicals, materials, and/or heat and power. Biorefineries process biomass into these products using biochemical processes (such as hydrolysis of biomass to sugars followed by fermentation of sugars to fuels and/or chemicals) or thermochemical processes (such as gasification of biomass to syngas followed by conversion of syngas to fuels or chemicals). Biorefinery configurations may vary as a function of site-specific conditions, including feedstock availability and price, local and regional market demand, and other factors. Heat and power produced within the biorefinery can be used for internal biorefinery power requirements, with excess electricity production sold externally.

As an interim step leading to future biorefineries, the program is working with corn ethanol production plants on near-term technologies aimed at increasing the ethanol production from traditional feedstocks (corn kernels) and enhancing the value of nonethanol coproducts such as animal feed additives. Only the starch portion of the corn kernels is currently converted to ethanol. Ethanol yield increases can be achieved with technology that converts the fibrous component of the corn kernels, which is composed of cellulosic material, to ethanol. This process also exposes the starch that is tightly bound by this fiber ("residual starch"), which is not currently available for conversion to ethanol in existing corn ethanol plants. A further benefit of this technology is the production of a higher-protein animal feed that may be more suitable for the poultry and swine markets. Cellulosic ethanol technology will be used to convert the fibrous component of kernels and expose the residual starch to fermentation. The advantage of introducing cellulosic ethanol technology into existing corn biorefineries is that the plants can utilize existing facilities for processing corn kernels, energy services, and fermenting and distilling ethanol, thus reducing capital expenditures and financial risks. Operators of corn biorefineries have expressed an interest in this technology as a means of expanding corn ethanol yields and increasing profits, and DOE has entered into partnership agreements with several plant operators. Positive experience with kernel fiber and residual starch conversion could facilitate the companies' decisions to investigate the possibility of converting additional cellulosic feedstock such as agricultural residues.

The GPRA07 benefits analysis is based on the concept that enhanced corn ethanol plants—with the added production of corn fiber ethanol, residual starch ethanol, and eventually stover-based ethanol—will lead to the development of mature stand-alone lignocellulosic ethanol plants.

Ligno-cellulosic biomass includes challenging feedstock such as corn stover, wheat straw, rice straw, woody forest wastes, and future energy crops, e.g., fast-growing trees such as hybrid poplars, and fast-growing grasses such as switchgrass. The time-based progression is as follows:

a. "Starch Biorefineries" (SBs) that use corn kernels or other grains to produce ethanol and a small volume of coproducts (chemicals and materials). Advanced starch biorefineries will convert some of the fiber in the corn kernels to ethanol using cellulosic ethanol technology.

b. "Cellullosic Biorefineries" (CBs) that use corn stover and/or other cellullosic biomass to produce ethanol.

A biorefinery industry is expected to result in biomass displacing petroleum feedstocks traditionally used in the production of fuels, chemicals, and materials. 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 operating and maintenance costs across multiple products. While the current analysis assumes that ethanol is the major output of biorefineries, future analyses could include additional fuels that the program may identify in the longer term.

When processing lignocellulosic biomass, the biorefinery will process the cellulosic portion of the biomass into ethanol and use the remaining lignin residues to generate electricity.[a] Excess electricity will be sold externally, thereby reducing the net ethanol cost. The program assumed the coproduction of a small quantity of nonfuel chemicals or materials in corn ethanol plants. These bio-based products were modeled as a "credit" that reduces the ethanol production cost. Analysts in EERE's Office of Planning, Budget and Analysis (PBA) used ethanol supply/demand data with biorefinery synergy credit—values for each year provided by the Office of the Biomass Program (OBP) —and "current law" tax incentives to estimate market penetration for ethanol.

A variety of chemicals and materials could potentially be coproduced at biorefineries. Sugar and starch products derived through fermentation and thermochemical processes include alcohols, acids, starch, xanthum gum, and other products. Some of these chemicals and materials represent end products, while others represent "intermediates" used in the production of other products. The potential target markets are even more diverse than the list of potential products. Therefore PBA analysts did not characterize or analyze specific target markets for bio-based products in this benefits analysis. Instead, this analysis represented the bio-based product as a "generic/composite" product. OBP assumptions for the "generic/composite" product were derived from several OBP-sponsored studies that assessed a wide range of possible bio-based products (polymers, solvents, etc.).

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[a] The structural materials that plants produce to form the cell walls, leaves, stems, stalks, and woody portions of biomass consists mainly of three biobased chemicals called cellulose, hemicellulose, and lignin. This composite material called lignocellulose is composed of rigid cellulose fibers embedded in a cross-linked matrix of lignin and hemicellulose that bind the fibers. Lignocellulose material is resistant to physical, chemical, and biological attack. In a biorefinery, the cellulose and hemicellulose can be broken down to produce fermentable, simple sugars through a process called hydrolysis. Cellulose is a very large polymer molecule composed of many hundreds or thousands of glucose molecules (polysaccharide).. Hemicellulose consists of short, highly branched, chains of sugars.

The discussion in this section will focus on describing target markets and technical characteristics used in the analysis of the market penetration and benefits attributable to the three types of biorefineries referenced above.

Target Markets for Biorefineries

Corn ethanol plants, both dry mills and wet mills,[b] currently use corn kernels (no cellulosic feedstock) to produce ethanol and some coproducts such as animal feed additives (both dry and wet mills), or corn oil and high-fructose corn syrup (wet mills).

In 2004, U.S. ethanol fuel production reached approximately 3.4 billion gallons, an increase of 21% from the previous year. As of January 2006, the estimated 2005 production is 3.9 billion gallons. According to the Renewable Fuels Association, in January 2006, the operating ethanol plants in the United States had a total production capacity of 4.37 billion gallons, with an additional capacity of 1.75 billion gallons under construction or in expansion. Ethanol competes in transportation fuel markets for light-duty vehicles. In 2004, the U.S. prime supplier sales volume of motor gasoline was approximately 140 billion gallons.[1]

In 2004, approximately 99% of the ethanol consumed in the United States was for the gasoline additive market and 1% was for use as a gasoline substitute.[2] In 2004, the majority of the ethanol consumed was used as an oxygenate component for gasoline, and the remainder is used as a gasoline additive to improve octane in conventional gasoline. Within the oxygenate market, in early 2004, methyl-tertiary-butyl-ether (MTBE) and ethanol each provided approximately 50% of the volume. However, ethanol has taken a much larger share of this market, because MTBE has been or is being phased out in many states due to environmental concerns (see discussion of MTBE later in this section for additional detail).

The original Clean Air Act required a minimum level of oxygen content in both reformulated gasoline (RFG) and oxygenated gasoline. The Energy Policy Act of 2005 repealed the oxygen content requirement for RFG to take place 270 days after enactment. However, the GPRA 2007 analysis was completed prior to the approval of the Energy Policy Act of 2005 and was based on current law at the time of this analysis. RFG is required in ozone nonattainment areas, and oxygenated gasoline is required in carbon monoxide (CO) nonattainment areas. Ethanol competed with MTBE in both of these oxygenate market segments. Most of the MTBE (and an increasing share of ethanol) used are used in RFG, which is the most important market segment for oxygenates. The Energy Policy Act did not enact a nationwide ban on MTBE,[c] but many states have already banned the use of MTBE in gasoline sold within their states. In addition, several major refiners have since announced their intent to discontinue the use of MTBE. Some refiners have indicated that, because of ethanol's desirable properties and restrictions on MTBE use, they will continue using ethanol in a substantial portion of their RFG after the repeal of the RFG oxygen requirement.

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[b] To learn more about these plants, see http://www.ethanolrfa.org

[c] MTBE is currently the subject of environmental concern in several communities, due to its leakage and contamination of groundwater. It imparts a turpentine odor to water at low concentrations.

Both ethanol and MTBE are used in the smaller oxygenated gasoline market segment, with ethanol being the dominant oxygenate. In a third market segment, ethanol is blended with conventional gasoline to make gasohol, which is primarily marketed in the Midwest. Gasohol consists of 90% gasoline and 10% ethanol by volume, with the ethanol serving as an octane enhancer and gasoline extender.

After adjusting for its Federal excise tax exemption, the price of ethanol has historically tracked with the price of gasoline, whereas MTBE has normally been priced at a premium relative to gasoline. MTBE had been the oxygenate of choice in RFG for most refiners outside the Midwest because of its wider availability, more favorable blending characteristics for summer Reid Vapor Pressure, and ease of distribution. When blended into gasoline, ethanol raises the vapor pressure of the mixture; adding MTBE to gasoline has only a minor effect on vapor pressure. Because ethanol absorbs water, which is typically present in small quantities in the U.S. petroleum products pipeline system, ethanol and ethanol blends are not routinely shipped via pipeline. Consequently, ethanol is shipped by rail, truck, and/or barge to distribution terminals, where it is blended into gasoline. MTBE is blended into gasoline at the refinery, and MTBE blends do not require any special handling compared with gasoline that has no MTBE.

The consumption of MTBE in 2002 was approximately 4 billion gallons, but MTBE consumption has been declining as California, New York, Connecticut, and other states transitioned from MTBE to ethanol. A national ban on MTBE would increase the demand for ethanol because ethanol, like MTBE, is a high-octane content, virtually sulfur-free additive that reduces toxic air emissions. Ethanol also will help solve the problem of fuel volume loss that would accompany an MTBE ban, because oxygenates such as MTBE (or ethanol or other oxygenates), when blended in gasoline, also are used by the automobile engine as a fuel. Reformulated gasoline containing MTBE typically contains 11% MTBE. Outside of California, reformulated gasoline containing ethanol typically contains 10% ethanol. In California, the current blend level is typically 5.7% ethanol.

Vehicle fleets provide additional demand for ethanol fuel. These include alternative-fuel vehicles that have been either modified or manufactured to accommodate the use of E85, i.e. 85% ethanol and 15% gasoline (the number of E95 vehicles is negligible at this time). The E85 vehicles are flexible-fuel vehicles that can use either gasoline or E85. The vehicle fleet market is dominated by government agencies, but also includes fleets owned by corporate entities and other organizations (taxi cabs, utilities, airport authorities, etc.). The use of green fuels in Federal Government fleets is driven largely by the alternative-fuel vehicle requirements under the Energy Policy Act (EPACT) of 1992.

The market penetration of E85 has been much lower than for E10 because (1) only a limited number or vehicles can use E85 (and fleet rules under EPACT do not necessarily require the use of alternative fuels in these vehicles), (2) E85 has generally been more costly than gasoline on an energy-equivalent basis, (3) the availability of E85 refueling stations is limited, and (4) the required investment for refueling infrastructure is greater for E85 than for E10. In the longer term, once production technology improvements achieve cost parity between ethanol and gasoline, ethanol will compete directly with gasoline in broader automotive fuel markets.

Baseline Technology Improvements

The degree to which this technology would progress in the absence of EERE's biomass R&D has not been studied in detail. Instead, EERE adopted the methodology recommended by the National Research Council (NRC) to estimate how EERE RD&D funding would accelerate technology improvements.[3] The NRC recommended using an N-year rule, in which technology deployment would be accelerated by N years with EERE R&D, or conversely delayed by N years in the absence of EERE R&D. PBA used a multitiered approach to recognize differences between shorter- and longer-term goals. PBA analysts assumed that without Federal investment in RD&D, technological advances would be delayed 7 years for corn fiber/recalcitrant starch, 12 years for bio-based products technologies for dry mills, and 15 years for ethanol production technologies using cellulosic feedstock.

<u>Compared to the program case, PBA assumed a delay of 7 years is used for baseline parameters for dry mill, plus corn fiber and residual starch conversion</u>. The reason for a moderate delay is that industry has shown interest and willingness to cost-share R&D in this area, and the estimated development time is short compared to that for lignocellulosic ethanol technology. OBP has already catalyzed work in this area, as indicated by several projects that are underway. It seems reasonable that, absent any further OBP involvement, industry would continue to build on work already accomplished, albeit at a slower rate. The rationale for assuming a 15-year delay for stand-alone cellulosic ethanol biorefineries is industry's reticence to underwrite cellulosic ethanol research, because of its greater risk and cost.

Baseline Market Acceptance for Ethanol Biorefineries

Gasoline is a mix of both high- and lower-value petroleum-based components, with the high-value components comprising only a small fraction of the total volume. With current ethanol tax incentives and ethanol's value to refiners due to its environmental and octane characteristics, corn-based ethanol is competitive with the small fraction of high-value petroleum-based constituents of gasoline that give gasoline acceptable octane and emissions levels. Therefore, a small amount of ethanol (10% or less) can be blended with 90% or more gasoline to produce a fuel that is competitive with conventional gasoline. Blending ethanol with gasoline in higher concentrations becomes less competitive, because a gallon of ethanol has only two-thirds the energy of a gallon of gasoline, which historically has made it difficult for ethanol to compete with gasoline on an energy-equivalent basis. In 2005, however, the price of oil reached new highs, and the cost of producing corn ethanol compared favorably with the cost of producing gasoline on an energy equivalent basis. Production capacity constrains the amount of ethanol that can enter the market, and the current production capacity for ethanol is much less than that of gasoline.

Ethanol is already widely used in gasoline and accepted as a component of transportation fuel in the target market. As the technology for producing cellulosic ethanol matures in the longer term, the retail value of cellulosic ethanol will become competitive with gasoline on an energy basis. At that point, fuel markets will likely accept nearly pure ethanol such as E85,because of its environmental characteristics and indigenous supply basis. In Brazil, for example, both E22 and

E100 are readily available,and most new cars sold are flex-fueled vehicles that can use either fuel. Increases in market penetration for ethanol will also be affected by competition from other alternative transportation fuels and success in overcoming the lack of an established nationwide E85 transportation and distribution infrastructure. Eventually, increases in market penetration may be constrained by the availability of feedstock, rather than market demand.

Biomass Program Technology Outputs for Corn Ethanol Biorefinery

Table C-1 summarizes ethanol production cost targets for corn ethanol dry mill biorefineries.

Table C-1. EERE Ethanol Production Costs - Targets in 2003$ per Gallon for Dry Mills Before Adding Feedstock Costs

Year	Operating $/gal EtOH	Capital $/gal EtOH	Denatured Ethanol Yield gal/bu	DDG Yield Lb/bu	DDG Enrichment Factor	Electricity Usage kWh/gal	Natural Gas Usage MMBtu/gal	Bio-based Product Credit $/gal EtOH
2007	$ 0.220	$ 0.152	2.80	18.50	1.00	0.77	0.03	$ -
2008	$ 0.220	$ 0.151	2.80	18.50	1.00	0.77	0.03	$ -
2009	$ 0.219	$ 0.151	2.81	18.50	1.00	0.77	0.03	$ -
2010	$ 0.219	$ 0.151	2.81	18.50	1.00	0.76	0.03	$ (0.01)
2011	$ 0.219	$ 0.151	2.82	18.50	1.00	0.76	0.03	$ (0.01)
2012	$ 0.218	$ 0.149	2.89	17.41	1.06	0.76	0.03	$ (0.02)
2013	$ 0.218	$ 0.146	2.96	16.43	1.13	0.75	0.03	$ (0.03)
2014	$ 0.218	$ 0.144	3.03	15.56	1.19	0.75	0.03	$ (0.03)
2015	$ 0.217	$ 0.142	3.10	14.78	1.25	0.75	0.03	$ (0.04)
2016	$ 0.217	$ 0.140	3.17	14.07	1.31	0.74	0.03	$ (0.05)
2017	$ 0.217	$ 0.138	3.24	13.43	1.38	0.74	0.03	$ (0.05)
2018	$ 0.216	$ 0.136	3.31	12.85	1.44	0.73	0.03	$ (0.06)
2019	$ 0.216	$ 0.134	3.38	12.31	1.50	0.73	0.03	$ (0.06)
2020	$ 0.215	$ 0.134	3.39	12.31	1.50	0.73	0.03	$ (0.07)
2021	$ 0.215	$ 0.133	3.39	12.31	1.50	0.73	0.03	$ (0.08)
2022	$ 0.215	$ 0.133	3.40	12.31	1.50	0.73	0.03	$ (0.08)
2023	$ 0.214	$ 0.133	3.40	12.31	1.50	0.72	0.03	$ (0.09)
2024	$ 0.214	$ 0.133	3.41	12.31	1.50	0.72	0.03	$ (0.10)
2025	$ 0.214	$ 0.132	3.41	12.31	1.50	0.72	0.03	$ (0.10)
2030	$ 0.212	$ 0.131	3.44	12.31	1.50	0.72	0.03	$ (0.14)
2035	$ 0.210	$ 0.130	3.47	12.31	1.50	0.71	0.03	$ (0.17)
2040	$ 0.209	$ 0.129	3.50	12.31	1.50	0.71	0.03	$ (0.20)
2045	$ 0.207	$ 0.128	3.53	12.31	1.50	0.70	0.03	$ (0.20)
2050	$ 0.205	$ 0.127	3.55	12.31	1.50	0.69	0.03	$ (0.20)

Source: John Jechura , *Adv Dry Mill Curve 8-25-2005 - DA changes.xls* , National Renewable Energy Laboratory

Dry mills process corn into ethanol, distillers dried grain solubles (DDGS), and carbon dioxide (CO_2). DDGS is sold into the animal feed market. Some dry mill operators are able to sell their CO_2 production, but the CO_2 market is limited and therefore not considered in this analysis. As dry mill plants begin to deploy the technology to convert the fiber and residual starch to ethanol, the yield of the weight DDGS coproduct decreases, but the protein component (weight) in the

DDGS remains constant. DDGS is valued in the marke place primarily for its protein. The relative protein content of the DDGS is computed by multiplying the DDGS weight by the DDGS enrichment factor, both of which are shown in the table. Most of the DDGS is now used in the cattle feed market, but it is expected that the higher-protein (percent) DDGS will be suitable for the poultry and swine markets.

The operating costs in the table do not include the energy costs. The table lists the per-gallon energy requirements for natural gas and electricity separately. NEMS and MARKAL use their endogenously computed energy prices to calculate the energy costs to produce corn-based ethanol (unit price of energy times energy consumption per gallon of ethanol). The Biomass Program assumed a bio-based coproduct credit of 1 cent per gallon of ethanol beginning in 2010, increasing gradually to 20 cents per gallon by 2040 for a dry mill processing corn kernels. The coproduct credit represents a generic bio-based product coproduced with ethanol and was provided by the National Renewable Energy Laboratory (NREL). The program's draft Multi-Year Program Plan of August 31, 2005, was not yet available when this analysis was conducted. PBA analysts assumed that commercialization of technologies for the conversion of corn kernel fiber and recalcitrant starch would begin in 2012, based on preliminary planning information developed by NREL. The successful technology will cause the industry-wide ethanol yield (gallons of ethanol per bushel of corn) to increase by 23% between 2012 and 2050(2).

Rather than assuming "instantaneous" deployment by all dry mills, the corn fiber and recalcitrant starch technology was assumed to be deployed by 100% of the dry mills by 2050, with a ramp-up beginning in 2012. The conversion of the corn fiber and recalcitrant starch was modeled as an increase in the conversion efficiency in terms of gallons of ethanol per bushel of corn. The ramp-up includes technology improvements and an estimate of the overall rate of adoption by ethanol plant operators, as shown in Denatured Ethanol Yield Column in Table C-1.

References:

John Jechura (NREL) provided the cost and conversion targets in an EXCEL spreadsheet titled *Adv Dry Mill Curve 8-25-2005 - DA changes.xls*. NREL report: *Evaluating progressive technology scenarios in the development of the advanced dry mill biorefinery,* Kelly Ibsen (NREL), Robert Wallace (NREL), Sue Jones (PNNL), Todd Werpy (PNNL), 3/04/05

Biomass Program Technology Outputs for Cellulosic Ethanol Biorefinery

Table C-2 summarizes ethanol production cost targets for cellulosic ethanol biorefineries as originally submitted to OMB as part of the original budget submission for the Biomass Program in October 2005. These targets represent an assumption of level funding for the Biomass Program, reflecting the level of funding experienced in recent budget cycles.

Table C-2. Cellulosic Ethanol Production Costs and Conversion Efficiency Targets. Costs are in 2003$ per Gallon and do not Include Feedstock Costs

Year	Operating $/gal EtOH	Annualized Capital $/gal EtOH	Ethanol Yield gal/ton	Electricity Usage kWh/gal	Nat Gas Usage MMBtu/gal
2018	$ 0.45	$ 0.46	83.8	-3.70	0
2019	$ 0.39	$ 0.44	86.8	-3.69	0
2020	$ 0.34	$ 0.43	89.8	-2.08	0
2021	$ 0.32	$ 0.42	89.9	-2.07	0
2022	$ 0.31	$ 0.41	90.1	-2.06	0
2023	$ 0.30	$ 0.40	90.2	-2.06	0
2024	$ 0.29	$ 0.39	90.3	-2.05	0
2025	$ 0.28	$ 0.38	90.5	-2.04	0
2030	$ 0.23	$ 0.34	91.2	-2.01	0
2035	$ 0.19	$ 0.30	91.9	-1.97	0
2040	$ 0.15	$ 0.27	92.6	-1.94	0
2045	$ 0.13	$ 0.24	93.3	-1.91	0
2050	$ 0.10	$ 0.22	94.0	-2.03	0

Source: John Jechura , *Adv Dry Mill Curve 8-25-2005 - DA changes.xls* , National Renewable Energy Laboratory

Conversion of corn stover to ethanol is assumed to begin in 2018, based on preliminary planning information developed by NREL.(3). NREL supplied the non-feedstock capital and operating costs on a per gallon of ethanol. A real capital cost recovery factor of 15% is used to calculate the per-gallon capital costs. Cellulosic ethanol plants combust the lignin portion of the lignocellulosic feedstock to produce heat and electricity. The plants produce excess electricity that is sold into the grid. The negative numbers in the electricity use column represent the sale of the excess electricity. The electricity credit is computed by multiplying the price of electricity times the excess electricity production. Electricity prices are determined endogenously in NEMS and MARKAL.

Reference:

The methodology used for the cellullosic cost estimates was documented in NREL Report *Determining the Cost of Producing Ethanol from Corn Starch and cellulosic Feedstocks*, NREL/TP-580-28893, Andrew McAloon, Frank Taylor, Winnie Yee, Kelly Ibsen and Robert Wooley, October 2000. John Jechura of NREL provided the cost and conversion targets in an EXCEL spreadsheet titled *Adv Dry Mill Curve 8-25-2005 - DA changes.xls*. NREL report: *Estimated Ethanol Cost Curves from Advanced Dry Mills to 2050,* John Jechura, 6/2/05

Corn ethanol growth is based on our latest assessment of the industry that was done prior to the enactment of the Renewable Fuels Standard. For cellulosic ethanol based on corn fiber conversion, a near-term technology being developed by the program and industry partners, we assumed success for dry mills only. While the other type of ethanol plants, wet mills, may also succeed in deploying this technology, the benefits from wet mills are not considered in order to make the estimates more conservative. The volume of cellulosic ethanol from corn fiber includes the ethanol resulting from converting the fiber in the corn kernel and the residual starch that can be converted once liberated from the fiber. The total increment in ethanol output would equal 20% of the current dry mill's ethanol output. As previously stated, future biorefineries are assumed to use cellulosic biomass such as corn stover and energy crops, and not the corn kernel or its fiber as feedstock. The cellulosic ethanol estimates from corn stover, other cellulosic wastes, and energy crops resulted from market equilibrium analyses that compete ethanol with petroleum constituents in the low-blend fuel market (E10) and versus corn ethanol.

Technical Characteristics - The cellulosic biorefinery analysis is based on a plant whose main product is fuel ethanol with coproduction electricity. Excess electricity is sold to the grid and is modeled as a reduction in the cost of producing ethanol. The analysis is for a biorefinery with a total throughput of 2,000 dry metric tons of feedstock per day and with a conversion efficiency increasing from approximately 83 gallons of ethanol per dry U.S. ton of feedstock in 2018 to 94 in 2050, as a result of technological advances. Corn ethanol plants produce a more uniform sugar stream. Therefore EERE is targeting these plants for the production of new, high-valued, bio-based products that will compete favorably with petroleum product counterparts. The market for these products is limited compared to the fuels market, and the final choice of which products will be produced is still in the formative stages. Consequently, the economics of new bio-based products are represented as credits to the corn biorefineries, similar to the way credits for animal feed co-products are handled.

Technical Potential - The biomass feedstock resources discussed here do not include wood waste and black liquor waste from paper mills, an important but captive resource—these resources are typically used within the forest and paper products industry. Under favorable R&D outcome and market scenarios, the upper bound for ethanol supply from U.S. biomass is estimated at 35 billion gallons per year from cellulosic feedstock and 15 billion gallons per year from starch crops. The farm-gate price and supply relationship for biomass used in the market analysis are presented in **Table C-3**.

While forest residues and some of the "other wastes" may not be optimal for sugar-based ethanol production, we recognize that future syngas-based fuels production may use forest residues and certain "other wastes" as feedstock. Therefore, this analysis is not deemed to be overly optimistic, in spite of the assumption that biorefineries are sugar-based.

Table C-3. Farm-gate Biomass Quantities Supplied vs. Price Range Excluding Mill Residues and Black Liquor Near Term (million dry tons per year)

Feedstock	up to $21.20/dt	up to $31.80/dt	up to $42.40/dt	up to $53.00/dt
Forest Residues	0	12	20	70
Agricultural Crops Residues	0	1	65	80
Potential Energy Crops	0	0	80	187
Other Wastes	0	17	25	35
Total	0	30	190	372

Transportation costs ranging from $7.50 to $15.0 per dry ton (depending on hauling distance) were added to farm-gate prices to account for hauling to the biorefinery, assuming no difference between the case without EERE and the case with EERE (this assumption will be improved in future analyses). After adding these costs and applying the factors shown in Table 5, the near-term supply as a function of price per dry ton at the biorefinery gate is shown in Table 6. Because the models do not represent all competing uses of biomass, e.g., for biopower or fiber uses which are competitors to OBP's biorefineries. The fraction of the total feedstock assumed to be available to biorefineries is used as a proxy for reserving some of feedstock for competing uses. The fractions in **Table C-4** are assumed values.

Table C-4. Fraction of Total Feedstock Assumed To Be Available To Biorefineries

Feedstock	Fraction
Forest Residues	0.70
Agricultural Crops Residues	0.70
Potential Energy Crops	0.66
Other Wastes	0.60

Table C-5. Biorefinery-gate Quantities Supplied vs. Price Range Excluding Mill Residues and Black Liquor Near Term (million dry tons per year)

Feedstock	Up to $29.15/dry ton	Up to $42.40/dry ton	Up to $55.65/dry ton	Up to $68.90/dry ton
Agricultural Crops Residues	0	0.7	45	56
Potential Energy Crops	0	0	53	123
Forest and Other Wastes	0	15	23	49
Total	0	16	121	228

The annual quantity available for ethanol production, at up to $68.90 per dry ton (including costs of transportation to the biorefinery), has been reduced from 372 million to 228 million dry tons after applying the reduction factors from **Table C-5.** In the longer term (2040, for example), crop yields increasing at the rate of 1% per year will result in additional feedstock as shown in **Table C-6,** assuming no difference between the case without EERE and the case with EERE (this assumption will be improved in future analyses).

Table C-6. Long-term Biorefinery-Gate Supply vs. Prices Excluding Mill Residues and Black Liquor, Year 2040 (Million dry tons per year and 2000$. Costs include transportation costs from farm to biorefinery)

Feedstock	Up to $29/dry ton	Up to $42/dry ton	Up to $56/dry ton	Up to $69/dry ton
Agricultural Crops Residues	0	1	68	83
Potential Energy Crops	0	0	78	184
Forest and Other Wastes	0	19	29	70
Total	0	20	175	337

At approximately 93 gallons of ethanol per dry ton of feedstock, the potential supply in the long term is 31 billion gallons in 2040. This potential would increase significantly with appropriate incentives such as those aimed at increasing feedstock availability.

Expected Market Uptake - This analysis was done prior to the enactment of the Energy Policy Act of 2005 and was limited to policies existing at that time. We will include the biofuel specific policies in Energy Policy Act of 2005 in the GPRA08 analysis. The GPRA07 analysis did not include the RFS enacted in the Energy Policy Act. Corn ethanol is projected to continue to expand in GPRA07 as a result of various states' phase-outs of MTBE, but only to approximately 4 billion gallons/year by 2012 compared with an RFS requirement of 7.5 billion gallons/year in 2012. Although GPRA07 did not include the RFS, the impact on benefits estimates is mitigated by the fact that in the longer term, where most of the program benefits accrue, ethanol consumption easily exceeds the RFS requirement. Future cellulosic ethanol capacity will slowly replace corn ethanol capacity as the new technology becomes more competitive relative to corn ethanol. The tables show corn ethanol continuing at a fairly constant level through 2050.

The Biomass Program estimates that, beginning in 2012, corn ethanol plants will deploy the technologies for processing corn fiber, a cellulosic feedstock, into ethanol. This would be in addition to their continuing production of ethanol from corn starch. Beginning in 2018, a number of the ethanol plants will also convert corn stover to ethanol if R&D is successful.

NEMS and MARKAL were used to estimate ethanol market penetration for cellulosic ethanol from corn stover, energy crops, and other cellulosic residues; but excluding corn fiber and residual starch. The market penetration of corn fiber and residual starch-based ethanol, small quantities in comparison with the other cellulosic ethanol, were modeled as increases in the ethanol yield per bushel of corn in corn ethanol plants. The following section describes ELSASBioref and its use for this analysis.

Methodological Approach - Biomass ethanol market penetration analysis was accomplished through the integration of the results of various analyses conducted primarily by national laboratory personnel and their subcontractors. NEMS and MARKAL served as the integrating tools.

Cellulosic Feedstock Supply - Oak Ridge National Laboratory (ORNL) developed cellulosic feedstock supply curves with the aid of BIOCOST,[4] POLYSYS,[5] and other regionally detailed models. The feedstock supply-curve information shows quantities of different categories of cellulosic feedstocks available at different prices and time periods. The current GPRA case uses ORNL data reported by Arthur D. Little Inc.[6] These data were modified, based on more recent ORNL work on agricultural residue availability and cost[7].

Cellulosic feedstock costs are adjusted to include transportation charges from the farm gate to the conversion facility, and feedstock supplies are allocated among different competing uses as described above in the Technical Potential section. In addition, the analysis assumes that agricultural residues and bio-energy crops will increase at an annual rate of 1% during the analysis period, due to increasing agricultural productivity. This assumption yields a total U.S. feedstock supply in 2040 approaching 337 million dry tons of agricultural residues, forest wastes, energy crops and other biomass wastes, after excluding potential competing uses.

Ethanol Conversion Costs - NREL, which is partnering with industry and universities to develop competitive ethanol production technologies, provided estimates of cellulosic ethanol production costs (other than feedstock-related costs) on a per-gallon basis. The NREL estimate of the efficiency of converting feedstock into ethanol is input as a function of date, namely the number of gallons per dry ton of feedstock increases in the future as a result of R&D success. This allows the ORNL-provided feedstock costs to be presented on a per-gallon basis and added to the NREL non-feedstock costs to obtain the cost of producing a gallon of cellulosic ethanol. Corn mills may also produce other high value bio-based products from the sugar streams in addition ethanol and animal feeds. Because of the large number of potential products, each with relatively small markets, that have been identified, a detailed analysis of the markets for potential bio-based products was not feasible. Instead, NREL estimated a generic credit for bio-based product to corn ethanol mills. The GPRA analysis did include the extra demand for corn used to produce bio-based products in calculating the market price for corn.

Benefits Estimation - In both NEMS-GPRA07 and MARKAL-GPRA07, reductions in fossil energy use and carbon emissions attributable to EERE R&D (Program case) were calculated by computing the fossil energy use and carbon emissions in the Program and Bases cases, and taking their differences. Fossil energy use includes the fossil energy embedded in the final product, e.g., in gasoline, as well as the upstream fossil energy consumption, e.g., the fossil energy used to extract and transport oil, refine the oil into gasoline, and to transport the gasoline to retail service stations. Fossil energy requirements to produce both corn and cellulosic ethanol are input into NEMS-GPRA07 and MARKAL-GPRA07. Both models calculate carbon emissions by multiplying fossil fuel consumption by carbon emission factors, which depend on the fossil fuel type. Both models calculate energy costs endogenously in the process of solving for market equilibrium conditions.

For GPRA07, the analysis only considers reductions in fossil fuel use and carbon emissions from the production and consumption of ethanol. It does not include that benefits that accrue from bio-based products that displace petrochemical products, because the analysis assumes a generic bio-based product. As the amount of bio-based products that are produced is small compared with the amount of ethanol produced, the GPRA benefits estimates are not materially understated.

Update to the GPRA07 Inputs Based on President's Initiative

In his State of the Union Address, the president described new initiatives for developing alternative fuels that will break the nation's "addiction to oil." Among these was increased funding for the development of ethanol from cellulosic biomass as a substitute for gasoline. This led to a major rethinking of the goals of the Biomass Program.

Corn ethanol technology

The original inputs for Biomass involved improvements to corn ethanol production technology as well as inputs for introduction of cellulosic ethanol technology. In this revised set of inputs, we have made no changes to the assumptions about the impacts of the program on the existing corn ethanol technology.

Cellulosic ethanol technology

The president's new initiative for biomass accelerates cellulosic ethanol technology development—achieving a nominal ethanol selling price of $1.07 per gallon of ethanol in 2012. See **Figure C-1** for a comparison of the revised nominal cost trajectory for cellulosic ethanol.

The nominal selling price is a proxy for cost performance that reflects:

- A minimum rate of return of 10% on capital investment
- A nominal feedstock cost of $40 per dry U.S. ton
- A plant gate price (no costs for fuel distribution, marketing and taxes)

We interpret the goal of $1.07 in 2012 to reflect projected nominal cost of ethanol for technology that has been proven at the pilot scale. Therefore, we assume that fully commercially available technology at this nominal cost is available by 2015, allowing three years for commercial demonstration and design, construction, and start-up of a full commercial-scale facility.
In NEMS and MARKAL, we do not use the nominal cost, but rather, break this cost down into annualized cost of capital, operating expenses excluding feedstock cost, and a credit for excess electricity sold to the grid (**Table C-7**).

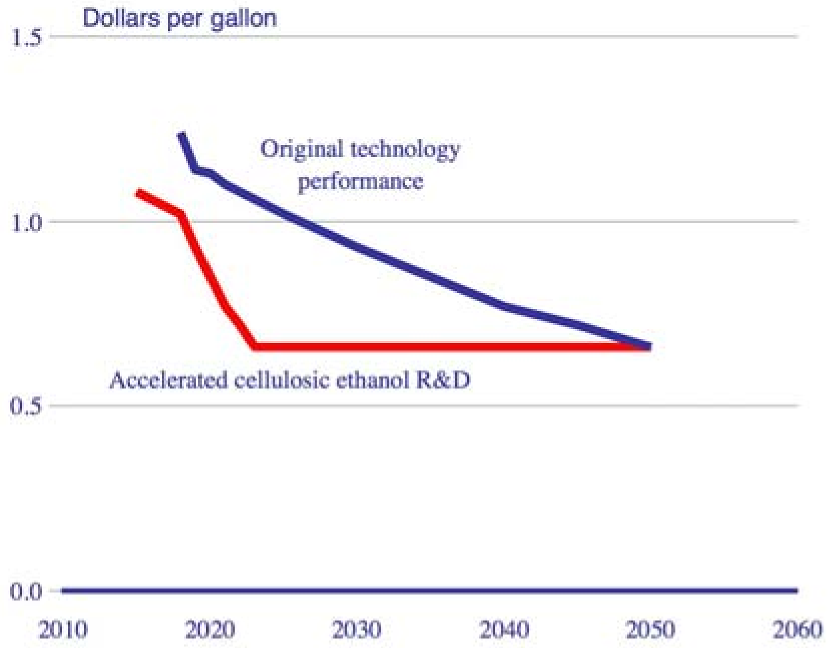

Figure C-1. Revised cost trajectory for nominal ethanol cost ($2003 per gallon of ethanol)

Table C-7. Revised Inputs to NEMS and MARKAL for Cellulosic Ethanol

Year	Annualized Cost of Capital ($2003/gal)		Non-biomass Operating Costs ($2003/gal)		Electricity Use (kWh per gal)		Ethanol Yield (Gal/ton)	
	Orig	Rev	Orig	Rev	Orig	Rev	Orig	Rev
2015		$0.41		$0.31		-2.06		90.10
2016		$0.40		$0.30		-2.06		90.20
2017		$0.39		$0.29		-2.05		90.30
2018	$0.46	$0.38	$0.45	$0.28	-3.7	-2.04	83.8	90.50
2019	$0.44	$0.34	$0.39	$0.23	-3.69	-2.01	86.8	91.20
2020	$0.43	$0.30	$0.34	$0.19	-2.08	-1.97	89.8	91.90
2021	$0.42	$0.27	$0.32	$0.15	-2.07	-1.94	89.9	92.60
2022	$0.41	$0.24	$0.31	$0.13	-2.06	-1.91	90.1	93.30
2023	$0.40	$0.22	$0.30	$0.10	-2.06	-2.03	90.2	94.00
2024	$0.39	$0.22	$0.29	$0.10	-2.05	-2.03	90.3	94.00
2025	$0.38	$0.22	$0.28	$0.10	-2.04	-2.03	90.5	94.00
2030	$0.34	$0.22	$0.23	$0.10	-2.01	-2.03	91.2	94.00
2035	$0.30	$0.22	$0.19	$0.10	-1.97	-2.03	91.9	94.00
2040	$0.27	$0.22	$0.15	$0.10	-1.94	-2.03	92.6	94.00
2045	$0.24	$0.22	$0.13	$0.10	-1.91	-2.03	93.3	94.00
2050	$0.22	$0.22	$0.10	$0.10	-2.03	-2.03	94	94.00

We have taken the numbers from Jechura's original analysis that correspond to $1.07 per gallon in 2022 and shifted those to start in 2015. In addition, we have taken remaining improvements that Jechura shows occurring through 2050 and accelerated them so that they reach their endpoint by 2020 instead of 2050. This corresponds to an aggressive R&D effort aimed at bringing the technology to its mature state more rapidly. After 2020, no further improvements in cost are assumed.

Biomass Supply Curves

Biomass supply curves have not been changed from the original inputs provided by the Biomass Program. Updated supply curves—currently used in the Biomass Transition Model—are available, but were not used in updating the GPRA models. This may have the effect of constraining biomass availability below the level available in the Biomass Transition Model. In the upcoming cycle for GPRA 08, we should consider updating the NEMS-GPRA08 and MARKAL-GPRA08 models to make them consistent with the Biomass Transition Model. In the case of NEMS, we will need to regionalize the supply curves.

Energy Markets

In the past, projections have changed little from year to year. Not so this year. The AEO 2006 projections were officially published in February 2006. They show what is nothing short of a "sea change" in EIA's perspective on energy prices. On average, for example, the new oil price projections are more than double the prices projected in AEO 2005.

The GPRA 07 benefits estimates are based on energy projections reported by the Energy Information Administration in their *Annual Energy Outlook 2005* (AEO 2005) report. The timing and level of effort involved in putting together the GPRA benefits forces us to use projections for energy markets that are roughly one year behind what is available by the time we publish our benefits estimates. While we realize that updating to AEO 2006 energy prices would make a big difference in projected market penetration of biomass technology and other energy efficiency and renewable energy technologies, we simply do not have time to completely redo the benefits estimates for the entire EERE technology portfolio. To remain consistent with the rest of the portfolio, the new inputs for the Biomass Program also use last year's lower energy prices.

Adjusting Industry Growth Constraints

In the NEMS-GPRA07 and MARKAL-GPRA07 models, we have increased the constraints on industry growth to make them consistent with assumptions in the Biomass Transition Model. Thus, bioethanol capacity now has a maximum growth rate of 25% per year, up to a limit of around 5 billion gallons per year of new capacity. These higher growth rates are based on historical data for growth of the existing corn ethanol industry and growth of U.S. gasoline refining capacity.

Sources

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[1] Petroleum Marketing Annual 2004, U.S. Energy Information Administration, Table 48.
[2] Davis, S.C., and S.W. Diegel, “Transportation Energy Data Book.” Oak Ridge National Laboratory, Edition 24, December 2004.
[3] *Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000*, National Research Council, http://www.nap.edu/catalog/10165.html

[4] Oak Ridge National Laboratory. BIOCOST: A Tool to Estimate Energy Crops on a PC. http://bioenergy.ornl.gov/papers/misc/biocost.html.

[5] Daryll E. Ray, Daniel G. De La Torre Ugarte, Michael R. Dicks, and Kelly H. Tiller, "The Polysis Modeling Framework: A Documentation." Agricultural Policy Analysis Center, University of Tennessee, May 1998, http://apacweb.ag.utk.edu/polysys.html
[6] “Aggressive Growth in the Use of Bioderived Energy and Products in the U.S. by 2010” Unpublished report prepared by Arthur D. Little Inc. for U.S. Department of Energy, Oct. 2001.
[7] Graham, R.L, "Key Findings of the Corn Stover Supply Analysis," Oak Ridge National Laboratory, unpublished paper, October 15, 2003.

Appendix D – GPRA07 Solar Energy Technologies Program Documentation

1. Introduction

This appendix provides detailed information on the assumptions and methods employed to estimate the benefits of EERE's Solar Energy Technologies Program. The benefits analysis for the Solar Program utilized both NEMS and MARKAL as the analytical tools for estimating the program's benefits. As will be discussed below, a number of assumptions and structural modifications to the models were made in order to represent the suite of solar technologies funded by the program as accurately as possible—photovoltaics (PVs) and concentrating solar power (CSP). Many of the assumptions used in the FY07 analysis are the same as or similar to those employed in the FY06 analysis; however, two key changes are important to highlight up-front. First, the program case cost targets for photovoltaics included here are considerably more aggressive than the GRPA06 targets. This reflects anticipated changes in FY07 in the solar program's structure and funding as included in the President's Solar America Initiative. Second, the FY07 analysis does not include Solar Hot Water (SHW) technology benefits which were included in the FY06 analysis. This change is based on zeroing out funding for SHW as reflected in the president's proposed in FY07 budget.

The body of this appendix contains two sections. The first discusses the assumptions used to construct the GPRA07 Solar Program baseline scenario. The second discusses the modifications that were made to this baseline to construct the GPRA07 solar program scenario.

2. GPRA07 Solar Program Baseline Assumptions

Several changes from the *AEO2005* Reference Case were incorporated into the GPRA07 Baseline. These changes include the following:

Revising projected PV cost. The residential and commercial PV system characteristics in the *AEO2005* were based on a recent Navigant Consulting report (Navigant 2003). This report lays out a projection of future PV system costs, but does not explicitly distinguish between Federal R&D and private activity effects. However, the projections are very similar to the program's FY06 targets as laid out in its recent draft Multi-Year Program Plan (DOE 2005). Thus, the *AEO2005* targets do appear to include R&D. As such, they are not appropriate for use as a Baseline from which the program's impacts are to be measured. Therefore, an alternative Baseline was developed assuming that private industry would continue to improve first-generation PV (crystalline silicon) technology, but would not invest significantly on its own in second- or third-generation PV (thin-film, etc.) technologies. As shown in **Figure 1**, changes in the program's structure and funding levels are expected to result in accelerated cost reductions through 2015 under the GPRA07 Program case. In constructing the GPRA07 baseline, the following approach was used. Between 2005 and 2015, the costs of PV are assumed to decline more slowly than in the *AEO2005* targets, leading to a five-year lag between the GPRA07 baseline and *AEO2005* targets by 2015. Beyond 2015, the GPRA07 baseline and GPRA07 program numbers are assumed to continue to diverge. This approach captures the notion of technological lock-in (Cowan and Kline 1996).

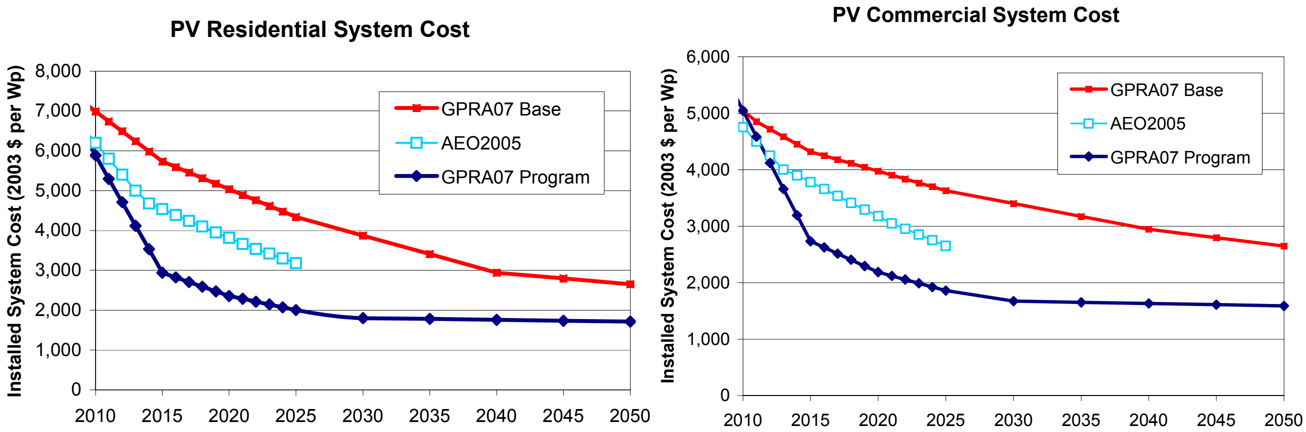

Figure 1. Projected PV System Costs

Increasing the average commercial building system size from 25kW to 100kW. A sample of data from 14 PV systems installed by PowerLight Corporation, between July 1999 and March 2003, reveals that the average commercial system installed by PowerLight during this period was 381kW (**Table 1**).

Table 1. Commercial System Size and Surface-Area Requirements

PowerLight System Installation Location	Date Completed	System Peak Capacity (kW)	PV Surface Area (sq. ft.)	W/sq.ft.
Santa Rita Jail – Alameda County, California	Apr-02	1,180	130,680	9.0
Cypress Semiconductor – San Jose, California	Jul-02	335	26,100	12.8
Fala Direct Marketing – Farmingdale, New York	Nov-02	1,010	102,700	9.8
Fetzer Vineyards – Hopland, California	Jul-99	41	3,750	10.9
Franchise Tax Board – a Sacramento, California	Aug-02	470	50,000	9.4
Greenpoint Manufacturing – Brooklyn, New York	Mar-03	115	11,500	10.0
Mauna Lani Resort – Kohala Coast, Hawaii	Jan-02	528	43,330	12.2
Naval Base – Coronado, California	Sep-02	924	81,470	11.3
Neutrogena Corp. – Los Angeles, California	Aug-01	229	30,154	7.6
Parker Ranch – Kameula, Hawaii	Jan-01	209	20,000	10.5
PSGA/Ortho-McNeil Facility – Pennsylvania	Apr-02	75	17,500	4.3
U.S. Coast Guard – Boston, Massachusetts	Sep-99	37	3,800	9.7
U.S. Postal Service – Marina del Rey, California	Nov-01	127	15,000	8.5
Yosemite National Park - Yosemite, California	Oct-01	47	4,500	10.4
Total		**5,327**	**540,484**	
Average		**381**	**38,606**	**10**

Source: PowerLight Case Study data sheets, Downloaded from www.powerlight.com, 5/21/03.
Note: Some of the locations shown in this table have multiple installations. In these cases, the total installed capacity is shown above, and the most recent installation date is shown in the date-completed column.

The average space required for these systems was 0.1 sq. ft/W., based on a U.S. average commercial building size in 2000 of 14,500 square feet (AEO2003), and assuming a ratio of usable roof space to floor space of 0.7. This ratio of usable roof space to floor space was based on the "architecturally suitable area" in an International Energy Agency (IEA) report, Table 2, examining the potential for integrated photovoltaics in buildings (IEA 2001). Using this approximation, the average commercial building could easily accommodate a 100 kW PV system, i.e., a 0.7*14,500 sq. ft. = 10,100 sq. ft. PV array. Thus, setting the average system size at 100kW is a conservative assumption based on industry trends, as well as the available roof space on a large share (50+%) of the commercial building stock. This is a very conservative assumption because it does not reflect expectations that the efficiency of PV cells will increase; the space requirements for a PV system will decrease; and, as system costs decline, facades and other spaces (such as parking lots) also could be utilized for PV systems.

Increasing the maximum share of commercial buildings with solar access from 30% to 55%. Similar to the preceding ratio of usable roof space to floor space, the share of roof space suitable for PV installations was based on the published IEA report on integrated photovoltaics in buildings (IEA 2001). This report indicates that a reasonable estimate for the share of roof space suitable for PV installations is 55%. This estimate includes shading and other factors that would limit the use of roof space for PV systems (IEA 2001).

Increasing the average residential building system size from 2kW to 4kW. A couple of years ago, a typical residential rooftop PV system was a 2kW system—this is most likely the source for EIA's 2kW system size in the *AEO2005* reference case. However, residential rooftop systems being installed in Japan, Europe, and the United States have been growing larger. For example, the average Japanese rooftop system size in 2002 was 3.7 kW (Ikki 2003) and the average rooftop system size in California in 2004 was 3.6 kW.[1] The average home in the United States has 1,700 square feet of floor space (this is expected to increase in the future). Using data from EIA's residential energy-consumption survey (EIA 1999, Table HC1-2a) one can estimate a floor- to roof-space ratio of 0.7 (based on distribution of one-story, two-story, and three-story single-family homes). This is a conservative estimate—most homes have pitched roofs, which would increase the total available roof space (yet may make a significant portion of the roof oriented away from the sun). If a typical system can accommodate 10 W/sq.ft (as above), then a 4kW system would require roughly 400 square feet of roof space, which is well below the average available space allowing for multiple floors and pitched roofs. Thus, roof space is not a constraint for installing residential rooftop PV systems in the 4kW range. Because the efficiency of PV cells is likely to improve, a trend toward larger systems on rooftops is likely to continue. Thus, based on available roof space and what is happening in the marketplace, setting the average system size at 4kW is a conservative assumption.

Increasing the maximum share of residential buildings with solar access from 30% to 60%. A maximum share of 60% for residential buildings with solar access was used. This estimate accounts for the fact that some homes will not be suitable for PV systems due to shading,

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[1] This estimate was based on data from the California Energy Commission's Emerging Renewables Program, downloaded on 1/27/05 from www.energy.ca.gov/renewables/emerging_renewables.html. Data on small PV systems (i.e., with a system size under 10kW) were extracted from the full dataset. It indicated that, during 2004, a total of 15.9 MW of PV was installed in 4,372 small PV systems in California, with an average system size of 3.6kW.

building orientation, roof construction, or other factors. This value was calculated from a combination of single-family homes (70%) and multifamily homes (30%), using a 75%-25% split between single-family and multifamily homes (EIA 2003, Table A4). Thus, the average maximum share was set at 0.7*0.75 + 0.3*0.25 = 0.6.

Including a declining PV buy-down program in California. This baseline is constructed under the assumption that the California renewable energy credit program that provided a PV credit of $4,000/kW in 2003 will continue to be available, but will decline by $400/kW per year. This credit is roughly in-line with the declining subsidy included in the recently past California Solar Initiative. This credit was included for the entire Pacific region. Given that a number of other local credits were not included in the GPRA baseline, applying the California state-level credit to the whole Pacific region is likely to be a reasonable approximation.

Modifying the adoption rate of distributed generation technologies. The modification to the adoption rate was based on information provided by the DER program (**Figure 2**). This applies to PV as well as gas-fired CHP technologies.

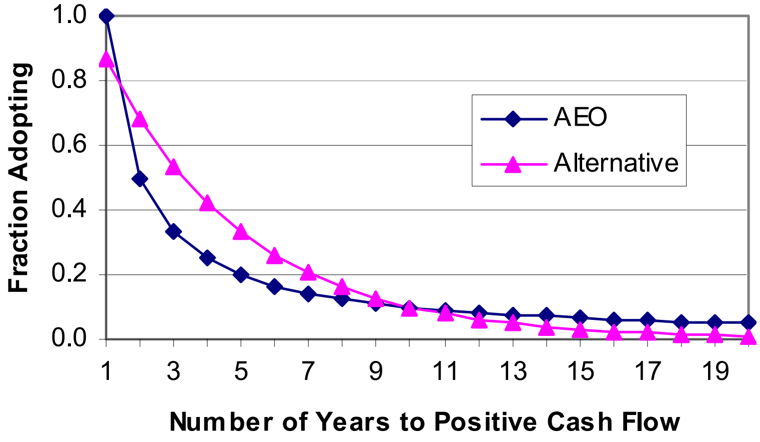

Figure 2. Commercial-Sector DG Adoption Rates

These changes lead to increased adoption of PV systems in the baseline. However, the *AEO2005* assumptions about PV installations through the Million Solar Roofs program were removed, so that there would not be double-counting when these were introduced in the Program Case.

3. GPRA07 Solar Program Scenario Assumptions

Three key sets of assumptions were modified to generate the GPRA07 Solar Program scenario.

Green power additions. Green power additions by region, from Princeton Energy Resources International (PERI), were added back into the Solar Program scenario (**Table 2**). These projections take into account the Baseline assumptions of noneconomic capacity additions. This capacity is added in NEMS-GPRA07 as exogenous additions in residential and commercial buildings.

Table 2. Incremental Green Power PV Capacity Additions (MW)

Incremental Green Power PV Capacity Additions (MW)					
	2007-2010	2011-2015	2016-2020	2021-2025	Total
ECAR	64	183	140	41	428
ERCT	58	167	129	38	392
MAAC	56	159	122	35	372
MAIN	16	47	36	11	110
MAPP	4	12	9	3	28
NY	12	35	27	8	81
NE	16	47	36	10	109
FL	75	214	164	47	500
STV	225	641	491	142	1,500
SPP	61	173	133	40	406
NWPP	11	31	23	7	72
RA	19	54	42	13	128
CNV	0	0	0	1	1
Total	618	1,761	1,350	396	4,125

Technology Characteristics. More aggressive technology targets were used for the range of solar technologies: concentrating solar power (CSP), central PV systems, and distributed PV systems. The CSP technology characteristics were based on the Solar Program's most recent draft Multi-Year Technical Plan (DOE 2005). The PV targets were based on anticipated changes in the Program's structure and funding.

In order to define a consistent set of long-term targets going out to 2050, a multi-lab, multi-technology team was assembled in 2003. This team produced technology cost projections for use in NEMS that are consistent with the Solar Program's Draft Multi-Year Program Plan (DOE 2005) through 2025 and extended the Solar Program's targets to 2050 (for details, see Margolis and Wood 2004). In setting the targets used for PV technology in the GPRA07 analysis, we also drew on the U.S. PV Industry Roadmap (SEIA 2004). Thus the targets shown in **Tables 3 and 4** are consistent with the Program's Draft Multi-Year Program Plan (DOE 2005), Margolis and Wood (2004), and SIEA (2004). It is important to note that beyond 2025, the targets are increasingly uncertain and are likely to be revised as the Solar Program continues to analyze the long-term prospects for technology cost reductions. Note that, on an annual basis, costs are assumed to decline linearly between the years shown in the tables below.

While the technology assumptions for commercial rooftop PV systems are shown above in **Figure 1**, detailed data for PV systems in the three markets modeled is provided in **Table 3**. Although the costs shown below are for specific years, the costs decline annually between the years shown. Note that in both the GPRA baseline and program scenarios, the *AEO2005* Reference Case assumptions for solar insolation and capacity factors were used.

Table 3. PV Systems

	Central Generation		Residential Buildings		Commercial Buildings	
Year	Installed Price (2003$/kW)	O&M (2003$/kW)	Installed Price (2003$/kW)	O&M (2003$/kW)	Installed Price (2003$/kW)	O&M (2003$/kW)
2005	5,500	40	8,500	100	7,000	40
2010	3,700	10	5,600	40	4,800	20
2015	2,100	4	2,800	20	2,600	10
2020	1,680	3	2,240	16	2,080	8
2025	1,428	2.7	1,904	13.6	1,768	7
2030	1,285	2.0	1,714	12.0	1,591	6
2050	1,221	2.0	1,628	12.0	1,512	6

Note: Installed costs do not include the impact of the 10% investment tax credit.

The data for CSP technology shown in **Table 4** are for California. The CSP costs are up to 13% higher in other regions with less solar insolation to account for greater capacity and storage requirements. The annual capacity factors by 2020 range from 49% in MAPP (the Upper Midwest) to 74% in the Southwest. The capacity factors by time period were computed by Sandia analysts to optimize the timing of solar output for each region within the bounds of the storage potential. Note that the *AEO2005* Reference Case assumptions include lower-cost CSP systems, but with significantly less storage and therefore lower electrical output.

The future cost assumptions for CSP technology in the Solar Program scenario are based on a funding level consistent with the FY07 budget request for FY07 and a funding level commensurate with those outlined in the Draft CSP Technology Transition Plan for years beyond FY07 (DOE 2005).

Table 4. Concentrating Solar Power

Year	**Installed Price (2003$/kW)**	**O$M (2003mills/kWh)**	**Capacity Factor**
2010	3,510	7.8	65%
2020	2,462	4.0	72%
2025	2,199	3.6	72%
2030	1,993	3.2	72%
2035	1,879	3.1	72%
2040	1,826	3.0	72%
2050	1,797	2.9	72%

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Appendix E – GPRA07 Wind Technologies Program Documentation

Introduction

GPRA benefits for the Wind Technologies Program are estimated primarily from model projections of the market share for wind technologies, based on their economic characteristics. Two models are utilized for this purpose: NEMS-GPRA07 (a modified version of the National Energy Modeling System), and MARKAL-GPRA07 (a modified version of standard MARKAL). This document describes the inputs and assumptions that are used by the models to calculate those benefits.

FY07 Program Goals Assessed

Program Objective

The mission of the Wind Technologies Program is to "*lead the Nation's research and development efforts to improve wind energy technology through public/private partnerships that enhance domestic economic benefit from development, and to address the barriers to the use of wind energy in coordination with stakeholders, resulting in greater energy security through more diverse, clean, reliable, affordable and secure domestic supply*." To achieve the mission, the Wind Program portfolio includes both short-term and long-term research and outreach to solve technology and institutional issues. Balancing this portfolio effectively will help maintain U.S. wind industry momentum.

Program Performance Goals

The Wind Program's Multi-Year Program Plan [6] contains the following goals[1]:

- By 2012, reduce the cost of electricity (COE) from large wind systems in Class 4 winds to 3.6 cents/kWh for onshore systems (from a baseline of 5.5 cents/kWh in 2002)
- By 2014, reduce the COE from large wind systems in Class 6 winds to 5 cents/kWh for shallow water (depths up to 30 meters) offshore systems (from a baseline of 9.5 cents in FY 2005)
- By 2016, reduce the COE from large wind systems in Class 6 winds to 5 cents/kWh for transitional (depths up to 60 meters) offshore systems (from a baseline of 12 cents in FY 2006)

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[1] Onshore system COEs are stated in 2002 dollars for consistency with other Wind Program documents. However, to be consistent with AEO 05 assumptions used in NEMS, the onshore COE figures should be converted to 2003 dollars using the GDP deflator of 1.018312. Likewise, offshore COE figures above are stated in 2005 dollars, and a deflator of 0.960338 should be used to convert those to 2003 dollars.

- By 2007, reduce the COE from distributed wind systems to 10-15 cents/kWh in Class 3 wind resources, from a baseline of 17-22 cents/kWh in 2002.
- By 2010, facilitate the installation of at least 100 MW of wind in at least 30 states from a baseline of eight states in 2002.

Resource Assumptions

The Fiscal Year 2007 budget request[2] for Wind Energy is $43.8 million, a nearly $5 million increase over the Fiscal Year 2006 Appropriation. A summary of the recent and requested budget, by major activity area, is shown in Table 1. The table shows a large portion of the appropriated FY 2006 budget for congressionally directed activities ($12.87 million).

Table 1. FY 2007 Budget Request for Wind Energy Program

Funding ($ in thousands)			
Activity	**FY 2005 Approp.**	**FY 2006 Approp.**	**FY 2007 Request**
Technology Viability..........................	25,961	18,353	35,905
Technology Application.....................	10,111	7,634	7,914
Congressionally Directed Activities....	4,559	12,870	0
TOTAL...	**40,631**	**38,857**	**43,819**

An estimated breakout of the FY 2007 requested budget by program performance goal categories is shown Table 2. Figures are based on preliminary assessments.

Table 2. Estimated FY 2007 Budget By Performance Goal Category

Performance Goal Category	Estimated 2007 Budget ($ million)
Low Wind Speed Technology	19.4
Offshore Wind Technology	15.0
Distributed Wind Technology	1.0
Wind Grid Integration/Systems Integration	4.1
Technology Application/Technology Acceptance and Coordination	3.9
Small Business Innovative Research (not a specific category)	0.9

Funding for congressionally directed activities for FY 2007 and beyond is assumed to be zero. Future program funding is assumed to remain level at the FY 2007 request level through completion of offshore wind turbine R&D in 2016. The program estimates the annual industry cost-sharing level for all private/public partnerships to be approximately 50%. Figure P.1 in the Preface to the main report depicts the logical flow of all generalized aspects of the program.

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[2] EERE's FY07 "Budget in Brief" may be accessed at http://www1.eere.energy.gov/ba/pba/budget_07.html.

Significant Changes

The program's 2012 goal for onshore low wind-speed technology (LWST) was revised in FY06 from 3.0 cents/kWh to 3.6 cents/kWh in Class 4 sites.[3] The leading factor for this revision was the reduction in discretionary FY06 funding, which caused a large reduction in research and industry subcontracts for onshore technology development.

As a result of funding reductions, several full system and component development projects had to be rescoped or terminated. Even if full funding were to be restored to these projects in future years, significant project momentum has been lost, thus reducing the likelihood of timely COE impacts. A closely related factor is the balance between the Wind Program onshore and offshore activities in a constrained funding environment. The values used for the wind technology cost and performance projections in the GPRA benefits analysis are consistent with this new goal.

The assessment of current status and future trends for offshore wind energy technology, and the formulation of R&D goals, has been under development for the past two years. The Wind Program continues to develop data and analysis toward that end. For this year's GPRA analysis, cost and performance estimates for offshore wind technology include a combination of shallow water technology (depths of 30 meters and less), which is competitive in near term; and transitional water technology (depths of 30-60 meters), which will be competitive beginning in the midterm, have been determined that are consistent with program goals. This is a change from the FY 2006 GPRA analysis, which used a combination of shallow and deep water technology, the latter in water from 60 to 900 meters. These depth figures were developed by the program. The program views this revised strategy as one of incremental technology development—moving from the better understood shallow water technologies to the transitional depth; and, finally, utilizing the accumulated knowledge base from those two applications for eventual deep water technology development.

Target Markets (The Base Case)

Target market Description

Large-scale wind energy is expected to penetrate in two market segments: the least-cost (competitive bulk power) power market and the segment comprising a combination of voluntary (green power) and mandatory (green power or renewable portfolio standards) market programs or requirements. Because of the geographic diversity of the resource, wind energy is also available in any combination of grid-integration scenarios, including large or small plants at long or short distances from transmissions and distribution tie-in points. For instance, large amounts of offshore wind energy is available near load centers in the Northeast Region, whereas the wind resource in the Southeast region is relatively far from the largest load centers in the western part of that.

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[3] COEs are stated in constant 2002 dollars, to be consistent with other program documents. To be consistent with the AEO 05 assumptions used in NEMS modeling for this GPRA report, the onshore COE figures should be converted to 2003 dollars using the GDP inflator of 1.018312. Thus, 3 and 3.6 cents/kWh become 3.05 and 3.67 in 2003 dollars.

Currently, wind turbines in Class 6 wind sites (6.4 – 7.0 m/s at 10 m height) compete well against conventional power producers such as gas, oil, and hydro; and the costs are becoming increasingly competitive with coal-fired power production. However, as the industry grows, the areas with excellent Class 6 wind resources located close to load centers are dwindling; and wind growth is hampered as it expands to the more remote, windy regions of the country, such as the Great Plains. In many of these windier (Class 6) locations, grid connection is problematic because they are so far from load centers and because of capacity constraints on existing transmission lines. A recent study illustrates this for North and South Dakota. [8]

Class 4 wind sites (5.6 – 6.0 m/s at 10 m height), covering a much broader area of the nation, are on average five times closer to load centers and represent 20 times more wind resource. [7] Modeling for the FY 2006 GPRA report showed that with successful implementation of the Wind Program activities that provide industry with the means to develop Class 4 sites, the annual generating capacity for land based wind applications could be more than 90 gigawatts (GW) by 2025. However; the only way wind can currently take advantage of Class 4 sites economically is with the support of the Federal production tax credit (PTC). The PTC has been available only intermittently. Through 2005, the PTC has been extended for no more than two years at a time, and there have been periods of uncertainty when the PTC has lapsed, which retards the development of a solid manufacturing base in the United States. The Energy Policy Act of 2005 extended the PTC through 2007, but it is unclear whether it will be extended beyond that time. The uncertain availability of the tax credit forces the wind industry into a boom or bust cycle, reducing efficiency and increasing costs. Reducing wind energy cost to levels that are competitive without dependence upon tax incentives is one of the drivers of the wind program.

The shallow water technology goal of 5 cents/kWh in class 6 winds by 2014 would achieve commercial costs at approximately 10% of U.S. sites between 5 and 50 nautical miles from shore, specifically in the constrained electricity markets along the east coast. Estimates place these resources at approximately an additional 90 GW for regions that have been surveyed. [6] A paper that further examines these estimates is due to be published in FY 07. [10] Gaining access to the shallow offshore market will allow wind technologies to supply low-cost energy to this congested region.

In the midterm, offshore technology development will focus on turbine support structures for installations at depths up to approximately 60 meters and technologies to offset inherent adversities such as increased distance from shore, decreased accessibility, and more severe environmental conditions. This technology development pathway is planned to begin in FY 2007 with a goal of 5 cents/kWh in Class 6 winds by 2016. If this technology is fully developed, then a total of 25% of surveyed resources between 5 and 50 nautical miles from shore would be available for wind deployment. Estimates of these resources add approximately 180 GW to the available development potential in the surveyed regions.

Distributed and small wind applications have also played a key, although smaller, role within the DOE's Wind Program. Focusing primarily on wind turbines rated less than 100 kilowatts (kW) in size, the needs of this market are expected to be met by approximately 13,000 units worldwide in 2005, of which about half will come from U.S.-based suppliers. Continued downward trends in the cost of energy (COE) of these turbines and expanded state-based subsidies are expected to greatly expand this market through 2011. Distributed Wind Technologies are currently not assessed as part of the GPRA benefits analysis.

Baseline Technology Improvements

The GPRA FY 07 baseline trajectory is based on the assumption that wind energy technology will continue to improve over time without EERE-sponsored R&D. The wind energy industry is comprised of several major international manufacturers and many smaller manufacturers, consultants, and government and university researchers. In addition to the United States, the primary expertise currently lies in Europe. Additionally, Japan—and, increasingly, India and China—will also provide expertise for future technology development. The baseline projections for onshore technology include only incremental improvements for higher wind-speed technology. The assumption for low wind-speed technology is that somewhat more R&D will be applied by non-EERE entities to continue to bring cost of energy down. Europe has much less land available in all wind classes than the United States, but especially in the higher classes. Therefore, they may be expected to focus some R&D on lower wind-speed technology. Additionally, since low wind-speed technology increases the international market potential, manufacturers should be interested in continuing improvements. Finally, because past R&D has focused on higher wind-speed technology, there is more potential for technical improvements to low wind-speed technology. However, current market trends demonstrate more interest among European turbine manufactures in considering shallow water offshore technologies operating in higher wind resource areas in place of further investments in low wind-speed technologies. Additionally, the European renewable electricity sector has a large environmental component, which allows wind technologies to be cost-competitive at a higher cost than would be acceptable in the U.S. market. Both of these factors indicate that although technology improvement in Europe will impact the U.S. market, they are unlikely to address several issues specific to the U.S. market.

More than 700 megawatts of offshore wind energy capacity is operating in shallow waters off the shores of several European countries, and some of these countries are pursuing plans for major expansions of offshore wind power. [6] Offshore turbines have been operating in Europe for more than 10 years, primarily using marinized versions of onshore wind turbines installed on monopile tube towers in shallow waters (under 20 meters). The primary drivers have been the limited availability of suitable land-based sites in Northern Europe and favorable wind energy pricing. Early efforts to develop offshore wind energy were not considered relevant to the United States, because of widely available U.S. onshore wind resources. However, the lack of low-cost environmentally friendly energy supply options, especially in the Northeast; positive market incentives; and the scarcity of excellent wind sites in proximity to load centers along the coasts, have made offshore wind technologies an increasingly economically competitive electric power generation technology.

European offshore conditions are fairly dissimilar to those in the United States. The continental shelf typically drops off much faster from our coasts. Without R&D support from EERE, European offshore technology can only be used for shallow water sites in the United States. The GPRA baseline assumes that there would be a 10-year lag in technology development for transitional depth technologies because, without the need for that technology in Europe, its development would be dependent on manufacturers, developers, installers, and operators first obtaining substantial experience with shallow water technology in the United States. The Wind Program based that estimate on expectations for a shallow water market to develop over the next 10 years. Given the difficulties faced by offshore projects in overcoming a variety of barriers to market acceptance during the past several years, and those projected for at least the next few years, the 10-year estimate may be a slight underestimate.

Baseline Market Acceptance

The U.S. large turbine wind energy market has been characterized by boom and bust cycles driven by the instability of the federal production tax credit (PTC). Table 3 shows the incremental installed wind capacity since 2000 and illustrates the sensitivity of annual installed capacity levels to the PTC, which was in place in 2001, 2003, and 2005. It also demonstrates the mainstream acceptance of wind energy technology in the current market. The American Wind Energy Association is predicting several more years of installation rates above 2,000 MW/year.

Table 3. U.S. Installed Wind Energy Capacity 2000–2006

	Annual Installed Capacity (MW)	Cumulative Installed Capacity (MW)
2000	67	2,578
2001	1,697	4,275
2002	446	4,685
2003	1,687	6,372
2004	389	6,740
2005	2,431	9,149
2006	3,000+	12,150+

References: Press Releases, American Wind Energy Association, May 12, 2005, and January 24, 2006

Key Factors in Shaping Market Adoption

Price

Through program-sponsored research, wind technology is projected to improve significantly over the next decade. This improvement is represented in the GPRA07 modeling effort by a declining capital cost trajectory, lower O&M costs, and increased performance. These projections match the program's performance goals, as described above. The Wind Energy Program forms its goals using a probabilistic modeling technique.[4] The projected COEs

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[4] The technique first requires a reference set of performance and capital and operating cost characteristics for wind plants, using a composite of leading-edge technology for the reference year. It next defines a set of Technology Improvement Opportunities (TIOs) that may lead to lower levelized cost of energy (COE). A set of quantitative estimates of improvements to COE equation inputs (e.g., turbine cost, net annual energy) are then made for each TIO. A wind plant COE spreadsheet model is then run using Monte Carlo simulation add-on software to obtain a probabilistic evaluating of COEs for possible turbine technology configurations, or "pathways," resulting from successful implementation of all possible combinations of those improvements. This approach captures the uncertainty of both R&D outcomes (potential sizes of various improvements) and the probability of achieving any improvement, (R&D "success"), regardless of the improvement size.

resulting from the cost and performance trajectories therefore represent figures that are close to the mean expected value, not the most optimistic or most conservative possible.

Although there is a standard mathematical formula for characterizing cost reductions in manufactured goods from "learning effects," there is no standard definition of the term, i.e. what effects it includes; nor is there an accepted single set of assumptions and overall methodological approach for calculating or predicting learning curve (sometimes referred to as "experience curve") impacts. While some cost reductions may result from "learning" that is dependent on cumulative volume levels, other cost reductions may be obtained from economies of scale due to levels of *annual* volume of production. Therefore, the program's analysis reflects the potential, on a probabilistic basis, for corresponding cost reductions that would result from both learning curve effects and economies of scale, the latter including discounts for large- volume purchase of materials, parts and components.

The Wind Program's "pathways analysis" assumes that there is at least a chance that the annual level of wind turbine manufacturing output will increase over time, along with cumulative volume. The program represents cost reductions from both annual and cumulative volume in a single number, for which an estimated range is discussed in the remainder of this section. The bottom end of that range is low enough (2%) to represent reductions from any combination of annual or cumulative volume increases. A complete discussion of cost-reduction potential from learning effects and economies of scale can be found in "Wind Energy Technology Pathways Analysis Methodology and Baseline Report" to be published by NREL in FY 2006.

Among the parameters affecting the magnitude of the learning rate for a global technology are: exchange rates, choice of inflators to correct for inflation, use of production costs versus market prices, choice of market boundaries and subsequent inclusion or exclusion of imports or exports from cumulative production levels, definition of production units (e.g., energy production, capacity or number of turbines), and cost or price (e.g., \$/turbine, \$/kW, \$/wind plant, \$/kWh produced). In addition, off-the-shelf components of wind energy plants that are already mass-produced will tend to show much less cost decrease over time than lower volume, custom-designed and -built components, because the former have already "come down" the learning curve.[4] The assumed mix of these two different types of components will impact the learning rate. There is also uncertainty concerning whether learning rates remain constant over time or tend to decrease, causing cost reductions to diminish as market diffusion increases. There are arguments to support the possibility of either case occurring.[5]

Although the application of learning curves to wind energy cost contains a large number of uncertainties, there have been many recent attempts to construct such curves from the growing set of empirical market data. Those data shows that most reductions in cost for the various markets studied have been from 2% to 15% for every doubling of cumulative installed capacity. Despite the difficulties in applying learning curve theory to projection of future costs, the relatively narrow range of results across those many studies can be used to develop a reasonable range of estimates for potential cost reductions from learning. Accordingly, the Wind Program chose a range of 2% to 15% cost reduction for overall capital cost-reduction potential from learning by 2012 for onshore wind plants, with the expected value of 5% chosen to skew the distribution of values toward the conservative side. In addition, lower rates of cost reduction were chosen for balance of station costs, O&M costs, and replacement costs, because it was assumed that a larger percentage of leaning from onshore experience transfers in these areas than in the specialized platforms that contribute heavily to the initial capital cost.

The program's projected cost reduction from learning and increased economies of scale can result from a wide range of assumptions for the combination of the learning and market diffusion rates (i.e. doublings of wind turbine production and increase in annual production levels). Even the maximum level of cost reduction estimated by 2012, 15%, can be met by quite conservative combinations of those factors. In addition, the small, incremental cost reductions beyond 2012 for onshore wind plants, and in the later years for offshore plants (i.e. in years past, the point where the have met the program goals), can be easily justified by conservative assumptions regarding learning effects and economies of scale.

Nonprice Factors

In addition to competing on an economic basis with other electricity generation technologies, wind capacity may be partly valued for its environmental attributes. Renewable energy credit markets, green power programs, and renewable portfolio standards are all examples of ways such value is beginning to be recognized in the market.

Electricity produced from offshore locations is expected to be of higher value than many onshore locations in many cases, because proximity of several major load centers to the coasts could reduce transmission constraints and costs facing large-scale onshore power generation.

Methodology and Calculations

Inputs To Base Case

The GPRA07 Baseline is a modification of the *AEO2005* Reference Case for onshore technologies. Offshore wind technology currently is not included in the AEO reference case, and so the program decided to use the technology characteristics (capital and operating costs, and energy production) equivalent to the preliminary program case values developed in June 2005[5], but lagged by 10 years. In other words, progress in offshore wind technology in the absence of program R&D was assumed to be slower but eventually achieve the program goals. The onshore wind technology representation was modified to reflect the fact that the Wind Program has a different view of the characteristics of current technology than that in the AEO, as well as the trajectory over time. The program estimates of wind capacity factors are 12% to 13% higher than EIA's (e.g. 0.47 for Class 6 versus 0.41), and their 2005 capital costs are just slightly lower. Justification for Wind Program estimates for both current and future technology characteristics for turbines in Class 4 sites are contained in a report expected to be published by NREL in FY 2006, tentatively titled, "Low Wind Speed Turbine Pathways Analysis Report," which updates earlier, preliminary documentation.[1]

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[5] Note, as a result of the emerging nature of the offshore program, its goals were later modified; but the GPRA Baseline was not revised due to timing constraints. The revised program cost and performance goals are less aggressive than the original ones. This discrepancy will be addressed in the FY 2008 GPRA analysis.

In addition, the *AEO2005* assumed that any cost improvement over time results only from a learning (or experience) effect that lowers cost proportional to the increase in cumulative installed volume, but not from R&D advances. Because the AEO projects a small amount of penetration (additional cumulative volume), the capital cost decrease in the AEO projections is negligible. Under that assumption, the onshore costs eventually become greater than the Wind Program's projected offshore costs because the rate of offshore improvements is higher than for the onshore. Although such a relative cost relationship in the long-term is not yet intuitively understood by researchers, the assumption used for this GPRA analysis is that offshore costs should remain higher than those for onshore. Studies initiated by the program are currently addressing this area in detail, and assumptions will be revisited for the FY 2008 GPRA analysis.[6]

A new baseline onshore cost trajectory was constructed to address those issues. The initial point in 2005 reflects an average of the program and AEO points. The levelized cost of energy (COE) trajectory then declines, so that by 2050 the onshore cost remains below the offshore costs by a ratio equivalent to that of the Program Case. Capital costs, O&M costs, and capacity factors were modified proportionally to achieve the target COE. The resulting COEs for Class 6 are illustrated in Figure 1. Table 4 provides the baseline values for the all the wind classes and technology types required for NEMS and MARKAL modeling.

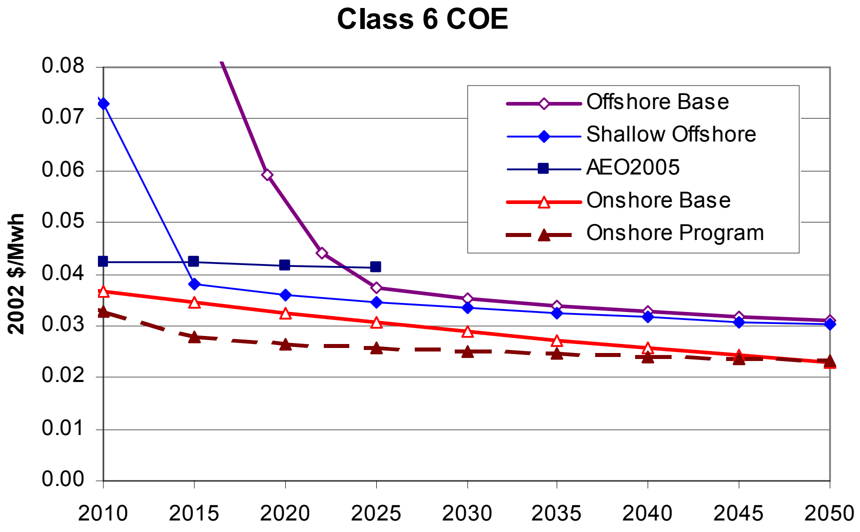

Figure 1. Class 6 Baseline and Program COE Trajectories

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[6] While cost characteristics for offshore wind turbine components will differ somewhat from their offshore counterparts, due to potential size differences and to unique requirements for reliability, durability, and serviceability in the marine environment, many aspects of the two systems will continue to be similar and are expected to track each other in terms of future cost reductions. However, the platform and anchoring components for offshore systems are unique to that application, and will be subject to steeper cost reductions from learning, relative to the rest of the plant equipment, as designs enter the market and subsequent cumulative volume increases.

Table 4. GPRA07 Baseline Technology Characteristics (Model Inputs)

2003 Dollars		2005	2010	2015	2020	2025	2030	2040	2050
Capital Costs*									
Onshore	Class 5&6	1069	1026	985	946	907	872	802	739
	Class 4	1123	1087	1051	1016	984	951	890	833
Offshore	Shallow	2132	2132	1691	1334	934	905	818	771
	Transitional	2519	2519	2203	1905	1143	953	905	858
O&M Costs									
Onshore	All Classes	25.5	23.6	21.9	20.3	18.7	17.4	15.0	12.8
Offshore	Shallow	45.2	45.2	45.2	41.9	36.5	33.8	32.1	30.3
	Transitional	67.9	67.9	67.9	73.9	44.5	35.6	32.1	30.3
Capacity Factors									
Onshore	Class 6	0.440	0.448	0.457	0.466	0.476	0.485	0.504	0.525
	Class 5	0.402	0.412	0.423	0.434	0.446	0.458	0.482	0.508
	Class 4	0.348	0.356	0.364	0.372	0.381	0.389	0.407	0.425
Offshore	Class 6	0.391	0.405	0.428	0.467	0.500	0.500	0.500	0.500
Shallow	Class 5	0.358	0.380	0.389	0.403	0.430	0.430	0.430	0.430
	Class 4	0.264	0.317	0.332	0.356	0.400	0.400	0.400	0.400
Offshore	Class 7	0.468	0.484	0.485	0.486	0.549	0.556	0.600	0.600
Transitional	Class 6	0.382	0.394	0.396	0.399	0.421	0.463	0.500	0.500
	Class 5	0.340	0.358	0.357	0.355	0.394	0.398	0.430	0.430

*Includes 1.05 contingency factor for onshore systems and 1.07 for offshore systems. [1] [2] [6]
Onshore cost were converted from 2002 dollars using GDP inflator of 1.018312. Offshore costs were converted from 2005 dollars using GDP deflator of 0.960338

Technical Characteristics

Description of Key Elements of the National Energy Modeling System (NEMS) Approach to Modeling Wind

The electricity-sector module performs an economic analysis of alternative technologies in each of 13 regions. Within each region, new capacity is selected based on its relative capital and operating costs, its operating performance (i.e. capacity factor, which reflects energy conversion efficiency, and both resource and plant availability), the regional load requirements, and existing capacity resources. NEMS-GPRA07 characterizes wind by three wind classes, each with its own capital costs and resource cost multipliers. Different wind classes are used for different technology applications—classes 4, 5 and 6 for land-based technologies, and 5, 6, and 7 for offshore technologies. The regional resource cost multipliers increase capital costs as increasing portions of a wind class are developed in a given region to reflect 1) declining natural resource quality, 2) required transmission network upgrades, 3) competition with other market uses, including aesthetic or environmental concerns. As the cost in that region increases, it may be more cost-effective to consider installing wind turbines in areas of lesser wind resource, but with lower ancillary costs and less costly access to the grid, as reflected in the model by the capital cost multipliers.

Other key assumptions that can affect projections include a limit on the share of generation in each region that can be met with intermittent technologies. The *AEO2005* assumption that wind may provide only a maximum of 20% of a region's generation was maintained, even though the program disagrees with that characterization. NEMS-GPRA07, as in the *AEO2005*, also assumes that the capacity value of wind diminishes with increasing levels of installed wind capacity in a region. Finally, another constraint on the growth of wind resource development is how quickly the wind industry can expand before costs increase due to manufacturing bottlenecks. The *AEO2005* assumption that a cost premium is imposed when new orders exceed 50% of installed capacity was maintained for the benefits analysis.

As part of the development efforts for the offshore wind energy activates, the program is currently working to upgrade the NEMS software to more accurately model offshore wind technologies. The first stage of these efforts is represented in the FY2007 version of the software, and additional improvements are expected to be made in the FY2008 GPRA analysis.

Further detail on the representation of wind power in NEMS may be found in Chapter 2.

Wind Program Case Assumptions

The assumptions about capital costs, capacity factors, and O&M costs—which are used as inputs into the NEMS-GPRA07 model for the Program Case—are provided in Table 5. These projections match the program's performance goals, as described above. Projections for onshore wind plants are consistent with the analysis described in [6]. The capital costs include a contingency factor of 5% for onshore wind and 7% for offshore wind, similar to other electric-generating technologies. The current technology characteristics in Table 5 represent leading-edge technology available in the market. The projected characteristics for low wind speed onshore wind plants result from the probabilistic path analysis approach described on Page 7 of this appendix. Estimates for future technology characteristics are consistent with mean values from that analysis or values that are between the mean and the best. However, they are always significantly below the best (at least 30% in the worst case). As the program develops further data on offshore technology, a similar path analysis is expected to be conducted in FY06 or FY07.

The Program Case wind capital costs were updated in December 2005 to reflect the impact of earmarks on existing and planned projects related to meeting the program goal. Long-term costs were also increased by 5% over FY 2006 values to reflect higher estimates of developer fees, based on analysis of confidential market data. It was too late to change the Baseline as well, so the long-term capital costs are slightly lower in the Baseline than the program case. However, because technologies compete on the basis of cost of energy in the market models, and the higher capacity factors in the program case dominate the difference in COE between the two cases, the impact on the benefits estimate for the program R&D is small.

Program analysis and documentation for offshore technology characteristics is an evolving process as offshore R&D activities ramp up. To develop the offshore cost and performance inputs shown in Table 5, program analysts scaled capital costs over six periods from 2006 to 2025, using learning rates (i.e., capital cost reductions for each period corresponding to a doubling of installed capacity) typical of wind industry experience, and that are assumed to include improvements in technology, production volume, learning curve effects, and improvements in operational proficiency. The doubling periods and learning rates used in the cost calculations were derived from IEA and European reports [3]. The learning rate was augmented by a one-time additional 10% reduction in capital cost in year 2015 due to technology R&D. The resulting levels of improvements to wind plant COE served as an upper boundary for Program Case estimates. That is, the Program Case projections in Table 5 are all within the bounds established by the cost-scaling exercise. The next analytic step for the program will be to apply its Wind Energy Technology Pathways Analysis methodology to transitional water depth offshore technology to obtain probabilistic data for technology characteristic projections.

Table 5. Program Projections for Capital Costs, Capacity Factors, and O&M Costs for Onshore and Offshore Wind Plants

2002 Dollars		2005	2010	2015	2020	2025	2030	2040	2050
Capital Costs*									
Onshore	Class 5&6	1050	982	893	872	866	840	819	798
	Class 4	1103	1034	971	945	919	893	872	851
Offshore	Shallow	2220	1816	1009	969	941	916	866	842
	Transitional	2623	2321	1211	1059	1015	990	941	916
O&M Costs									
Onshore	All Classes	25.0	20.0	16.0	15.0	14.2	13.8	13.2	12.8
Offshore	Shallow	47.1	47.1	38.7	35.8	34.9	33.9	32.1	30.2
	Transitional	70.7	66.0	47.1	37.7	34.9	33.9	32.1	30.2
Capacity Factors									
Onshore	Class 6	0.440	0.475	0.500	0.511	0.517	0.519	0.523	0.525
	Class 5	0.402	0.445	0.470	0.482	0.490	0.492	0.497	0.500
	Class 4	0.348	0.400	0.460	0.469	0.472	0.474	0.479	0.480
Offshore	Class 6	0.405	0.435	0.500	0.505	0.510	0.511	0.513	0.515
Shallow	Class 5	0.380	0.400	0.430	0.435	0.440	0.441	0.443	0.445
	Class 4	0.317	0.355	0.400	0.405	0.410	0.411	0.413	0.415
Offshore	Class 7	0.484	0.486	0.516	0.544	0.556	0.574	0.574	0.574
Transitional	Class 6	0.381	0.387	0.458	0.478	0.494	0.511	0.513	0.515
	Class 5	0.304	0.356	0.394	0.412	0.426	0.441	0.443	0.445

*Includes 1.05 contingency factor for onshore systems and 1.07 for offshore systems. [2] [3]

It was necessary to make one major modification to the offshore wind resource inputs for the NEMS model. The current NEMS-GPRA07 projections include very high offshore wind penetration in the Southeastern Electric Reliability Council (SERC) region. The NEMS model splits the United States electricity market into 13 North American Electric Reliability Council (NERC) regions. The SERC region includes the Virginia-Carolinas sub-region (VACAR), the TVA sub-region (Tennessee and adjacent portions of Alabama, Georgia, Kentucky, and Mississippi), and the Southern sub-region (Georgia, Alabama, part of Mississippi, and the panhandle of Florida), and is the largest of the NERC regions in terms of electricity sales (almost 23% of total U.S. sales[7]). All electricity technologies represented in NEMS compete within these 13 regions for market share.

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[7] Energy Information Administration, Annual Energy Outlook 2005 Supplemental Tables (Tables 60-72).

Updated resource curves for the SERC region are being used for the FY 2007 GPRA NEMS analysis. The resource curves provided by NREL for the SERC region account for offshore wind classes 5 and above that are located off the shores of Virginia, North Carolina, and South Carolina. Because SERC includes many inland areas far from these offshore wind resources, one can argue that there might be significant portions of the region where the transmission of electricity produced by these wind resources would be cost-prohibitive. However, because the NEMS model treats the region as one market, transmission costs are assumed to be equal throughout the region. This explains why the model tends to produce offshore wind penetration levels in the SERC region much higher than expected.

In order to address this issue within the current GPRA cycle, a short-term solution was developed; namely, to adjust the SERC offshore wind data to reflect the portion of the region that is in close enough proximity to the resources for cost-effective transmission. The latest electricity sales data by state from EIA[8] indicates that the three states nearest to the offshore wind resources (Virginia, North Carolina, and South Carolina) account for roughly 38% of total sales in the SERC region. Because a small portion of southwestern Virginia is located in the East Central Area Reliability Council (ECAR) region, it was assumed that only 95% of Virginia's sales are included in SERC. This 38% market share then is used to adjust the SERC offshore wind resource data.

MARKAL

The program goals are represented in the MARKAL-GPRA07 model by changing the capital and O&M costs and capacity factors for wind turbines to match the program goals as represented in Table 5.

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

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[8] Energy Information Administration, Electric Power Annual 2003 – Spreadsheets (sales_state.xls).

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Appendix F – GPRA07 Vehicle Technologies Program Documentation

1. Introduction

The target markets for the Office of FreedomCAR and Vehicle Technologies (FCVT) program include light vehicles (cars and light trucks) and heavy vehicles (trucks more than 10,000 pounds Gross Vehicle Weight). Each will be discussed separately below.

1.1 Target Market: Alternate Technology Light Vehicle (ATV) Market

The alternate technology light vehicles (ATVs) included in the FCVT program are gasoline hybrid vehicles, diesel hybrid vehicles, advanced diesel, and advanced gasoline vehicles. The market for these technologies includes all cars and light trucks sold for both personal and business use. Today, the size of this market is approximately 17 million vehicle sales per year. Total car and light truck stock is about 220 million vehicles. EIA projects both sales and stock to grow to more than 20 million and 300 million, respectively, by 2025. Additional growth is expected post-2025, as explained in Chapter 2. The vehicle miles of travel are projected to grow from 3.28 trillion in 2020 to 5.63 trillion in 2050.

1.2 Key Factors in Shaping the Market Adoption of ATVs

Key factors associated with the adoption of new vehicle technologies include how the new vehicle technologies compare with the baseline vehicle technologies in terms of the following vehicle attributes:

- Vehicle Price
- Fuel Economy
- Range
- Maintenance Cost
- Acceleration
- Top Speed
- Luggage Space

Of these, vehicle price and fuel economy are the most important.

Nonvehicle attributes that are important factors in a consumer's decision to purchase new vehicle technologies include the following:

- Fuel Price
- Fuel Availability

1.3 Methodology and Calculations

The factors listed above include the factors used in the modeling of new vehicle technology penetration by the NEMS and MARKAL models. ATV attributes and other factors are discussed below.

1.3.1 ATV Attributes: General

ATV attributes were developed based on the FCVT program goals, discussions with FCVT program managers, Powertrain Systems Analysis Toolkit (PSAT) modeling and payback analysis (Refs. 1-5). The PSAT model is a simulation model used by DOE to evaluate the fuel economy and performance of light vehicles using various technologies. Section 1.3.2 below discusses the fuel economy estimates developed in this analysis. Payback analysis was used to estimate what the incremental price of ATVs would be (given the fuel economies from the PSAT model) when they become cost competitive with conventional vehicles, a goal of the program. Section 1.3.3 below discusses the price estimates in further detail. Other attributes were based on a review of past GPRA characterizations (e.g., Ref. 6).

Because the NEMS and MARKAL models require different levels of detail, two separate vehicle characterizations are provided. In both cases, most of the attributes are provided as ratios to the vehicle attributes of conventional vehicles. (For NEMS, the $ value of the price increments were provided.) The attributes are for new vehicles in the year listed. **Table F-1** contains the vehicle attributes for ATVs provided for input to the NEMS model. Attributes are provided for all six car size classes and six light truck (LT) classes that NEMS uses.

Table F-2 contains vehicle attributes for ATVs provided as input to the MARKAL model. MARKAL uses only vehicle price and fuel economy attributes. MARKAL does not disaggregate cars and light trucks into various classes.

1.3.2 Estimation of ATV MPG Estimates

PSAT model results underlie the fuel economy and cost estimates that serve as input to the GPRA benefits models. This section explains how PSAT results have been used to develop the fuel economy inputs to the GPRA models. While the discussion mentions FCVs (because the same methodology was applied to estimate FCV fuel economy), we do not present the FCV MPG estimates in this appendix.

1. There are two GPRA models: NEMS-GPRA07 and MARKAL-GPRA07. The NEMS-GPRA07 model requires characterization of six cars and six LTs for each technology to 2025. The MARKAL-GPRA07 model requires characterization of an average car and an average LT for each technology to 2050. **Table F-3** summarizes the vehicle classes used in both models.

2. The PSAT model itself only provides fuel economy estimates for 4 of the 12 vehicle classes required by NEMS. The four classes in PSAT are also presented in Table 3. They include compact and midsize cars, a SUV and a pickup. PSAT results for those four classes thus must be adjusted in order to develop the fuel economy estimates required by the GPRA models. This adjustment is made as discussed below using a simple spreadsheet model.
3. Two sets of PSAT results were used in this analysis. One set of PSAT results (new vehicle fuel economies) was provided for five vehicle technologies (advanced gasoline, gasoline HEV, advanced diesel, diesel HEV and FCV) in 3 vehicle classes (midsize car, SUV, and pick-up) in 2 years (2010 and 2020) (3). "Low," "high," and "average" results were provided. The "high" results are the only one of the three sets of results that represent achievement of the goals of the FCVT (and HFCIT) program to 2020 for these three vehicle types. Therefore, we used the

"high" results in our analysis. Because PSAT results were not available for the compact car, we assumed that the "high" results of the midsize cars also apply to the compact cars. We do not use the same fuel economies, but instead use the same ratio or "X" factor of ATV fuel economy relative to the baseline gasoline vehicle fuel economy.

4. For GPRA, estimates need to be developed to 2050. The PSAT results discussed above only extend to 2020. Another set of PSAT results were provided for two vehicle technologies (gasoline HEV and FCV) in 3 vehicle types (compact, midsize car and SUV) in 4 years (2010, 2020, 2035, and 2050) (4). Again, "low" and "high" results were provided. Using the "high" results, we estimated the improvement rate in fuel economy from 2020 to 2035, and 2035 to 2050 for the midsize car and SUV for these two technologies. We then applied the improvement rates for the gasoline HEV to the 2020 estimates developed in No. 3 (midsize car to midsize and compact car and SUV to SUV and pickup) to generate new vehicle fuel economy estimates to 2050 for all the technologies (except the FCV).

5. The payback analysis discussed below uses on-road vehicle fuel economy. We assume a 20% degradation factor between the new vehicle fuel economy estimates generated by PSAT and the fuel economies actually achieved "on-road." (The NEMS and MARKAL models also make this assumption.) This fuel economy degradation factor is then applied to the new vehicle fuel economies developed in No. 3 and No. 4 for ATVs.

6. The PSAT results are developed relative to current gasoline vehicles. EIA projects improvements in conventional gasoline vehicles. The NEMS-GPRA07 and MARKAL-GPRA07 models assume such improvements. We applied EIA's rate of improvement to the current gasoline vehicles modeled in PSAT and developed new vehicle and on-road fuel economies for the four conventional vehicle types characterized so far (midsize car, SUV, pickup and compact car.) For 2025 to 2050, we used EIA's 2020-2025 improvement rate.

7. Given the new vehicle fuel economies developed for advanced technologies in No. 5 and for comparable conventional vehicles in No. 6, the final fuel economy ratios (X factors) for those five technologies (advanced gasoline, gasoline HEV, advanced diesel, diesel HEV and FCV) in four vehicle types (compact -car, midsize car, SUV, and pick-up) in several years (2010, 2020, 2025, 2030, 2035, and 2050) are estimated.

8. For the NEMS model, the new vehicle fuel economy X factors of the compact cars are assumed to apply to the mini-compact, subcompact and two-seater as well as the compact. The new vehicle fuel economy X factors of the midsize cars apply to medium and large cars. The new vehicle fuel economy X factors of the SUV (which is a large SUV according to the NEMS classification) are assumed to apply to large and small SUVs and all vans. The new vehicle fuel economy X factors of the pickup (which is a large pickup according to the NEMS classification) are assumed to apply to both small and large pickups.

9. The fuel economy estimates finalized in No. 7 and No. 8 are for the years 2010, 2020, and 2025. For the NEMS model we need to provide estimates for intervening years. For those intervening years, we use linear interpolation to estimate the X factors.

10. As stated above, the MARKAL model uses only one car and one light truck. We examined current sales volumes of the six different car and six different LT types. Based on that examination, we weighted the compact and midsize cars 50-50 to estimate the fuel economy X factors of an average car and we weighted the SUV and pickup 67-33 to estimate the fuel economy of an average LT.

1.3.3 Incremental Vehicle Price Estimates

As indicated above, payback analysis was used to estimate what the incremental price of ATVs would be when they become cost competitive with conventional vehicles, a goal of the program. The incremental price equals the present value of the energy cost reduction achieved by ATVs over three years, assuming a fuel price of $1.50/gallon gasoline equivalent and 7.5% discount rate. Incremental prices are higher in the early years of market introduction. In fact, we develop three sets of prices for each class of vehicle for input to NEMS. Prices are developed for a "market introduction" date, a "price success" date and a "price maturity" date. The price at "price maturity" is the "final" incremental price; the price at "market introduction" is 50% higher than it would be if the technology were "mature" and the price at "price success" is 10% higher than it would be if the technology were "mature." These dates vary for the different technologies.

For MARKAL, we weight the incremental prices estimated for each technology in 2025 in the same manner that we weighted the fuel economy estimates as described in No. 10 of Section 1.3.1. We then assume a gradually declining incremental price to 2050 for each technology.

1.3.4 ATV Market-Penetration Methodology

Brief descriptions of how the NEMS and MARKAL models each project new vehicle technology penetration using these vehicle attributes can be found in **Chapter 2** (NEMS-GPRA07) and **Chapter 3** (MARKAL-GPRA07).

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Table F-1. ATV Attributes Input to NEMS
All units are ratios to the conventional gasoline vehicles of the specific year, except for the incremental price (which is in 2003 dollars)

	2-SEATER				MINI-COMPACT				SUB-COMPACT				COMPACT			
	Market Intro	Price Success	Price Maturity		Market Intro	Price Success	Price Maturity		Market Intro	Price Success	Price Maturity		Market Intro	Price Success	Price Maturity	
Advanced Diesel	**2014**	**2019**	**2024**	**2025**	**2018**	**2023**	**2025**	**N/A**	**2012**	**2017**	**2022**	**2025**	**2011**	**2016**	**2021**	**2025**
Incremental Vehicle Price ($)	1266	984	900	902	1280	956	925		1003	788	738	742	1001	788	750	753
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20		1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	1.00	0.90	0.90	0.90	0.90	0.90	0.90		0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.41	1.47	1.49	1.49	1.45	1.49	1.49		1.39	1.44	1.48	1.49	1.38	1.43	1.48	1.49
Diesel Hybrid	**2016**	**2021**	**2025**	**N/A**	**2020**	**2025**	**N/A**	**N/A**	**2016**	**2021**	**2025**	**N/A**	**2014**	**2019**	**2024**	**2025**
Incremental Vehicle Price ($)	1843	1414	1303		1871	1360			1509	1160	1072		1480	1167	1066	1067
Range	1.25	1.25	1.25		1.25	1.25			1.25	1.25	1.25		1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05		1.05	1.05			1.05	1.05	1.05		1.05	1.05	1.05	1.05
Acceleration	1.00	1.00	1.00		0.90	0.90			0.90	0.90	0.90		0.90	0.90	0.90	0.90
Top Speed	1.00	1.00	1.00		0.90	0.90			0.90	0.90	0.90		0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95		0.95	0.95			0.95	0.95	0.95		0.95	0.95	0.95	0.95
Fuel Economy	1.75	1.86	1.87		1.86	1.87			1.75	1.86	1.87		1.70	1.83	1.87	1.87
Gasoline Hybrid	**2013**	**2018**	**2023**	**2025**	**2011**	**2016**	**2021**	**2025**	**2010**	**2014**	**2019**	**2025**	**2007**	**2012**	**2017**	**2025**
Incremental Vehicle Price ($)	1370	1116	1042	1043	1245	1035	1010	1009	1023	840	847	858	1057	805	825	871
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel Economy	1.45	1.56	1.61	1.61	1.41	1.52	1.60	1.61	1.39	1.47	1.58	1.61	1.39	1.43	1.54	1.61

Table F-1 (continued)

	MEDIUM CAR				LARGE CAR			
	Market Intro	Price Success	Price Maturity		Market Intro	Price Success	Price Maturity	
Advanced Diesel	**2010**	**2015**	**2020**	**2025**	**2009**	**2014**	**2019**	**2025**
Incremental Vehicle Price ($)	1113	882	851	848	1216	935	903	905
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.36	1.42	1.48	1.49	1.36	1.41	1.46	1.49
Diesel Hybrid	**2014**	**2019**	**2024**	**2025**	**2014**	**2019**	**2024**	**2025**
Incremental Vehicle Price ($)	1682	1324	1205	1205	1808	1419	1287	1286
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Acceleration	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Fuel Economy	1.70	1.83	1.87	1.87	1.70	1.83	1.87	1.87
Gasoline Hybrid	**2006**	**2011**	**2016**	**2025**	**2009**	**2014**	**2019**	**2025**
Incremental Vehicle Price ($)	1200	888	917	983	1281	1037	1042	1048
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Acceleration	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	0.90	0.90	0.90	0.90	1.00	0.90	0.90	0.90
Luggage Space	0.85	0.95	0.95	0.95	0.85	0.95	0.95	0.95
Fuel Economy	1.39	1.41	1.51	1.61	1.39	1.47	1.58	1.61

Table F-1 (continued)

	SMALL SUV				LARGE SUV				SMALL TRUCK				CARGO (Incl. 2b) TRUCK			
	Market Intro	Price Success	Price Maturity		Market Intro	Price Success	Price Maturity		Market Intro	Price Success	Price Maturity		Market Intro	Price Success	Price Maturity	
Advanced Diesel	**2008**	**2013**	**2018**	**2025**	**2007**	**2012**	**2017**	**2025**	**2008**	**2013**	**2018**	**2025**	**2006**	**2011**	**2016**	**2025**
Incremental Vehicle Price ($)	2018	1455	1293	1298	2518	1827	1615	1607	1346	1057	1049	1113	1701	1233	1241	1352
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.75	1.75	1.74	1.78	1.75	1.75	1.74	1.78	1.43	1.48	1.56	1.64	1.43	1.44	1.53	1.64
Diesel Hybrid	**2011**	**2016**	**2021**	**2025**	**2015**	**2020**	**2025**	**N/A**	**2012**	**2017**	**2022**	**2025**	**2016**	**2021**	**2025**	**N/A**
Incremental Vehicle Price ($)	2314	1704	1553	1555	2897	2116	1926		2034	1528	1419	1426	2537	1894	1767	
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20		0.90	0.90	0.90	0.90	0.90	0.90	0.90	
Maintenance Cost	1.05	105	1.05	1.05	1.05	1.05	1.05		1.05	1.05	1.05	1.05	1.05	1.05	1.05	
Acceleration	0.90	0.90	0.90	0.90	0.90	0.90	0.90		0.90	0.90	0.90	0.90	0.90	0.90	0.90	
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00		0.90	0.90	0.90	0.90	0.90	0.90	0.90	
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00		0.80	0.90	0.90	0.90	0.80	0.90	0.90	
Fuel Economy	1.99	2.02	2.06	2.10	2.01	2.05	2.10		1.83	1.90	1.97	2.00	1.89	1.95	2.00	
Gasoline Hybrid	**2007**	**2012**	**2017**	**2025**	**2008**	**2013**	**2018**	**2025**	**2010**	**2015**	**2020**	**2025**	**2010**	**2015**	**2020**	**2025**
Incremental Vehicle Price ($)	1984	1479	1374	1401	2530	1858	1714	1735	1568	1250	1211	1236	1918	1530	1477	1502
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Acceleration	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.95	1.00	1.00	0.80	0.95	1.00	1.00
Fuel Economy	1.75	1.77	1.82	1.89	1.75	1.78	1.83	1.89	1.54	1.63	1.71	1.76	1.54	1.63	1.71	1.76

Table F-1 (continued)

	MINIVAN				LARGE VAN			
	Market Intro	Price Success	Price Maturity		Market Intro	Price Success	Price Maturity	
Advanced Diesel	**2008**	**2013**	**2018**	**2025**	**2006**	**2011**	**2016**	**2025**
Incremental Vehicle Price ($)	1914	1393	1245	1258	2538	1775	1574	1547
Range	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Maintenance Cost	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Acceleration	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Top Speed	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Luggage Space	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.75	1.75	1.74	1.78	1.75	1.75	1.74	1.78
Diesel Hybrid	**2013**	**2018**	**2023**	**2025**	**2012**	**2017**	**2022**	**2025**
Incremental Vehicle Price ($)	2221	1642	1505	1508	2804	2051	1861	1854
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.09	1.05	1.05	1.05	1.09	1.05	1.05	1.05
Acceleration	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Fuel Economy	2.00	2.03	2.08	2.10	1.99	2.03	2.07	2.10
Gasoline Hybrid	**2009**	**2014**	**2019**	**2025**	**2010**	**2015**	**2020**	**2025**
Incremental Vehicle Price ($)	1903	1432	1335	1358	2416	1813	1668	1670
Range	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Maintenance Cost	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
Acceleration	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Top Speed	0.75	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Luggage Space	0.90	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Fuel Economy	1.75	1.79	1.84	1.89	1.75	1.80	1.85	1.89

Table F-1 (continued)

	2-SEATER				MINI-COMPACT				SUB-COMPACT				COMPACT			
Advanced Gasoline	**2010**	**2015**	**2020**	**2025**	**2010**	**2015**	**2020**	**2025**	**2010**	**2015**	**2020**	**2025**	**2010**	**2015**	**2020**	**2025**
Incremental Vehicle Price ($)	283	449	581	588	271	432	561	569	230	367	477	484	233	371	483	491
Range																
Maintenance Cost																
Acceleration																
Top Speed																
Luggage Space																
Fuel Economy	1.07	1.16	1.26	1.27	1.07	1.16	1.26	1.27	1.07	1.16	1.26	1.27	1.07	1.16	1.26	1.27

	MEDIUM CAR				LARGE CAR			
Advanced Gasoline	**2010**	**2015**	**2020**	**2025**	**2010**	**2015**	**2020**	**2025**
Incremental Vehicle Price ($)	258	419	546	551	278	450	584	588
Range								
Maintenance Cost								
Acceleration								
Top Speed								
Luggage Space								
Fuel Economy	1.07	1.16	1.26	1.27	1.07	1.16	1.26	1.27

Table F-1 (continued)

	SMALL SUV				LARGE SUV				SMALL TRUCK				CARGO (Incl. 2b) TRUCK			
Advanced Gasoline	**2010**	**2015**	**2020**	**2025**	**2010**	**2015**	**2020**	**2025**	**2010**	**2015**	**2020**	**2025**	**2010**	**2015**	**2020**	**2025**
Incremental Vehicle Price ($)	991	759	714	705	1242	946	887	873	627	649	732	730	767	794	893	886
Range																
Maintenance Cost																
Acceleration																
Top Speed																
Luggage Space																
Fuel Economy	1.27	1.29	1.31	1.31	1.27	1.29	1.31	1.31	1.16	1.25	1.34	1.34	1.16	1.25	1.34	1.34

	MINIVAN				LARGE VAN			
Advanced Gasoline	**2010**	**2015**	**2020**	**2025**	**2010**	**2015**	**2020**	**2025**
Incremental Vehicle Price ($)	944	729	690	684	1201	917	858	841
Range								
Maintenance Cost								
Acceleration								
Top Speed								
Luggage Space								
Fuel Economy	1.27	1.29	1.31	1.31	1.27	1.29	1.31	1.31

Table F-2. ATV Attributes for Input to MARKAL
(Units are ratios to the conventional gasoline vehicles of the specific year. Prices are in 2003 dollars.)

Ratios to Conventional Vehicles		**2010**	**2020**	**2025**	**2030**	**2035**	**2050**
CARS							
Advanced Gasoline	MPG	1.07	1.26	1.27	1.29	1.31	1.30
	Incremental Price			1.022			1.019
Diesel	MPG	1.36	1.48	1.49	1.51	1.53	1.64
	Incremental Price			1.033			1.029
Gasoline HEV	MPG	1.39	1.60	1.61	1.64	1.66	1.77
	Incremental Price			1.039			1.020
Diesel HEV	MPG	1.59	1.86	1.87	1.90	1.93	2.06
	Incremental Price			1.047			1.030
LIGHT TRUCKS							
Advanced Gasoline	MPG	1.23	1.32	1.32	1.32	1.32	1.25
	Incremental Price			1.027			1.024
Diesel	MPG	1.64	1.69	1.73	1.77	1.81	1.82
	Incremental Price			1.045			1.028
Gasoline HEV	MPG	1.68	1.80	1.85	1.89	1.94	1.94
	Incremental Price			1.05			1.025
Diesel HEV	MPG	1.92	2.01	2.07	2.12	2.17	2.17
	Incremental Price			1.056			1.029

Table F-3. Vehicle Classes Used in Various Models

	Car Classes						**Light Truck Classes**					
MARKAL	Cars						Light Trucks					
NEMS	2-seater	Mini-compact	Sub-compact	Compact	Medium	Large	Small SUV	Large SUV	Small Truck	Cargo Truck	Minivan	Large Van
PSAT				Compact	Midsize			SUV		Pick-up		

2.0 Heavy Vehicle Benefits Analysis Introduction

The following sections describe the approach to estimating the fuel economies, incremental costs, and market penetration of heavy vehicles resulting from the Heavy Vehicle Technologies activities of the FreedomCAR and Vehicle Technologies Program of EERE, which are then provided as inputs to the NEMS and MARKAL models. It also describes how the oil savings benefits of these activities are estimated at a detailed level that the NEMS and MARKAL models cannot provide. The scope of the effort includes:

- Characterizing baseline and advanced technology vehicles for **Class 3–6 and Class 7 and 8 trucks**. Gross Vehicle Weights for these vehicle classes are as follows (Ref. 1):
    - Class 310,001 – 14,000 lbs
    - Class 4: 14,001 – 16,000 lbs
    - Class 5: 16,001 – 19,500 lbs
    - Class 6: 19, 501 – 26,000 lbs
    - Class 7 : 26,001 – 33,000 lbs
    - Class 8: 33,001 lbs and up.
- Identification of technology goals associated with the DOE EERE programs,
- Estimating the market potential of technologies that improve fuel efficiency and/or use alternative fuels,
- Determining the petroleum savings associated with the advanced heavy vehicle technologies. These estimates are developed at the program element level to assist project prioritization by the FCVT program. These savings are slightly different from the savings generated by NEMS and MARKAL.

In FY05, the Heavy Vehicles program activity expanded its technical involvement to more broadly address various sources of energy loss as compared to focusing more narrowly on engine efficiency and alternative fuels. This broadening of focus has continued in the activities planned for FY07. These changes are the result of a planning effort that occurred during FY04 and FY05 (Ref. 2).

This narrative describes characteristics of the heavy truck market as they relate to the analysis and provides a description of the analysis methodology—including a discussion of the models used to estimate market potential and benefits. The market penetration of advanced heavy vehicle technologies estimated here is then modeled as part of the EERE-wide integrated analysis (using NEMS and MARKAL) to provide final benefit estimates reported in the FY07 Budget Request.

2.1 Target Market: Heavy Vehicle Target Market

"Heavy Vehicles" are defined in this analysis as including Classes 3 through 6 (Medium Trucks) and Classes 7 and 8 (Heavy Trucks). The Heavy Truck classes are further subdivided by end-use types: i.e., Long-Haul, Intermediate, and Local Use. Vehicle Inventory and Use Survey (VIUS) data were examined for all vehicles in use and vehicles two years old or less (Ref. 3). The Heavy

Truck vehicle market was then disaggregated into these three end-use types. The specific vehicle configurations grouped in each of the three types have similar patterns of travel and annual vehicle mile usage patterns. The vehicle type segments are made up of the vehicle configurations listed below:

- Local Use (Type 1) – multistop, step van, beverage, utility, winch, crane, wrecker, logging, pipe, garbage collection, dump, and concrete delivery;
- Intermediate Use (Type 2) – platform, livestock, auto transport, oil-field, grain, and tank;
- Long-Haul (Type 3) – refrigerated van, drop frame van, open top van, and basic enclosed van.

The lower speed and "stop and start" duty characteristics of Type 1 trucks greatly reduce the potential efficiency benefits in that sector compared to Types 2 and 3. For similar reasons, fuel economy improvements due to other speed-dependent measures such as improved tires will have lower benefit here than in the other two types.

As compared to long distance, over the road travel, Type 2 vehicles tend to be used in a mix of local and regional delivery; and, as a result, will also realize greater fuel economy benefit from aerodynamic improvements than Type 1, but not as great as Type 3. Distances traveled by Type 2 vehicles are typically greater than Type 1, which infers that the typical speeds are higher. These characteristics make them a somewhat better market sector for measures that perform in relation to speed such as advanced tires. In general, Type 3 vehicles are the best candidates for technologies that reduce drivetrain or vehicle losses.

Refueling characteristics; i.e. central-source refueling or non-central source also are considered in the market characteristics, as centrally refueled vehicles would find an alternative fuel source more practical than vehicles that always refuel at road-side facilities.

Eleven travel distance categories for medium trucks and heavy trucks are represented in the model. These categories were determined using travel distributions developed with the VIUS data by Oak Ridge National Laboratory (ORNL) (Refs. 3, 4).

Exhibit 1 shows the distribution of annual travel for Class 3 through 6 and the three types of Class 7 and 8 vehicles. Type 3 vehicles display the greatest amount of annual travel of all heavy vehicle classes as is evidenced in part by the curve's peaking in the 120,000- to 139,000-mile segment.

Exhibit 2 shows the vehicle use pattern for Local or Type 1 Heavy trucks. The distributions based both on vehicles and vehicle-miles traveled are indicated.

The contrast in distribution by type is evident when Exhibits 2 and 3 are compared. Exhibit 3 shows the same information as Exhibit 2, but for Type 3 trucks. For Type 1, the distribution peaks in the 20,000- to 39,000-mile segment. For Type 3, the peak distribution shows annual travel of 100,000 miles greater than Type 1: 120,000 to 139,000 miles.

Centrally refueled and non-centrally fueled vehicle use characteristics also have been analyzed. Centrally refueled vehicles travel less per year than non-centrally refueled vehicles. In the non-centrally refueled vehicle segment, the majority of travel occurs from 100,000 to 140,000 miles per year. In the central refueling segment, the majority of travel occurs in a more even distribution between 20,000 and 140,000 miles per year.

Heavy vehicle market characteristics that are pertinent to the analysis are summarized in Exhibit 4. In the medium truck market segment (Classes 3 through 6), all vehicle types, with the exception of auto transport, travel about 20,000 miles per year on average. Heavy trucks, depending on type, travel an average of 40,000 miles to 92,000 miles per year. The base fuel economy for all 3 truck types was updated using VIUS 2002 data (Ref. 5).

2.2 Key Factors Shaping Market Adoption of Technology

Based on a survey conducted by the American Trucking Associations in 1997, energy-conservation purchase decisions for this sector are significantly affected by economic viability—specifically the payback of the investment (Ref. 6). The survey of 224 motor carriers revealed that paybacks of one to four years were acceptable for energy-conserving technologies. Based on those findings, we model the market acceptance of the various technologies based on payback performance.

2.2.1 Effects of Lower Emissions on Heavy Vehicle Fuel Economy

The Environmental Protection Agency (EPA) has initiated regulation of emissions from Heavy Trucks. This is changing engine technology and diesel fuel refining. Some reduction in fuel economy with the new engines is also expected as the combustion process optimization is addressing reduction of emissions. Normally, a requirement for reduced emissions will cause a decline in fuel economy. These changes will impose both operating and capital costs on truck operators.

One such EPA rule addressed Ultra-low-Sulfur Diesel (ULSD). The ULSD rule is designed to lower the sulfur content of transportation diesel fuel produced by refineries by 2007. The content of other pollutants, including Nitrogen Oxides (NO_X), Particulate Matter (PM) and Hydrocarbons (HC) are being reduced as well.

These new standards have started to go into effect with 2004 engines and will continue on for model years 2007 and 2010 for highway vehicles, and later for other applications. Major elements of these rules include the following:

- Reduce nitrogen oxides (NOx) and fine particulate matter $PM_{2.5}$ from new heavy-duty highway diesels (e.g., trucks and buses) by about 90%, effective in 2007 for PM, and 2007-2010 for NOx.
- Reduce the sulfur content in highway diesel fuel to 15 ppm ("ultra-low sulfur diesel" fuel, or "ULSD" fuel) beginning in late 2006.
- Reduce nitrogen oxides (NOx) and fine particulate matter $PM_{2.5}$ from new heavy-duty nonroad diesels (e.g., construction, farming and logging equipment) by about 90%, effective in the 2011-2014 time frame depending on the pollutant and the size of engine.
- Reduce the sulfur content in diesel fuel used in stationary engines in two steps, to 500 ppm in 2007 and 15 ppm beginning in 2010.
- Reduce the sulfur content in diesel fuel used in new locomotive and many marine engines in two steps, to 500 ppm in 2007 and 15 ppm beginning in 2012.

The EPA rule-making process includes a cost analysis for the technologies required to meet the new standards. The costs for the new emission control technologies for the 2004 models assumed that fuel injection and turbocharger improvements would happen without the new standards. So in estimating increases in engine costs, the EPA excluded 50% of the technology cost from the total estimated cost. The incremental costs for heavy-duty engines were estimated at $803 in 2004, decreasing to $368 in 2009. The EPA also estimates the increase in annual operating cost for heavy-duty engines to be $104 for the maintenance of the exhaust gas recirculation (EGR).

The effect of additional equipment that is used for treating emissions was also considered. The added weight of the equipment requires additional horsepower output from the engine, which results in a reduction in fuel efficiency. The EPA expects NOx adsorbers to be the most likely emission control technology applied by the industry. NOx adsorber regeneration will require small injections of diesel fuel for "light off" and desorption of stored NO for downstream catalysis under rich-burn conditions. This could result in additional fuel use beyond combustion for propulsion of 2-4%, depending on system maturity. The majority of the reduction in efficiency is associated with the control of sulfur-containing emissions (Ref. 7-9).

2.3 Methodology and Calculations: Overview

The analysis of the benefits expected from achieving the Heavy Vehicle technologies program goals was developed based on four primary reference sources:

- Technology energy efficiency and fuel-use characteristics—as provided by the managers of the technology programs;
- Vehicle characteristics and use information—as obtained from the 1997 VIUS. This provides information on both vehicle performance characteristics, such as fuel economy, and vehicle-use patterns such as miles traveled per year (Ref. 3);
- Truck operator investment requirements—as provided by a survey of Owner-Operators performed by the American Trucking Associations in 1995 (Ref. 6);
- Important "background" information such as energy prices and baseline technology fuel economies—as provided in the Annual Energy Outlook (Reference Case) prepared by the Energy Information Administration (Ref. 10). This information is used in the market penetration methodology which is needed to estimate future fuel economies.

The methodology involves the definition of the energy conservation or displacement and cost attributes of the advanced technologies being fostered by the program, the characterization of the markets affected, and the estimation of the benefits. Several models are used. Specifically, initial benefits estimates are generated through the linkage of four spreadsheet models: (Refs 11-12).

- HTEB - Heavy Truck Energy Balance Model (Version 2.0)
- TRUCK 2.0 - Heavy Vehicle Market Penetration Model
- VISION 2005, and
- Heavy Truck Summary (HVS) report generator.

The relationship of these four models is indicated in **Exhibit 5.**[1] Cost estimates are developed separately.

The **Heavy Truck Energy Balance Model** (HTEBM) was developed to assess the overall fuel economy effect of several changes to the vehicle involving both the engine and other elements of the vehicle. It takes into account energy losses based on user selected inputs of vehicle use. It is a steady-state model. It was required as a result of the lack of existence of publicly available vehicle simulation tool. The fuel economies of new advanced heavy vehicle technologies estimated with the HTEB model are presented in **Exhibit 6.**

The price estimates for these vehicles are also presented in **Exhibit 6.** All prices are in 2003 dollars. Technology cost is not really estimated, any assumed added cost is selected to have a two year payback. As an example, the price schedule for the **Exhibit 6** technologies in the Long Haul vehicle application is indicated in **Exhibit 7**. This process was replicated for Medium Trucks to develop similar cost estimates.

The values for fuel economy improvement from HTEBM and cost are then input to **TRUCK 2.0.** This model was developed to estimate the potential market impacts of new technologies on the medium and heavy truck market. The results generated by this model are:

- Market penetrations, in units of percent of new vehicles sold for each type and class of vehicle, and
- Composite fuel economy rating (new mpg) of the vehicles sold, for each truck type.

As discussed, the TRUCK 2.0 model estimates market penetration based on the cost-effectiveness of the new technology. Cost-effectiveness is measured as the incremental cost of the new technology less the expected energy savings of that technology over a specified time period in relation to specified payback periods**.**

Exhibit 8 shows the payback distribution assumed in the TRUCK model. This payback distribution was generated from the American Trucking Association's survey described above (Ref. 6). The survey found that, for example, 16.4% of the truck operators responding require a payback of one year on an investment. The TRUCK model market penetration calculation method for Class 7 and 8, Type 1 vehicles is described in **Exhibit 9.**

The market penetration results are supplied through a link to the **VISION** model (Ref. 11). The VISION model is used to estimate preliminary or first order oil/energy use and CO_2 emissions from highway vehicles through 2050 by program element. It contains a baseline estimate of heavy vehicle energy use to 2050. Through 2025 that baseline is the same as that of the AEO.

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[1] The HTEB was developed by William Shadis and James Moore of TA Engineering. The TRUCK (2.0) Model was developed as a collaborative effort, initially by John Maples of Oak Ridge National Laboratory (ORNL), with assistance from James Moore, of TA Engineering, Inc. Subsequent enhancements have been performed by Shadis and Moore (TA Engineering). The Vision model was developed by Maples, Anant Vyas and Margaret Singh of ANL. The Heavy Truck Summary Model is a report generating spreadsheet. It was initially developed by Maples, and has subsequently been modified by TA Engineering.

For the period from 2026 to 2050 the baseline energy use is very similar to that of MARKAL. By inputting the market penetration and fuel economy of the advanced heavy vehicle technologies into the model, an alternative estimate of future heavy vehicle energy use is generated and benefits relative to the baseline can be estimated.

Since VISION does not disaggregate Types 1-3 Heavy Trucks or Hybrid-Non-hybrid Medium Trucks, the fuel economy multipliers generated by Truck 2.0 are aggregated on both a sales and VMT-weighted basis for input to VISION. These aggregated fuel economy multipliers are provided in **Exhibit 10**. They are also adjusted to take into account differences in baseline fuel economies provided in VIUS (used in TRUCK 2.0) and the AEO (used in VISION). These factors and the market penetration estimates also presented in Exhibit 10 are the factors ultimately used in the EERE-wide integrated analysis. **More specifically, the factors in cells that are highlighted in yellow are provided for input to the NEMS and MARKAL models.**

Finally, the **Heavy Truck Summary** report generator summarizes the first order benefits for the period covering 2000 through 2050. Benefits (that are used by the FCVT program) include the following:

- Heavy Truck Petroleum Use and Savings, by Class 3-6 and Class 7-8, Million BPD
- Heavy Truck Petroleum Savings - %
- Class 7&8 Truck Savings by Program Element (Technology), Million BPD
- Local Use Truck Savings by Program Element (Technology), Million BPD
- Intermediate Truck Savings by Program Element (Technology), Million BPD
- Long-Haul Truck Savings by Program Element (Technology), Million BPD.

These first order benefits have been generated and will be reported in a forthcoming report. The benefits by FreedomCAR Program Element can not be generated by the NEMS and MARKAL models, and are, therefore, generated by the TRUCK and VISION models.

2.4 Heavy Truck Energy Use Models: Workbooks, Inputs and Outputs

Specific workbooks used in the modeling system are listed below. **Exhibit 11** provides a detailed view of the relationships among the four principal models. In practice, calendar dates indicating times of use are added to the file names for specific Energy Benefits analysis exercises, but these are omitted in this discussion.

1. Heavy Truck Energy Balance Model (HTEBM)-Version 2.0
    - Energy Balance Workbook-Baseline Model
    - Energy Balance Workbook-Technology Model(s) (copied from the Baseline Model)
    - Combined –Effects (used to allocate fuel savings among several technologies).
2. TRUCK (Market Penetration) Models
    - TRUCK-2 Type 1 (projects market penetration of Class 7&8, Type 1 heavy trucks to 2050).

  - TRUCK-2 Type 2 (projects market penetration of Class 7&8, Type 2 heavy trucks to 2050).
  - TRUCK-2 Type 3 (projects market penetration of Class 7&8, Type 3 heavy trucks to 2050).
  - TRUCK-2 Type M (projects market penetration of Classes 3-6 Type heavy trucks to 2050).
  - TRUCK-2 Composite (combines all Type 1, 2, 3, M results to obtain summary market penetrations and fleet average fuel economies).

3. VISION MODELS
   - VISION 2005 AEO ICE MPG Base Case (projects energy use of baseline truck fleet to 2050).
   - VISION GPRA0 7Veh.Mi-1 (projects energy use of improved truck fleet to 2050).
4. HvyTrkSum-GPRA-V1 mkt pen veh mi (calculates energy and carbon savings-total heavy truck fleet, classes 3-8, to 2050).

All workbooks should be copied into the same hard-drive subdirectory and all should be loaded so that all of the links are active during the data entry-calculation process.

2.4.1 HTEBM (Heavy Truck Energy Balance Model) Version 2.0

The Heavy Truck Energy Balance Model is based on a simplified calculation of average road loads experienced by typical heavy trucks. It calculates an average fuel economy that balances the truck engine output with the needs to meet engine friction, accessory loads, auxiliary loads and road loads (rolling resistance, aerodynamic resistance, and vehicle braking loads). The model is a method to match baseline vehicles with actual road-load fuel economy results and then to estimate the variations in fuel economy that will occur when various engine and vehicle operational characteristics are changed. Therefore, it is important that actual, simulation-based, or program goals for road-load vehicle fuel economy values be available.

Fuel savings are caused by a combination of technologies-load reducing technologies and engine efficiency-increasing technologies. Each technology under consideration and each analysis year requires a separate run of HTEBM. Since each run includes both input assumptions and results, they need to be maintained for adequate support and documentation.

Engine/Vehicle improvements that lead to reduced fuel use can be categorized under the following headings.

- Increased engine cycle efficiency
  - Increase compression ratio
  - Reduced engine thermal losses
- Reduced engine internal friction loads
  - Air-Breathing Losses
  - Pistons & Piston Rings
  - Rod and crankshaft bearings

  - Valve train/camshaft
- Reduced engine accessory loads
  - Fuel Injector
  - Power Steering
  - Oil Pump
  - Coolant Pump
  - Engine fan
- Reduced drive-train parasitic loads
  - Transmission
  - Driveshaft
  - Axle/Transaxle
  - Differential
  - Axle & Wheel bearings
  - Brake Drag
- Reduced vehicle auxiliary system loads
  - Alternator
  - Air Conditioner
  - Air Brake Compressor
- Reduced road-loads
  - Aerodynamic loads
  - Rolling resistance loads
  - Braking loads.

For the Government Performance and Results Act (GPRA), vehicle characteristics to support fuel economy goals at 10-year increments are developed (2010, 2020, 2030, 2040, and 2050).

- **"Combined Effects" Workbook**

The results of the multiple runs of HTEBM are collected in this summary workbook. Whereas HTEBM permits only one set of conditions per-run, "Combined Effects" can store any number of HTEBM results.

The Combined Effects Submodel is used to allocate the fuel savings among the several technologies included in the Truck Technology option. This is done by assuming that the percentage of fuel savings attributable to each separate technology will be proportional to the relative fuel economy improvement of each separate technology, taken separately.

Currently, "Combined Effects" includes four individual heavy vehicle technologies (accessory loads reduction, engine efficiency increase, vehicle weight reduction, and aerodynamic drag reduction). These can be varied to other technologies or Technology Program definitions by the user, if desired.

2.4.2 TRUCK 2.0 Market Penetration Models

The fuel-saving technologies under analysis are characterized in the TRUCK 2.0 models in terms of the projected fuel economy improvement ratio (new fuel economy divided by the baseline fuel economy), the installed cost of the improvement ($ per vehicle), and the cost of the fuel type being used. Market penetration occurs for technologies that meet payback values of 4 years or less. If technology cost information is not available, cost equivalent to a two-year payback is assumed. TRUCK 2.0 can be set to assume the following heavy truck fuels: diesel fuel, gasoline, liquefied propane gas (LPG), ethanol, compressed natural gas (CNG), or electricity (battery storage).

The output from the TRUCK 2.0 Models for each truck Type is a projection of market penetration rates (percent of new vehicle sales) by class and type over the future time from current through year 2050 (or shorter if modeled for a shorter time period). The absolute number of trucks projected to be equipped with the new technology is calculated in the VISION model (see below).

- **"TRUCK Composite" Submodel**

This model collects the market penetration data from the four TRUCK models. It was created as a separate workbook since the TRUCK models are all driven by macros and with distinct inputs. The market penetration and fuel economy results for each of the truck types are linked to this workbook.

2.4.3 VISION Models

- **VISION Base Case Model**

The VISION models accept average new fleet MPG values for Class 3-6 and Class 7 & 8 vehicles and calculate the amount of fuel used each year as these vehicles mature, age and eventually wear out within the operating fleet. Calculations are made for the years 2000 to 2050.

- **VISION Enhanced Case Model**

This version of VISION calculates the fleet energy use assuming that the proposed technologies (fuel savings technologies) are introduced into the new vehicle fleet as calculated by the TRUCK models. Fuel economy and market penetration results from the TRUCK models are consolidated into a single value (for each year to 2050) for Class 7 and 8, and a single value for Classes 3 through 6, using VMT data to weight the fuel economies of each truck Type.

2.4.4 Heavy Truck Summary Submodel (HvyTrkSum)

Key inputs and results of the Truck Model analysis are summarized in the HvyTrkSum workbook. The format used here is intended to meet the needs and requirements of the FutureCar and Vehicle Technologies program, as well as the Planning and Evaluation Office.

HvyTrkSum results form the basis of the GPRA and related reports generated annually presenting the benefits of the Heavy Truck program elements.

2.5 Sources

1. TRANSPORTATION ENERGY DATA BOOK:EDITION 24. Stacy C. Davis, Susan W. Diegel. Oak Ridge National Laboratory. December 2004
2. FreedomCAR and Vehicle Technologies R & D Plan (Draft), August 22, 2003.
3. "1997 Vehicle Inventory and Use Survey," EC97TV-US U.S. Bureau of the Census, Washington, D. C., 1999.
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5. Personal Communication with Stacy Davis, ORNL, June 2005
6. "1997 Return on Investment Survey," American Trucking Association, Arlington Va., 1997.
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8. The Transition to Ultra-Low-Sulfur Diesel Fuel: Effects on Prices and Supply 2. Efficiency and Cost Impacts of Emission Control Technologies: http://www.eia.doe.gov/oiaf/servicerpt/ulsd/chapter2.html
9. *The Potential Effect of Future Energy-Efficiency and Emissions-Improving Technologies on Fuel Consumption of Heavy Trucks.* A. Vyas, C. Saricks, and F. Stodolsky. Argonne National Laboratory. August 2002.
10. "Annual Energy Outlook 2004, With Projections to 2030," Energy Information Agency, Department of Energy, Washington, D. C., (Web site address: http://www.eia.doe.gov/bookshelf.html *Library/Archives-Forecasting)*.
11. Singh, M.; A. Vyas, and E. Steiner, "VISION Model: Description of Model Used to Estimate the Impact of Highway Vehicle Technologies and Fuels on Energy Use and Carbon Emissions to 2050," ANL/ESD/04-1 (Dec. 2003).
12. FreedomCAR and Vehicle Technologies Heavy Vehicle Program FY 2006 Benefits Analysis: Methodology and Results -- Final Report. (ANL Report No. 05/60) James Moore, Bill Shadis. TA Engineering, Inc. November 2005.

Exhibit 1: Annual Miles Traveled for Four Truck Categories, 1997

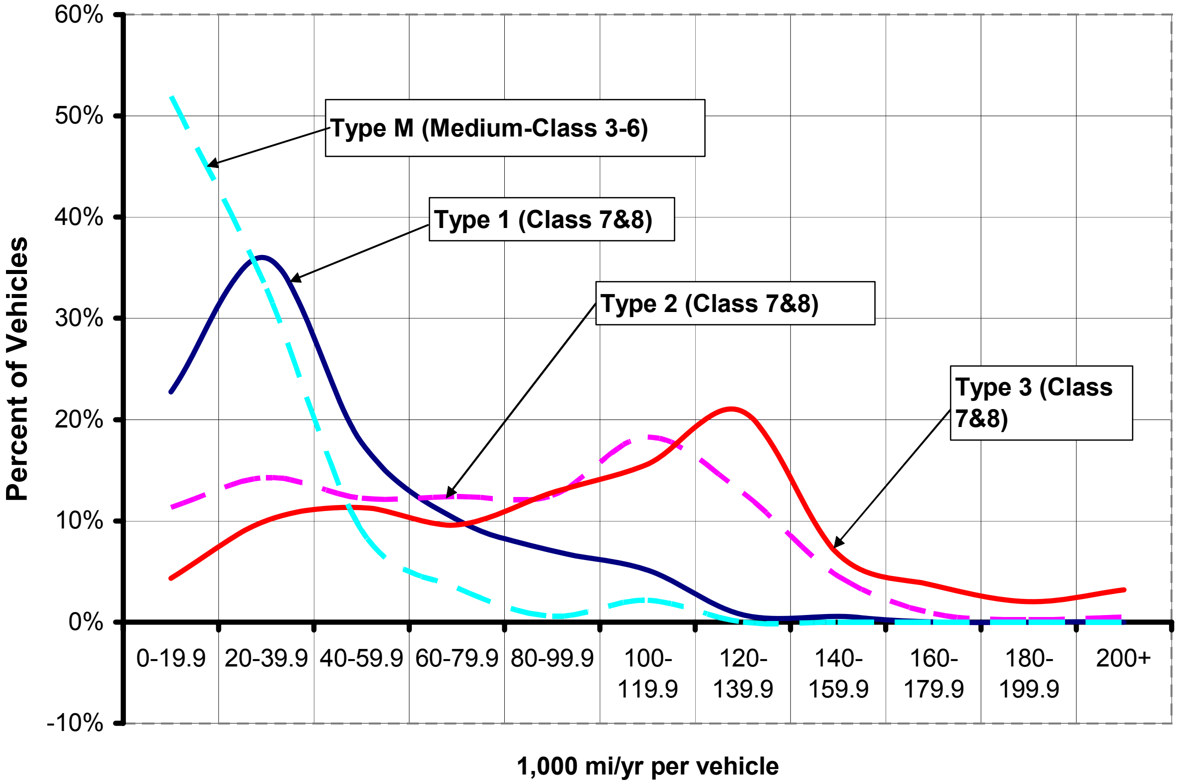


Exhibit 2: Type 1 Vehicle Use

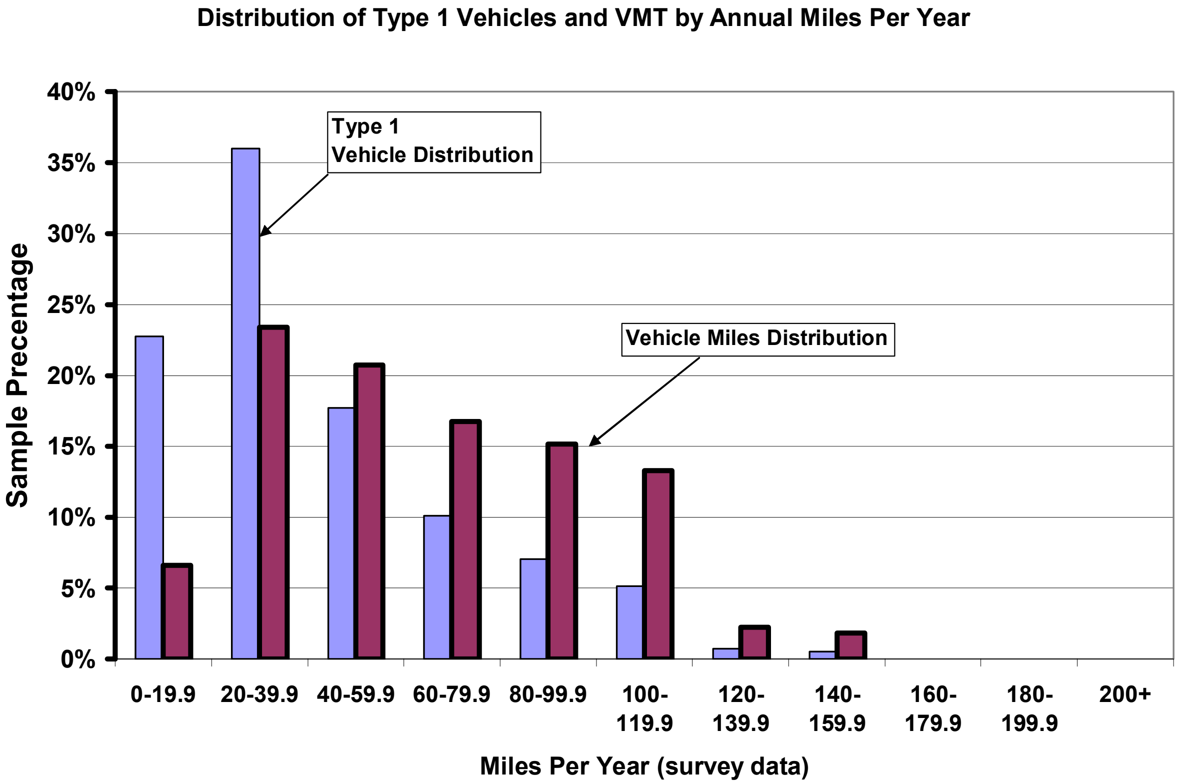


Exhibit 3: Type 3 Vehicle Use

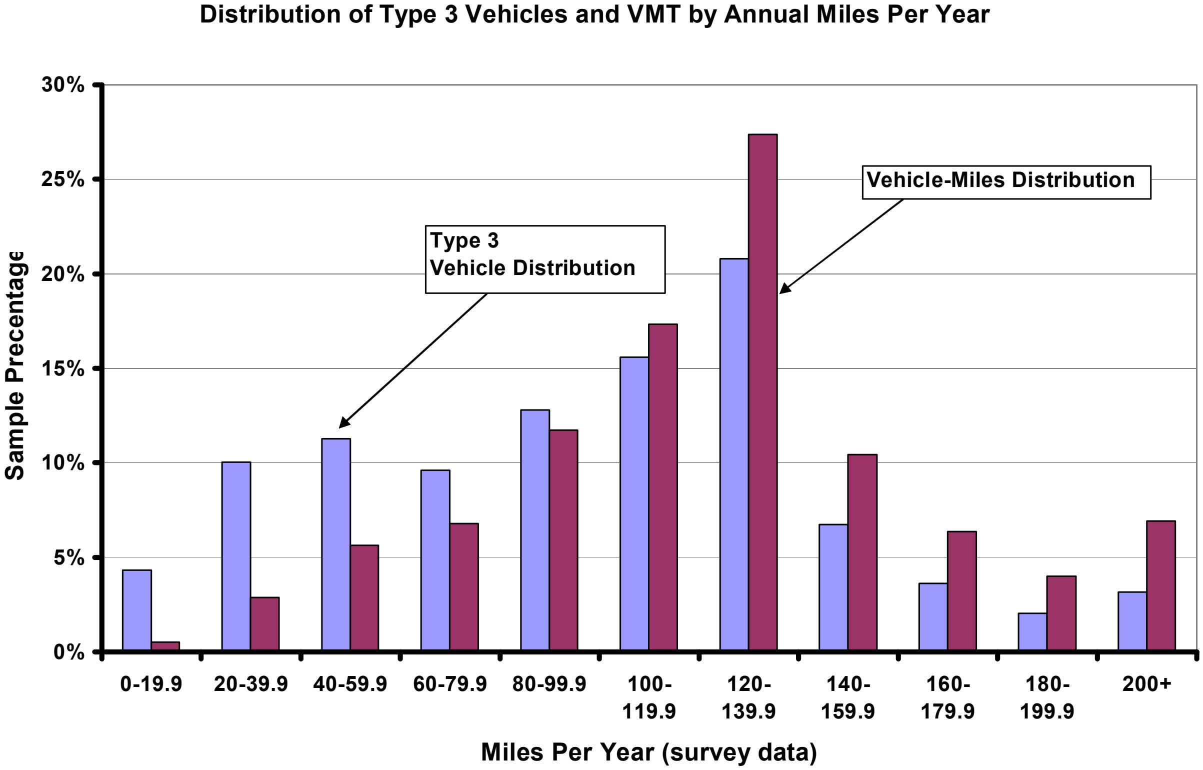


Exhibit 4: Heavy Vehicle Characteristics (1997)

Vehicle Type	Class 7 & 8, Type 1	Class 7 & 8, Type 2	Class 7 & 8, Type 3	Class 3 through 6	Comments
Body Types	**Note 1**	**Note 2**	**Note 3**		
Fuel Economy (Baseline)	5.60	5.60	5.90	8.90	
Fuel Economy Improvement, %	146%	164%	179%	170%	Combined effect of FCVT Technologies, 2020; Class 3 thru 6 is w/o Hybrid
Average Miles Traveled, miles	40,043	74,066	92,434	20,126	
Portion of Heavy Truck Fuel Use, %	11.2%	19.6%	52.9%	4.3%	Estimated--Year 2005
Portion of Vehicle Travel < 50 k Miles,	47%	14.3%	1.6%	73.6%	
Portion of Vehicle Travel 50 k to 100 k	44%	43.5%	35.7%	24.4%	
Portion of Vehicle Travel >100 k	9%	42.2%	53.8%	2.0%	

Note 1: Local Use (Type 1) – multi-stop, step van, beverage, utility, winch, crane, wrecker, logging, pipe, garbage collection, dump, and concrete delivery

Note 2: Intermediate Use (Type 2) – platform, livestock, auto transport, oil-field, grain, and tank;

Note 3: Long-Haul (Type 3) – refrigerated van, drop frame van, open top van, and basic enclosed van.

Exhibit 5: Heavy Truck Benefits Analysis Models

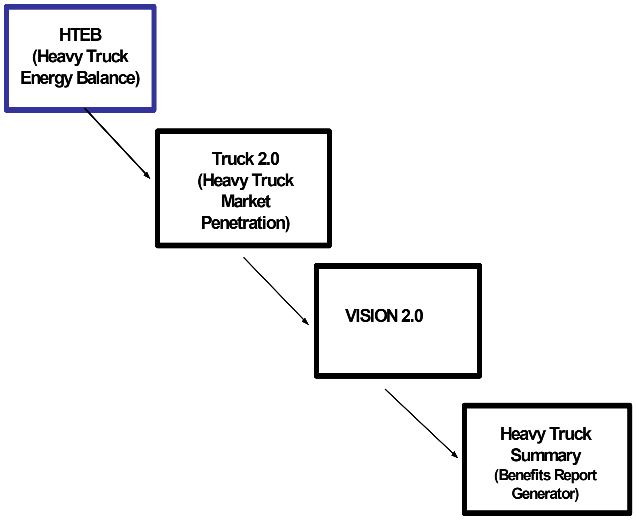


Exhibit 6: Advanced Heavy Vehicle Characterization - New Vehicles (prices are in 2003 dollars)

	Characteristic	2010	2020	2030	2040	2050
1	Fuel Economy Class 7-8, Local Travel (Type 1) mpg Multiplier	1.20	1.51	1.53	1.54	1.54
2	Fuel Economy Class 7-8, Intermediate Travel (Type 2) mpg Multiplier	1.21	1.53	1.56	1.57	1.57
3	Fuel Economy Class 7-8, Long Haul Travel (Type 3) mpg Multiplier	1.25	1.59	1.63	1.63	1.63
4	Fuel Economy Class 3-6- Hybrid, mpg Multiplier	1.41	1.61	1.61	1.61	1.61
5	Fuel Economy Class 3-6- Non-hybrid, mpg Multiplier	1.20	1.46	1.48	1.48	1.48
6	Class 7-8, Iincremental Cost, $	$ 40,000	$ 20,000	$ 10,000	$ 7,000	$ 7,000
7	Class 3-6 Hybrid, Incremental Cost, $	$ 19,000	$ 5,400	$ 2,700	$ 2,700	$ 2,700
8	Class 3-6 Nonhybrid, Incremental Cost, $	$ 5,400	$ 1,700	$ 1,700	$ 1,700	$ 1,700

Exhibit 7: Example Price and Efficiency Schedule for Advanced Technologies (2003 dollars)

		Non-Hybrid Technologies	
		Diesel Fuel (only)	
Year	Baseline Vehicle Cost ($)	Gross 1st Cost ($)	Efficiency Ratio
2000	150,000	0	1.000
2005	150,000	45,000	1.200
2010	150,000	40000	1.250
2015	150,000	30000	1.350
2020	150,000	20000	1.590
2025	150,000	15000	1.610
2030	150,000	10000	1.630
2035	150,000	7,600	1.630
2040	150,000	7,000	1.630
2045	150,000	7,000	1.630
2050	150,000	7,000	1.630

Exhibit 8: ATA Survey Payback Preference Distribution

Number of Years	Percent of Motor Carriers
1	16.4%
2	61.7%
3	15.5%
4	6.4%

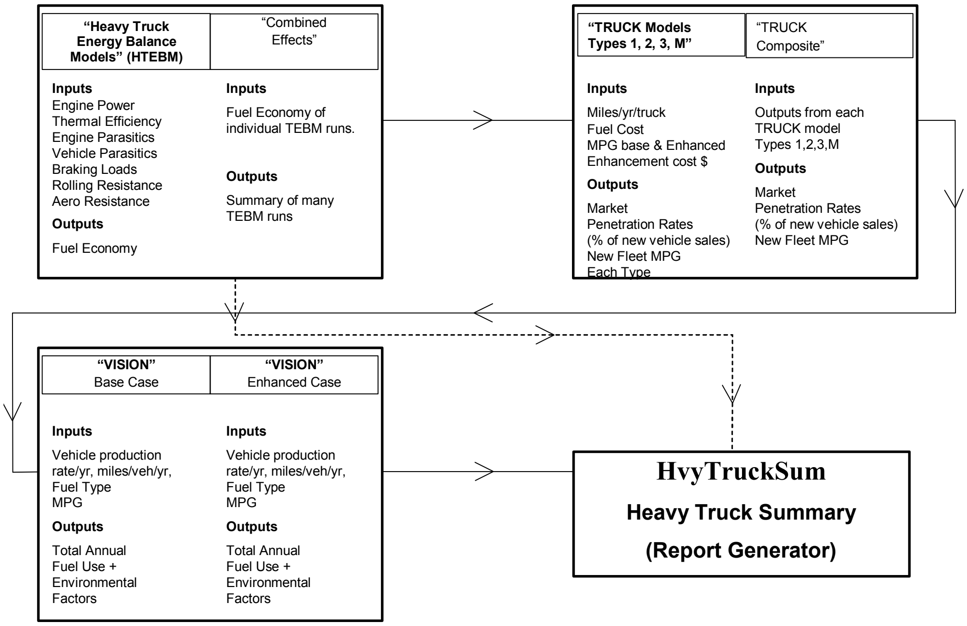
Exhibit 9: Truck Payback Algorithm—Type 1 Trucks

Spreadsheet Location	Description	Comments
Column A	**Year**	Identifies year for which values, calcuations and results are representative.
Columns B - F	**Fuel Economy by Technology**	Values are developed based on baseline technology mpg assumptions and efficiency ratios for advanced technologies.
Column G	**Cost of Alternative Fuel in $/GGE**	Links to Fuel Prices Page
Columns H - I	**Calculates annual savings for 2 alternative technologies**	For Advanced Diesel: (VMT(C10)x$/GGE/Baseline MPG - VMT x $/GGE/Adv. Diesel MPG)
Columns J - M	**Calculates Net Present Value of Savings for 'Advanced Diesel'**	Column J: 1 Year, K: 2 years, L: 3 years; M: 4 years
Columns N - Q	**Calculates Net Present Value of Savings for 'Alternative Fuel Technology'**	Column N: 1 Year, O: 2 years, P: 3 years; Q: 4 years
Columns R - U	**If-then Statement to determine 'Cost Effectiveness Factor' (CEF)**	If NPV of savings is > Cost of Technology, cell value is (cost - NPVSavings)/Cost; Otherwise cell value is 0. Columns are for paybacks of 1, 2, 3, and 4 years.
Column V	**Technology purchase cost 'Alternative Fuel Technology'**	Values are linked to Cost values on 'Inputs' page.
Column W - Z	**Repeats calcuations in Columns R through U for 'Alternative Fuel Technology'**	
Column AA	**If-then Statement to determine 'Technology Adoption Factor' (TAF) for 'Advanced Diesel'**	If 'Cost Effectiveness Factor' for Year 1 PB is 0, cell value = 100; Otherwise (100-((exp(1995 CE Factor-Current Yr. Factor) - 1)/10 x 100)
Column AB	**Continuation of TAF Calculation for Year 1 Payback market**	If AA<0, cell value is 1; Otherwise the Value is the same as AA.
Columns AC + AD	**Repeat AA and AB for 2 year payback market**	
Columns AE + AF	**Repeat AA and AB for 3 year payback market**	
Columns AG + AH	**Repeat AA and AB for 4 year payback market**	
Columns AI - AP	**Repeat Columns AA through AH methodology for 'Alt. Fuel Technology'**	
Column AQ	**If-then statement. Start of Market Penetration for 'Advanced Diesel'**	If AB = 100, then cell value is 0; Otherwise cell value is (1/(1+Abvalue/exp(-2 x Col. R CEF for 1 Year PB))
Column AR	**Same as AQ, but for 2 year PB market.**	
Column AS	**Same as AQ, but for 3 year PB market.**	
Column AT	**Same as AQ, but for 4 year PB market.**	
Column AU	**Final, Step 1; Weighted average market penetration for year 1 through year 4 markets weighting factors**	Weighting factors are based on ATA survey results and are listed at the top of Columns AQ-AT.
Column AV	**Final, Step 2: Reduces Market Penetration to account for market penetration of 'Atl. Fuel Technology' and stay below 100% share.**	=+(AU+(1-BA)*AU)/2
Columns AW - AZ	**Same as columns AQ - AT for 'Alterntive fuel technology'.**	
Column BA	**Final, Step 1; For 'Alt. Fuel Tech.', weighted average market penetration for year 1 through year 4 markets weighting factors**	
Column BB	**Final, Step 2: Reduces Market Penetration to account for market penetration of 'Atl. Fuel Technology' and stay below 100% share.**	
Columns BD - BN	**Macro Results Array-Centrally Refueled Advanced Diesels**	Central1 Macro results are printed in this part of spreadsheet
BO	**Final Step 3: 'Advanced Diesel' (Centrally Refueled) Summation of %VMT that is centrally refueled for the VMT range (e.g. 0-19.9k)* % Market penetration for BD - BN array.**	Results are linked to Market Penetration Page
Columns BQ - CA	**Macro Results Array-Centrally Refueled Alternative Fuels**	Macro results are printed in this part of spreadsheet. Alt Fuel technology only competes in Centrally Refueled Segment
CB	**Final Step 3: 'Alt. Fuel' Summation of %VMT that is centrally refueled for the VMT range (e.g. 0-19.9k)* % Market penetration for BD - BN array.**	Results are linked to Market Penetration Page
Columns CD - CN	**Macro Results Array-Non Centrally Refueled Advanced Diesels**	Macro results are printed in this part of spreadsheet
CO	**Final Step 3: 'Advanced Diesel' (Non-centrally refueled) Summation of %VMT that is centrally refueled for the VMT range (e.g. 0-19.9k)* % Market penetration for BD - BN array.**	Results are linked to Market Penetration Page

Exhibit 10: Advanced Heavy Vehicle Market Penetration and Fuel Economy Results for NEMS Modeling

							Class 3 - 6							
Year	Combined Market Penetration, % VMT	Base MPG (VISION) in gasoline equivalent gallons	Fuel Economy for All New Technology Sales, mpg	Fuel Economy Multiplier only for trucks with new techology which achieve the market penetration shown in Column 2	Estimate of fuel economy for all new 7-8 trucks	Estimate of X factor to input to VISION (only those for 2010, 2020, 2030, 2040 + 2050 are input)	Efficiency, % VMT	Hybrid, % VMT	Combined Market Penetration, % VMT	Base MPG (VISION) in gasoline equivalent gallons	Fuel Economy for All New Technology Sales, mpg	Fuel Economy Multiplier only for trucks with new techology which achieve the market penetration shown in Column 6	Estimate of fuel economy for all new 3-6 trucks	Estimate of X factor to input to VISION (only those for 2010, 2020, 2030, 2040 + 2050 are input)
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
2010	0%	5.64	6.97	1.24	5.639	**1.00**	0%	0%	0%	8.54	10.27	1.20	8.54	**1.00**
2011	0%	5.69	7.15	1.27	5.69	1.00	0%	0%	0%	8.55	10.49	1.22	8.55	1.00
2012	0%	5.76	7.34	1.30	5.76	1.00	0%	0%	0%	8.55	10.72	1.25	8.55	1.00
2013	0%	5.85	7.53	1.34	5.85	1.00	0%	0%	0%	8.55	10.94	1.28	8.55	1.00
2014	0%	5.96	7.71	1.37	5.97	1.00	0%	0%	0%	8.55	11.17	1.30	8.56	1.00
2015	1%	6.08	7.90	1.40	6.09	1.00	1%	0%	1%	8.56	11.40	1.33	8.58	1.00
2016	2%	6.12	8.08	1.43	6.15	1.00	1%	0%	1%	8.57	11.62	1.35	8.60	1.00
2017	2%	6.18	8.27	1.47	6.22	1.01	3%	0%	3%	8.58	11.85	1.38	8.65	1.01
2018	4%	6.25	8.46	1.50	6.31	1.01	4%	0%	4%	8.58	12.07	1.41	8.69	1.01
2019	7%	6.25	8.64	1.53	6.36	1.02	13%	0%	13%	8.58	12.30	1.43	8.93	1.04
2020	12%	6.25	8.83	1.57	6.48	**1.04**	15%	0%	15%	8.59	12.53	1.46	9.02	**1.05**
2021	14%	6.26	8.85	1.57	6.53	1.04	17%	0%	17%	8.59	12.54	1.46	9.08	1.06
2022	18%	6.28	8.87	1.57	6.63	1.06	22%	0%	22%	8.59	12.56	1.46	9.24	1.08
2023	21%	6.30	8.89	1.58	6.72	1.07	24%	0%	24%	8.59	12.57	1.47	9.30	1.08
2024	24%	6.31	8.91	1.58	6.79	1.08	23%	1%	24%	8.59	12.59	1.47	9.31	1.08
2025	31%	6.33	8.93	1.58	6.96	1.10	23%	2%	25%	8.59	12.60	1.47	9.34	1.09
2026	32%	6.34	8.95	1.59	7.00	1.10	25%	2%	27%	8.59	12.62	1.47	9.41	1.09
2027	47%	6.36	8.97	1.59	7.37	1.16	29%	3%	32%	8.59	12.64	1.47	9.56	1.11
2028	48%	6.38	8.99	1.60	7.42	1.16	35%	6%	40%	8.59	12.65	1.47	9.87	1.15
2029	59%	6.39	9.01	1.60	7.70	1.21	35%	7%	41%	8.59	12.67	1.48	9.91	1.15
2030	61%	6.41	9.03	1.60	7.78	**1.21**	40%	7%	47%	8.59	12.68	1.48	10.13	**1.18**
2031	62%	6.43	9.04	1.60	7.83	1.22	40%	8%	47%	8.59	12.69	1.48	10.14	1.18
2032	68%	6.44	9.04	1.60	8.00	1.24	36%	12%	48%	8.60	12.69	1.48	10.18	1.18
2033	68%	6.46	9.04	1.60	8.02	1.24	36%	13%	48%	8.60	12.70	1.48	10.19	1.19
2034	70%	6.48	9.05	1.60	8.07	1.25	34%	17%	51%	8.60	12.70	1.48	10.28	1.20
2035	70%	6.49	9.05	1.61	8.11	1.25	29%	25%	54%	8.60	12.71	1.48	10.43	1.21
2036	71%	6.51	9.05	1.61	8.12	1.25	29%	28%	57%	8.60	12.71	1.48	10.55	1.23
2037	71%	6.53	9.06	1.61	8.13	1.25	29%	28%	57%	8.60	12.72	1.48	10.57	1.23
2038	71%	6.54	9.06	1.61	8.15	1.25	29%	29%	58%	8.60	12.72	1.48	10.59	1.23
2039	71%	6.56	9.06	1.61	8.16	1.24	30%	29%	59%	8.60	12.73	1.48	10.63	1.24
2040	71%	6.58	9.07	1.61	8.18	**1.24**	33%	29%	62%	8.60	12.73	1.48	10.76	**1.25**
2041	71%	6.60	9.07	1.61	8.19	1.24	48%	27%	76%	8.60	12.73	1.48	11.39	1.32
2042	72%	6.61	9.07	1.61	8.20	1.24	43%	35%	78%	8.60	12.73	1.48	11.51	1.34
2043	72%	6.63	9.07	1.61	8.21	1.24	41%	38%	79%	8.60	12.73	1.48	11.58	1.35
2044	72%	6.65	9.07	1.61	8.23	1.24	40%	39%	79%	8.61	12.73	1.48	11.58	1.35
2045	72%	6.66	9.07	1.61	8.24	1.24	40%	39%	79%	8.61	12.73	1.48	11.59	1.35
2046	73%	6.68	9.07	1.61	8.27	1.24	40%	39%	79%	8.61	12.73	1.48	11.59	1.35
2047	73%	6.70	9.07	1.61	8.29	1.24	40%	40%	80%	8.61	12.73	1.48	11.59	1.35
2048	74%	6.72	9.07	1.61	8.30	1.24	40%	40%	80%	8.61	12.73	1.48	11.60	1.35
2049	74%	6.73	9.07	1.61	8.31	1.24	40%	40%	80%	8.61	12.73	1.48	11.61	1.35
2050	74%	6.75	9.07	1.61	8.33	**1.23**	41%	40%	81%	8.61	12.73	1.48	11.65	**1.35**

Exhibit 11: Heavy Truck Energy Modeling System Details



Appendix G – GPRA07 Building Technologies (BT) Program Documentation

Introduction

The mission of the Building Technologies Program is to develop technologies, techniques, and tools for making residential and commercial buildings more energy efficient, productive, and affordable. **Table G-1** outlines the activities characterized for the GPRA07 Building Technologies Program. Characterizations and inputs for these activities were provided to the Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE) as inputs to EERE's integrated modeling effort. Between the time that the original activity list was developed for the integrated modeling process and the time that the final budget request was submitted, a small number of activities were added into, subtracted from, or moved within the request; however, these changes were not reflected within the modeling process. The specific impact of these changes on the integrated benefits estimates is not known, but would be expected to be minimal.

Table G-1. Building Technologies Subprograms, Projects, and Activities

Subprogram	Project	Activity
Residential Buildings Integration	Research & Development: Building America	Research & Development: Building America
	Residential Building Energy Codes	Residential Building Energy Codes
Commercial Buildings Integration	Research & Development	Research & Development
	Commercial Building Energy Codes	Commercial Building Energy Codes
Emerging Technologies	Lighting R&D	Lighting R&D: Solid-State Lighting
		Lighting R&D: Controls *
	Space Conditioning & Refrigeration R&D	Refrigeration R&D: Hy-Pak MA *
		Refrigeration R&D: Thermotunneling Based Cooling
		Refrigeration R&D: Integrated Heat Pump
	Appliances & Emerging Technologies R&D	Appliances & Emerging Tech R&D: Solid-State Lighting Market Acceptance **
	Building Envelope R&D	Window Technologies: Electrochromic Windows
		Window Technologies: Superwindows
		Window Technologies: Low-E Market Acceptance
		Thermal Technologies: Advanced Wall Systems
		Thermal Technologies: Next Generation Attic Systems
		Thermal Technologies: Next Generation Envelope Materials
	Analysis Tools and Design Strategies	Analysis Tools and Design Strategies
Equipment Standards and Analysis	Equipment Standards and Analysis #	Standards: Electric Motors, 1-200 HP
		Standards: HID Lamps
		Standards: Distribution Transformers
Technology Validation and Market Introduction	Rebuild America	Rebuild America
	Energy Star	Energy Star: Clothes Washers
		Energy Star: Refrigerators

		Energy Star: Room Air Conditioners
		Energy Star: Dishwashers
		Energy Star: CFLs
		Energy Star: Windows
		Energy Star: Home Performance

* activities that were not funded in the final FY07 budget request
** activity that was moved to Lighting R&D
\# excludes other Standards activities that were added following the passage of the Energy Policy Act of 2005

Often such analysis requires the development and use of enabling or simplifying assumptions. In many cases, no citable sources exist for substantiating assumptions. Therefore, assumptions are developed through an iterative process with project managers, project contractors, and GPRA analysts. Often, we base these assumptions on project knowledge and experience, as there are varying degrees of corroborative studies available on which project information can be substantiated, depending on the maturity of the project. Enabling assumptions are sometimes relatively crude and should be revisited annually as new and better data are developed.

1.0 Residential Buildings Integration

The long-term goal of Residential Buildings Integration is to develop cost-effective technologies and building practices that will enable the design and construction of net Zero Energy Buildings (ZEB) – houses that produce as much energy as they use on an annual basis – by 2020.

1.1 Residential Building Energy Codes

Project Description. The Residential Building Energy Codes project improves the minimum or baseline energy efficiency of new federal and model residential building codes. The project promulgates upgraded standards for Federal residential buildings. The project works with the International Code Council to upgrade the energy-efficiency requirements of its model energy codes. State, and local jurisdictions then adopt and implement these upgraded model energy codes. The long-term goal is to improve the minimum energy efficiency by 20% to 25% in new low-rise residential building construction.

1.1.1 Significant Changes from FY06

No significant changes were made to this program for the FY07 effort. In previous years, all of the building codes activities have been modeled together, independent of funding source, with code development funded activities funded under BT and codes training and deployment activities funded as part of the Weatherization and Intergovernmental Activities Program (WIP). The impact of the individual codes activities (residential, commercial, and training and assistance) has been allocated to the individually funded activities based on the presumed impacts of greater compliance of existing codes as well as future code development and adoption. The FY 2006 activity within WIP to provide incentive funding and technical assistance to aid in the adoption, compliance, and enforcement of codes was discontinued in FY 2007, although the State Energy Program Grants program within WIP is expected to continue to fund similar activities, as they have done historically. The expected impact on the BT-funded portion of the codes activities is not anticipated to be significant.

1.1.2 Target Market

Market Description. The market includes new and renovated residential low-rise buildings, three stories or less in height, requiring code permits.

Size of Market. In recent years approximately 1.6 million single-family residential building permits have been issued(2). Although not all jurisdictions currently have energy efficiency building codes in place, the Pacific Northwest National Laboratory (PNNL) estimates that about 80 percent all new residential construction comes under building energy code requirements. Also, consumers spend several billion dollars a year on remodeling and renovating projects in private residences, about half of which are estimated to be covered by an energy code. One market not covered by codes is manufactured homes, which fall under Housing and Urban Development (HUD) jurisdiction and regulations.

Baseline Technology Improvements. Initial compliance with new codes was assumed to be lower in the base case, i.e., without the Building Energy Codes project, than with the project. For FY07, the percentage of potential savings, in the first year of implementation of the single future code, was assumed to be approximately 35% for heating and cooling measures without the project.

Baseline Market Acceptance. Under the baseline scenario, 23 states were assumed to have adopted the International Energy Conservation Code (IECC 2000 or IECC 2003) standard by the end of 2005. The GPRA estimates were partly based on states' accelerated schedule of adoption of the IECC 2000 and IECC 2003 codes. Through the efforts of the Building Energy Codes project, 31 states were assumed to have adopted the 2000 or 2003 standard by the end of 2005. The project was assumed to accelerate the adoption of the standard by an average of three years nationwide.

1.1.3 Key Factors in Shaping Market Adoption of EERE Technologies

Price. BT assumed a five-year payback period on investment to develop incremental investment costs (i.e., an annual energy cost savings of $1 implies an initial investment of $5).

Key Consumer Preferences/Values. The following nonenergy characteristics were not considered in developing savings estimates.

- Improved environment and more comfortable buildings.
- Lower home maintenance and repair activities
- Reduced pollution due to the reduced burning of fossil fuels and electricity generation, which improves air quality and mitigates the negative impacts of global warming.

1.1.4 Methodology and Calculations

Inputs to Base Case. With respect to codes, it is indeterminate as to whether, and to what extent potential future code improvements are incorporated into the National Energy Modeling System (NEMS) base case. The NEMS-GPRA07 base case includes some improvements to the building shell efficiency; however, the basis for these improvements (e.g., general building practice improvements, changes in codes requirements, improvements in materials) is not specified by the Energy Information Administration (EIA). Codes that have been issued (but that have not gone into effect) may be included in the NEMS-GPRA07 base case, but would not be included in the GPRA forecast of savings for the code development activity, because it no longer would be funded. The GPRA estimates include only an estimate of savings due to potential future codes.

Technical Characteristics. The FY 2007 GPRA estimates are based on the future development of more stringent building codes. The energy-savings methodology was applied at a state level to better link changes in the national codes (e.g., IECC 2006) with variations in climate by states (and differences among states) in their adoption and enforcement of codes.

The IECC's ongoing activities are expected to lead to more stringent residential standards in the future. The Department of Energy (DOE) is assumed to play a major role in developing the analytical and economic basis for such standards. For the GPRA process, these activities were subsumed in a single upgrade of the IECC standard projected to become available in the latter part of the current decade. BT estimated that the results of these upgrades were to reduce heating and cooling loads in new residential structures by 10%. Without these activities, BT assumed that an equivalent national (IECC) standard would not be developed within the time frame of the analysis.

Expected Market Uptake. The project's activities were assumed to improve future building codes. The analysis assumed that when states first adopt the new standard (assumed to become available in the 2006-2007 time frame), the potential energy savings from moving to the new standard would be 84% at the time of adoption, increasing to 90% with the effect of the project after the first 10 years. [a]

1.1.5 Sources

(1) “Building Technologies Program: 2006 Multi-Year Program Plan.” U.S. Department of Energy Buildings Technology Program, March 2005.
(2) U.S. Bureau of Census. New Privately Owned Housing Units Authorized: Annual 2004 Data. Accessed online on January 2006 at http://www.census.gov/const/www/C40/table2.html#annual.

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[a] The 84% assumption is based upon two other assumptions: 1) 60% of new homes fully comply with the new code, and 2) for the other 40% of new homes, 60% of the potential energy savings is achieved.

1.2 Research and Development: Building America

Project Description(1,2). The project's long-term goal is to develop integrated cost-effective whole-building strategies to enable residential buildings to use up to 70 percent less total energy than current code-compliant buildings by 2020 and provide up to 30 percent in additional energy savings through the use of integrated onsite power systems.[b] BT also will develop techniques to integrate new home energy efficiency and onsite power technology into existing homes to improve the energy efficiency of existing homes by up to 30 percent. In addition, user-friendly residential control packages are expected to be designed that interconnect and drive all components and reduce summer peak energy consumption by 100 percent when needed and annual energy consumption by 10-20 percent, by 2025.

1.2.1 Significant Changes from FY06

Existing buildings were added to the target market for the input characterization for FY07.

1.2.2 Target Market

Market Description (1): The target market primarily includes all new residential homes. The new home energy conservation approaches will also be tested and demonstrated in existing homes beginning FY 2007. The impacts on existing homes from this program are modeled to begin in 2010.

Size of Market(4): Each year about 1.6 million new single-family housing unit building permits are issued.

Market Introduction: Initial penetration of zero-net energy designs began in the southwest in 2003 and the design approach is anticipated to expand into the northern climate zones beginning in 2008(5). The renewable technologies supported by this project currently exist; however, penetration into the general market is expected to continue to be extremely low without DOE funding because the technology is currently unaffordable for production home builders. BT assumed that Building America activities would not occur without DOE funding; therefore, no acceleration of market acceptance was modeled.

Baseline Technology Improvements. There are no technology improvements assumed apart from what appears in the Energy Information Administration (EIA) baseline.

1.2.3 Key Factors in Shaping Market Adoption of EERE Technologies

Price - Incremental Cost for each level of energy savings in new homes(2):

- 40% whole house savings costs $1,850/household (HH)
- 60% whole house savings costs $5,300/HH

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[b] Whole house energy savings are measured relative to the BA Research Benchmark Definition (Building America, Building America Research Benchmark Definition, Version 3.1, November 11, 2003, National Renewable Energy Laboratory) which consists of the 2000 IECC requirements plus lighting, appliances and plug load energy levels (www.buildingamerica.gov)

- 70% whole house savings costs $15,000/HH
- By 2020, incremental costs are assumed to fall by 50%.
- One hundred percent savings (including renewable resources) costs $31,000/HH declining to $9,100 by 2020.

In developing the cost of solar technologies as part of the 70% incremental cost, BT assumed that the solar program meets it stated goal. BT assumed that Building America is credited for savings beyond 20% of the baseline (see the Methodology and Calculations section below). Incremental costs for existing buildings have not yet been determined.

Key Consumer Preference/Values – Nonenergy Benefits. The following nonenergy characteristics were not considered in developing savings estimates:

- Improved comfort, durability, and occupant health from better indoor air quality
- Reduced on-site generated waste
- Reduced maintenance.

1.2.4 Methodology and Calculations

New Residential Technical Characteristics and Market Uptake

For any one year, the Building America project's energy savings are calculated by multiplying the number of homes built with Building America techniques that year multiplied by the percent savings per home. Added to this are the energy savings, accrued in that year, for Building America homes built in previous years, beginning in 2007.

BT developed incremental costs for whole-building energy savings using Navigant Consulting's Residential Optimization Model (ROM, Version 5.7)(2). Cost increments were developed for three levels of percentage savings from the baseline: -40%, -60%, and -70%. BT assumed that half of the costs and corresponding savings for the first level (equivalent to 20% savings from the baseline) would occur as a result of other related programs in BT, namely appliance standards, building codes, and Energy Star homes. Thus, the net savings percentages with Building America are translated to 20%, 40%, and 50% of the baseline unit. The ROM model simulations and savings percentage assumptions formed the inputs for NEMS-GPRA07.

The ROM simulations were conducted for four cities: Minneapolis, Boston, Atlanta, and Phoenix (see **Table G-2**). Each city represents a proxy for a climate region in the U.S. Population weights to develop a national average were assigned in rough fashion (see **Table G-3**). Because the NEMS shell module only treats heating and cooling, the energy savings from the inputs shown in **Table G-2** will underestimate the potential savings from BT's Residential R&D program. NEMS does produce the number of new homes that are deemed to use one of the five shell packages available in the model. Assuming the same cost and performance of the technologies not modeled specifically in the shell module, the total savings are assumed to be roughly three times that shown in the model.[c] These additional savings beyond heating and cooling would occur in lighting, water heating, and other appliances in homes built to Building America criteria. The challenge for the integrated modeling effort is to

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[c] The factor of "three" is based on PNNL's assumption that space conditioning energy use in new homes would be about one-third of the total end-use energy affected by these technologies.

try to incorporate these additional savings which are due to the program, with a link to the number of homes using advanced shell packages four and five (as shown in **Table G-4**).

Shell package #4 is assumed to represent a "baseline" scenario for high-efficiency homes, based upon current costs. Building America activities are designed to seek innovative methods to reduce those costs in the future. The impact of this aspect of the program is shown in Shell package #5. Starting in 2010, the overall cost of the package is assumed to be 20% lower than the baseline ($223 versus $278), and then falling an additional 10% relative to the baseline every five years.

Table G-2. ROM Simulation Results for Representative Cities

		Minneapolis		Boston		Atlanta		Phoenix	
Cost Impact									
All Technologies	Building America	Total Cost	Delta Cost	Total Cost	Delta Cost	Total Cost	Delta Cost	Total Cost	Delta Cost
Base		$46,499		$25,164		$22,884		$28,384	
20%									
40%	20%	$48,297	$899	$27,373	$1,105	$24,818	$967	$29,646	$631
60%	40%	$51,543	$5,044	$30,793	$5,629	$28,376	$5,492	$32,671	$4,287
70%	50%	$62,467	$15,968	$39,880	$14,716	$39,784	$16,900	$40,112	$11,728
Energy Use		MMBtu/HH		MMBtu/HH		MMBtu/HH		MMBtu/HH	
Base		214.9		191.7		164.2		176.0	
20%		172.0		153.4		131.3		140.8	
40%		129.0		115.0		98.5		105.6	
60%		107.5		95.9		82.1		88.0	
70%		64.5		57.5		49.3		52.8	

Table G-3. Population Weights and Incremental Costs for Representative Cities

		Incremental Costs, Building America		
City	Weight	20%	40%	50%
Minneapolis	0.2	$899	$5,044	$15,968
Boston	0.3	$1,105	$5,629	$14,716
Atlanta	0.3	$967	$5,492	$16,900
Phoenix	0.2	$631	$4,287	$11,728
Average *		$927	$5,203	$15,024
HVAC share **	0.3	$278	$1,561	$4,507

*Costs for percentage reduction in whole-building energy use
**Costs for percentage reduction in heating and cooling consumption

Table G-4. Suggested Adjustments to NEMS Shell Factors

Heating Shell Efficiency Adjustments (multiplicative factors)

Package	2003	2005	2010	2015	2020	2025
4*	1.00	0.80	0.80	0.60	0.50	0.50
5*	1.00	1.00	0.80	0.60	0.50	0.50

Cooling Shell Efficiency Adjustments (multiplicative factors)

Package	2003	2005	2010	2015	2020	2025
4	1.00	0.80	0.80	0.60	0.50	0.50
5	1.00	1.00	0.80	0.60	0.50	0.50

Shell Cost Adjustment Factors (Amount Subtracted)

Package	2003	2005	2010	2015	2020	2025
4	0	-$278	-$278	-$1,561	-$4,507	-$4,507
5			-$223	-$1,093	-$2,704	-$2,254

* Packages 4 and 5 represent Building America
** Costs are incremental, above the baseline

The fundamental premise that leads to wide adoption of the technology is that existing technologies and DOE projects will eventually reduce energy use by about 70% and reduce summer peak loads to zero. This, in turn, will result in significantly less solar electric and solar thermal technology needed to supply the home's load. The combination of lower building loads and onsite power will shave summer peak loads and thereby alleviate some of the need to expand the grid to accommodate system summer peaks.

Existing Residential Technical Characteristics and Market Uptake

The performance goal for existing residential is to reduce whole-house energy use by 20% by 2010. The expected market uptake is based on U.S. Census renovated space estimates and project management input.(8) Estimated market penetration rates for whole house design for existing homes are found in **Table G-5**.

Table G-5. Whole House Energy Efficient Design - Existing Residential Homes Market Penetration

Year	Percent of Existing Stock
2007	0.0000
2008	0.0000
2009	0.0000
2010	0.0092
2011	0.0203
2012	0.0336
2013	0.0487
2014	0.0653
2015	0.0829
2016	0.1006
2017	0.1178
2018	0.1337
2019	0.1479
2020	0.1600

1.2.5 Sources

(1) "Building Technologies Program: 2006 Multi-Year Program Plan." Draft. U.S. DOE, March 2005.
(2) Final Draft: Zero Energy Homes' Opportunities for Energy Savings: Defining the Technology Pathways Through Optimization Analysis, U.S. Department of Energy Building Technologies Program, October 2003.
(3) U.S. Department of Energy, Building America Research Benchmark Definition. Version 3.1, November 11, 2003. Accessed online March 2004, at http://www.eere.energy.gov/buildings/building_america/benchmark_def.html.
(4) U.S. Bureau of Census. New Privately Owned Housing Units Authorized: Annual 2004 Data. Accessed online on January 2006 at http://www.census.gov/const/www/C40/table2.html#annual.
(5) Information obtained in discussions with the project manager, Lew Pratsch, August/September 2003.
(6) New Houses Sold, by Region, by Sales Price: Annual Data. U.S. Census Bureau, Manufacturing and Construction Division. www.census.gov/const/regsoldbypricea.pdf, accessed August 8, 2003.
(7) Buildings Energy Databook (July 26, 2003), Table 5.1.1., "2001 Five Largest Residential Homebuilders."
(8) U.S. Census Bureau 2000. *1997 Economic Census Construction Geographic Area Series."* U.S. Department of Commerce, March 2000. Washington D.C.

2.0 Commercial Buildings Integration

The long-term goal of the Commercial Buildings Integration subprogram is to develop cost-effective technologies and building practices that will enable the design and construction of net Zero Energy Buildings – commercial buildings that produce as much energy as they use on an annual basis – by 2025.

2.1 Commercial Building Energy Codes

Project Description. The Commercial Building Energy Codes project improves the minimum energy efficiency of new commercial and multifamily high-rise buildings and additions and alterations to existing buildings requiring code permits. The project promulgates upgraded energy-efficiency requirements for federal commercial and high-rise residential building types. Similarly, the project works with model energy code groups to upgrade the energy-efficiency requirements of their codes. These upgraded national energy standards are then adopted by federal, state, and local jurisdictions as part of their building codes. The project's long-term goal is to improve minimum energy efficiency by 30% to 35% in new commercial building construction. Energy use will be reduced by states and local jurisdictions widely adopting the national standards as building energy codes.

2.1.1 Significant Changes from FY06

No significant changes were made to this program for the FY07 effort. In previous years, all of the building codes activities have been modeled together, independent of funding source, with code development funded activities funded under BT and codes training and deployment activities funded as part of the Weatherization and Intergovernmental Activities Program (WIP). The impact of the individual codes activities (residential, commercial, and training and assistance) has been allocated to the individually funded activities based on the presumed impacts of greater compliance of existing codes as well as future code development and adoption. The FY 2006 activity within WIP to provide incentive funding and technical assistance to aid in the adoption, compliance, and enforcement of codes was discontinued in FY 2007, although the State Energy Program Grants program within WIP is expected to continue to fund similar activities, as they have done historically. The expected impact on the BT-funded portion of the codes activities is not anticipated to be significant.

2.1.2 Target Market

Market Description. The market includes new commercial and multifamily high-rise (above three stories) buildings and all additions/renovations to commercial buildings requiring permits.

Size of Market. The commercial market size is about 2 billion square feet of new commercial floor space each year. The Federal sector represents nearly 2.3% overall of new commercial building construction.

Baseline Technology Improvements. Initial compliance with new codes was assumed to be lower in the base case, i.e., without the Building Energy Codes project. For FY07, the percentage of potential savings, in the first year of the single future code, was estimated to be approximately 20% for envelope measures and 30% for lighting measures without the project.

Baseline Market Acceptance. The FY 2007 GPRA estimates are based on the future development of more stringent building energy codes.

2.1.3 Key Factors in Shaping Market Adoption of EERE Technologies

Price. BT developed incremental investment costs by assuming a five-year payback period on investment (i.e., an annual energy cost savings of $1 implies an initial investment of $5).

Key Consumer Preferences/Values. The following nonenergy characteristics were not considered in developing savings estimates.

- Improved environment and more comfortable buildings.
- Lower building maintenance and repair activities
- Reduced pollution due to the reduced burning of fossil fuels and electricity generation, which improves air quality and mitigates the negative impacts of global warming.

2.1.4 Methodology and Calculations

Inputs to Base Case. With respect to building codes, it is indeterminate the extent to which potential future code improvements are incorporated into the NEMS-GPRA07 base case. The NEMS-GPRA07 base case does include some improvements to the building shell efficiency; however, the basis for these improvements (e.g., general building practice improvements, changes in code requirements, and improvements in materials) is not specified by EIA. The impact of accelerated adoption and improved compliance by states of recently issued national building standards (e.g., ASHRAE 90.1-1999) is included in the GPRA forecast of savings. Therefore, BT did not provide inputs to change the base case assumptions for program markets.

Technical Characteristics. Energy savings from this project result from some basic improvements to the overall energy efficiency of commercial buildings in their space-heating, space-cooling, and lighting loads. This project funds research analysis of cost-effective levels of energy codes for new commercial and multifamily high-rise buildings.

Improvements to building codes are primarily supported by research efforts to review existing codes and specific targeted areas of building energy use, as well as the adoption of code modifications that promote cost-effective reductions in these energy-use areas. The adoption process for the research work has typically taken place in three areas:

- Upgrading ASHRAE/IES Standard 90.1-1989, "Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings"(1)
- Upgrading the Federal commercial and multifamily high-rise building energy code, 10 CFR 434, "Energy Code for New Federal Commercial and Multi-Family High Rise Residential Buildings"(2)
- Upgrading the International Energy Conservation Code (IECC).(3)

The FY 2007 GPRA estimates are based on the future development of more stringent building energy codes. The energy-savings methodology was applied at a state level to better link changes in the codes with variations in climates by states and differences among states in their adoption and enforcement of building codes. The discussion below uses national averages of some of the key assumptions related to adoption and compliance to help summarize the methodology, but appropriate state averages were used in the analysis.

The ongoing activities of the ASHRAE 90.1 committee were assumed to lead to more stringent commercial-building standards in the future. DOE was assumed to play a major role in developing the analytical and economic basis for such standards. For the GPRA process, these activities were subsumed in a single upgrade of the ASHRAE standard, estimated to become available in the latter part of the current decade. The GPRA analysis assumed that the overall result of these upgrades is to reduce electricity consumption by 10% and natural gas consumption by 10% in new commercial buildings.

Expected Market Uptake. As part of work for an unpublished analysis of the historical impacts of Building Energy Codes in August 2003, the baseline assumptions regarding the acceleration effect of the overall program were modified (e.g., program training and assistance) activities leading to states adopting (the most recent national ASHRAE or IECC) codes more rapidly than they would have otherwise). In general, *without* the training and assistance elements of the building codes project, the states were classified into groups that: 1) immediately (one or two years) adopted the 90.1-1989 ASHRAE code, 2) would have adopted within five years or 3) would have adopted within 10 years..[d] These time periods were then reduced by one year for each successive major code cycle after the 1989 code. (For example, a five-year lag for 90.1-1989 is assumed to fall to four years for the 90.1-1999 code, three years for the ASHRAE 90.1-2004 code, and two years for the next major update of the code). The overall impact of this change was to decrease the average lag between the publication of a new standard and when it is adopted – without the project. For the scenario involving a new commercial code (circa 2009), states are assumed to adopt that code over a period extending from 2011 to 2022, with a mean adoption year of 2015.

2.1.5 Sources

(1) ASHRAE/IES Standard 90.1-1989, "Energy Efficient Design of New Buildings Except Low-Rise Residential Buildings," American Society of Heating, Refrigeration, and Air-Conditioning Engineers and Illuminating Engineering Society.
(2) 10 CFR 434, "Energy Code for New Federal Commercial and Multi-Family High Rise Residential Buildings," *Code of Federal Regulations*, as amended.
(3) International Energy Conservation Code. 2003. International Code Council, Falls Church, Virginia.
(4) ASHRAE/IES Standard 90.1-1999, "Energy Standard for Buildings Except Low-Rise Residential Buildings," American Society of Heating, Refrigeration, and Air-Conditioning Engineers.

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[d] The historical record for states adopting the 90.1-1989 standard was 1) two states adopted within the first two years of publication, and 2) 24 states had adopted by 1998. Three states are not considered in the analysis as they had had active code development programs in their own states: California, Oregon, and Florida.

(5) ASHRAE/IES Standard 90.1-2001, "Energy Standard for Buildings Except Low-Rise Residential Buildings," American Society of Heating, Refrigeration, and Air-Conditioning Engineers.
(6) U.S. Department of Energy. March 2002. "Commercial Buildings Determinations, Explanation of the Analysis and Spreadsheet (90_1savingsanalysis.xls)." http://www.energycodes.gov/implement/determinations_com.stm

2.2 Research and Development

Project Description.(1) In order to reach net zero conventional energy buildings (ZEB) by 2025, DOE will employ integrated whole-building strategies to enable commercial buildings to be designed and constructed to use 70% less energy. By 2010, the BT goal is to integrate design approaches, highly efficient component technologies and controls, improved construction and maintenance practices, and operating procedures that will make new and existing commercial buildings durable, healthy and safe for occupants, and will reduce energy use for new buildings by 50% and by 30% for existing buildings, relative to conventional practice. [e]

2.2.1 Significant Changes from FY06

For FY07, BT changed the out-year performance and cost inputs for new buildings, which were held constant through the analysis period for the FY06 effort. Additionally, BT estimates that Commercial Technology R&D would accelerate the adoption of relevant energy-savings products, technologies and designs by 5 years. This estimate is a revision from a 10 year period (assumed in FY06).

2.2.2 Target Market

Market Description(1): Although this project does not explicitly exclude any particular building type, the types of commercial buildings that will most likely be impacted by the technologies developed by this project primarily include small commercial buildings with relatively high energy use intensities such as assembly, education, food service, food sales, lodging, mercantile and service, and office buildings.

Baseline Technology Improvements. There are no technology improvements assumed apart from what appears in the Energy Information Administration (EIA) baseline.

Baseline Market Acceptance. In 1998, PNNL conducted a study examining the historical market penetration for 10 energy-efficient products related to the buildings sector. The results of this study are documented in the PNNL report, *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort* (2004)(6). The study suggested several generic penetration curves based on the type of equipment of interest. BT used the curve related to design products to model this project.

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[e] Energy savings are measured relative to the 2001 International Energy Conservation Code (IECC).

2.2.3 Key Factors in Shaping Market Adoption of EERE Technologies

Price.
Total Building Cost of Conventional Technology(4): Average of \$101/ft^2 for the targeted new commercial and multifamily; \$0 for existing buildings.
Total Building Cost of BT Technology(5): \$103/ft^2 for new commercial and multifamily, increasing to \$107/ft^2 in 2020[f]; \$4/ ft^2 for existing buildings.
Incremental Cost(5): 2% above base for new buildings, increasing to 6% above base in 2020; \$4/ft^2 for existing buildings.

Key Consumer Preference/Values – Nonenergy Benefits. The following nonenergy characteristics were not considered in developing energy output estimates:

- Reduced operation and maintenance expenses
- Improved indoor environmental quality
- Increased property asset value
- Higher tenant satisfaction and retention rates
- Increased technology sales.

2.2.4 Methodology and Calculations

Inputs to Base Case. BT did not provide inputs to change the base case assumptions for the program markets. BT's calculations were based on a baseline that was developed from the Energy Information Administration's (EIA's) Commercial Buildings Energy Consumption Survey (CBECS), Residential Energy Consumption Survey (RECS), and the Annual Energy Outlook (AEO).

Technical Characteristics (2,3). In concert with the Analysis, Tools, and Design Strategies project, the performance goals are to reduce heating and cooling loads by 50% in new small commercial construction as compared with ASHRAE 90.1-2004, increasing to 70% savings by 2020. The goal is also to save 30% in existing buildings.[g]

Expected Market Uptake. The market penetration goal(3) is to accelerate the penetration of high-performance building designs, such that 55% of new commercial and multifamily construction (**Figure G-1**) and 20% of existing construction incorporates the products supported by this project by 2025 (**Figure G-2**). Penetration curves were developed based on market diffusion curves developed by PNNL(6). BT assumed that this project accelerates the adoption of relevant energy-savings products, technologies and designs by 5 years.

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[f] Cost estimates corresponding with 70% energy savings are based on escalation estimates associated with similar energy savings in residential sector. Cost escalation estimates are based on Navigant Consulting's Residential Optimization Model (Version 5.7)

[g] The percentage of the load reduction attributed between Commercial R&D and Analysis Tools and Design Strategies is in proportion with their respective budget requests.

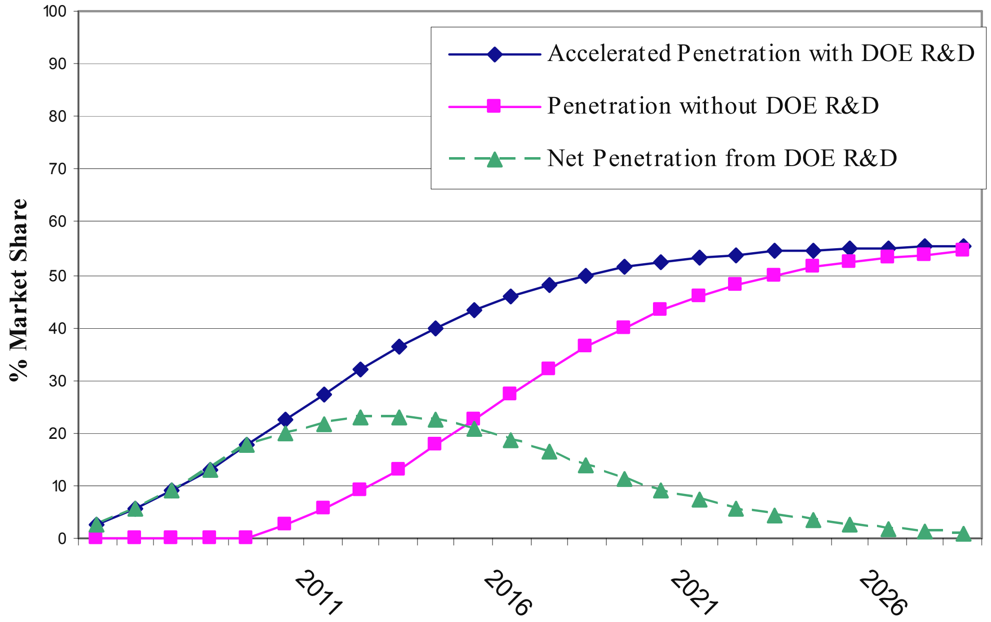

Figure G-1. Market-Penetration Curve for Commercial R&D Project Targeting New Buildings

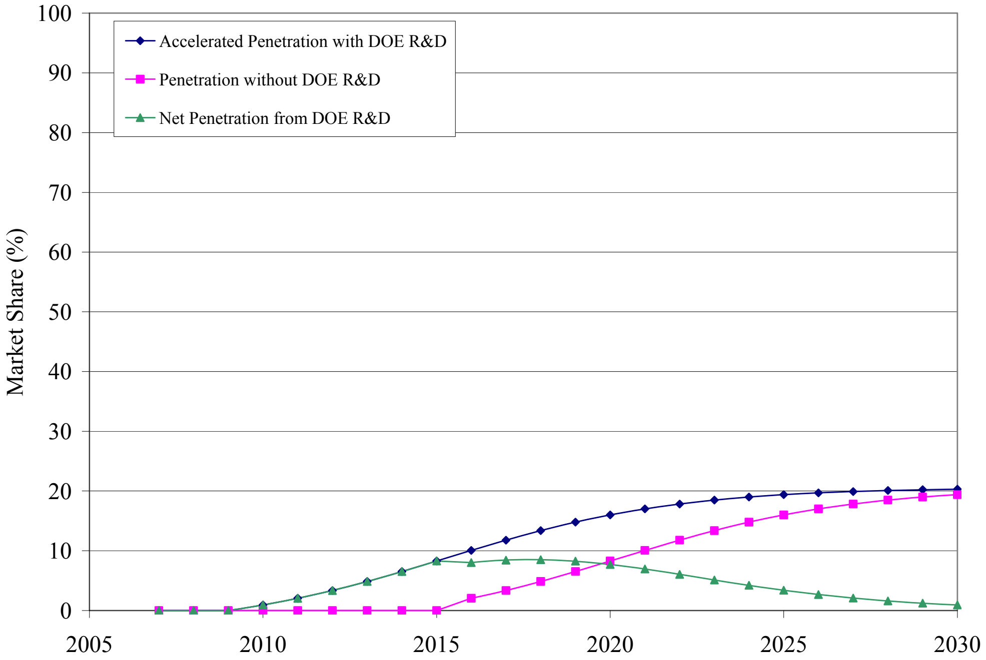

Figure G-2. Market-Penetration Curve for Commercial R&D Project Targeting Existing Buildings

2.2.5 Sources

(1) "Building Technology Program: Research, Development and Demonstration Plan, Planned Program Activities for 2004-2010." Final Draft. U.S. DOE, January 9, 2004.
(2) Torcellini, Paul, et. al. Lessons Learned from Field Evaluation of Six High-Performance Buildings, NREL/CP-550-36290, National Renewable Energy Laboratory, June 2004.
(3) E-mail correspondence with project manager, Dru Crawley, June 2003.
(4) RS Means Company, Inc. 2002. "RS MEANS Square Foot Costs." 23rd Edition, Kingston, MA.
(5) Kats, Greg (Capital E), et. al. "The Costs and Financial Benefits of Green Buildings," A Report to California's Sustainable Building Task Force. October 2003.
(6) Elliott, D.B., D.M. Anderson, D.B. Belzer, K.A. Cort, J.A. Dirks, D.J. Hostick. 2004. *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort*. PNNL-14697. Pacific Northwest National Laboratory, Richland, Washington.

3.0 Equipment Standards and Analysis

The Equipment Standards and Analysis subprogram seeks to develop minimum energy efficiency standards that are technologically feasible and economically justified.

3.1 Electric Motors, 1-200 HP

Project Description(1). The Energy Policy Act of 1992 (EPAct) requires that general purpose, polyphase, single speed, squirrel-cage induction motors rated from 1-200 horsepower (HP) manufactured for sale in the U.S. from October 1997 onward meet minimum efficiency standards. The EPAct standard was adapted from earlier standards promulgated by the National Electrical Manufacturer's Association (NEMA). NEMA maintains a more stringent voluntary standard known as NEMA Premium^{TM}. DOE is proposing to change the minimum requirements for motor efficiency to be comparable to the NEMA Premium^{TM}. The efficiency standard targets motors designed for use under usual service conditions without restriction to a particular application or type of application. Motors covered by the Energy Policy Act (EPAct) account for 50-70 percent of all integral[h] horsepower motors sold.

3.1.1 Significant Changes from FY06

This characterization represents a new activity for FY07.

3.1.2 Target Market

Market Description(1). Industrial motor systems are the largest single electrical end use in the U.S. economy. According to the United States Industrial Electric Motor Systems Market Opportunity Assessment, electric motors used in industrial processes consumed 679 billion kWh (approximately 7.5 quads of primary energy) in 1994. Commercial sector motors are much more numerous than industrial motors, and tend to be smaller. In 1995, there were 123 million commercial sector motors in total. About 36 million commercial motors fall in the EPAct size range.

Size of Market. There is an installed base of 12.3 million industrial sector units and 4.1 million commercial sector units, 1-200HP, that are subject to EPAct. There are about 1.5 million industrial motors shipped annually, and an additional 0.54 million commercial units.

Baseline Technology Improvements. There are no technology improvements assumed apart from what appears in the Energy Information Administration (EIA) baseline.

3.1.3 Key Factors in Shaping Market Adoption of EERE Technologies

Price. No price information was available or used to model this program.

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[h] Motors below 1 horsepower (HP) are known as fractional horsepower motors; those 1 HP and above are known as integral.

Key Consumer Preferences/Values. The following nonenergy characteristics were not considered in developing energy output estimates:

- Reduced CO_2 and SO_X emissions
- Increased life of equipment operating at cooler temperatures
- Reduced first costs that transform new technologies into commodities.

3.1.4 Methodology and Calculations

Technical Characteristics.
Energy performance assumptions are based on DOE's FY2005 Technical Support Document, Appendix A, and include the following:

- Base Case: Average electric motor energy consumption: 25.61 thousand kWh/yr
- Performance: Standard results in 2% average reduction in energy
- Equipment lifetime: 15 years
- Start Date: Effective date of standard is 2010.

Expected Market Uptake. BT assumed that the entire stock of existing motors is replaced with motors meeting the standard by 2025 (the standard goes into effect in 2010, so within 15 years, the estimated lifetime, all motors have been replaced). Subsequent increases in savings are only from increases in new sales (as opposed to replacement sales).

Based on forecasted shipment data(1), **Tables G-6 and G-7** contain the energy savings calculations.

Table G-6. Annual Industrial Energy Savings

Year	In-Year Energy Savings from Sales (million kWh/yr Site)	Total Annual Energy Savings – Installed Base (million kWh/yr Site)	Annual Energy Savings – Installed Base (TBtu/yr Site)
2007	0.0		
2008	0.0		
2009	0.0	-	-
2010	652.3	652.3	2.2
2011	665.3	1,317.6	4.5
2012	678.6	1,996.2	6.8
2013	692.2	2,688.3	9.2
2014	706.0	3,394.4	11.6
2015	720.1	4,114.5	14.0
2016	734.5	4,849.0	16.5
2017	749.2	5,598.3	19.1
2018	764.2	6,362.5	21.7
2019	779.5	7,142.0	24.4
2020	795.1	7,937.1	27.1
2021	811.0	8,748.1	29.8
2022	827.2	9,575.3	32.7
2023	843.8	10,419.1	35.5
2024	860.6	11,279.7	38.5
2025	225.6	11,505.3	39.3
2026	230.1	11,735.4	40.0
2027	234.7	11,970.1	40.8
2028	239.4	12,209.5	41.7
2029	244.2	12,453.7	42.5
2030	249.1	12,702.8	43.3

Table G-7. Annual Commercial Energy Savings

Year	In-Year Energy Savings from Sales (million kWh/yr Site)	Total Annual Energy Savings – Installed Base (million kWh/yr Site)	Annual Energy Savings – Installed Base (TBtu/yr Site)
2007	0.0		
2008	0.0		
2009	0.0	-	-
2010	176.7	176.7	0.6
2011	180.2	356.8	1.2
2012	183.8	540.6	1.8
2013	187.5	728.1	2.5
2014	191.2	919.3	3.1
2015	195.0	1,114.3	3.8
2016	198.9	1,313.3	4.5
2017	202.9	1,516.2	5.2
2018	207.0	1,723.2	5.9
2019	211.1	1,934.3	6.6
2020	215.3	2,149.6	7.3
2021	219.6	2,369.3	8.1
2022	224.0	2,593.3	8.8
2023	228.5	2,821.8	9.6
2024	233.1	3,054.9	10.4
2025	61.1	3,116.0	10.6
2026	62.3	3,178.3	10.8
2027	63.6	3,241.9	11.1
2028	64.8	3,306.7	11.3
2029	66.1	3,372.9	11.5
2030	67.5	3,440.3	11.7

3.1.5 Sources

(1) U.S. Department of Energy 2005. Appendix A: FY2005 Technical Support Document. Accessed online on January 2006 at http://www.eere.energy.gov/buildings/appliance_standards/pdfs/fy05_priority_setting_app_a.pdf

3.2 HID Lamps

Project Description. (1) High Intensity Discharge (HID) Lamps are electric lamps that produce light in a small arc tube under high internal pressure. Typical applications for these lamps are street and roadway lighting, area lighting such as parking lots and stadiums, industrial and commercial building interior lighting, commercial, industrial and residential security lighting, and landscape lighting. There are three HID lamp types: mercury vapor, metal halide, and high pressure sodium and the least efficient of these is mercury vapor. The Energy Policy and Conservation Act (EPCA, 42 U.S.C.6317(a)(1)) requires the Department of Energy (the Department) to undertake a determination to see if energy conservation standards for HID lamps would be technologically feasible and economically justified, and would result in significant energy savings.

3.2.1 Significant Changes from FY06

This characterization represents a new activity for FY07.

3.2.2 Target Market

Market Description: According the draft Technical Support Document published in December 2004,(2) mercury vapor lamps account for about one-sixth of the approximately 140 TWh used by all high intensity sources. Thus mercury vapor lamps use about 75 TBtu of delivered electricity per year.

Baseline Technology Improvements. There are no technology improvements assumed apart from what appears in the Energy Information Administration (EIA) baseline.

Market Introduction. BT assumed that the effective date of the standard would be 2010.

3.2.3 Key Factors in Shaping Market Adoption of EERE Technologies

Price. Costs as defined by the NEMS commercial model (file Ktech.txt)

Key Consumer Preferences/Values. The following nonenergy characteristics were not considered in developing energy output estimates:

- Reduced CO_2 and SO_X emissions
- Increased life of equipment operating at cooler temperatures

3.2.4 Methodology and Calculations

From documents on the BT web site(1) related to the setting of efficiency standard for HID lamps, the basic impact will likely be the elimination of mercury vapor lamps via a federal efficiency standard. As stated in the documentation of expected impacts in the Technical Support Document, "… the focus is on a possible standard that could be met by lamps with efficacies above those typical of today's MV lamps." Subsequent events have confirmed that choice for modeling the standard. The EPAct 2005 requires that mercury vapor lamp ballasts shall not be manufactured or imported after January 1, 2008.

Technical Characteristics.
The commercial model in NEMS contains several lighting segments that include mercury vapor, metal halide (MH), and high pressure sodium (HPS). The market segments considered by the NEMS model are low-bay applications (< 25 feet high) and high-bay applications (> 25 feet high) for high-intensity discharge lamps. **Table G-8** shows the efficacies used in the NEMS input files for these common lamp technologies and the typical wattages for those lamps. For purposes of modeling the HID standard in the GPRA integrated model, mercury vapor lamps were no longer one of lighting technology choices in these two market segments in the expected year of the standard.

Table G-8. Efficacies for Common HID Lamp Types in NEMS (Lumens/Watt, lpw)[i]

Application	Mercury Vapor	Metal Halide	High Pressure Sodium
Low-bay	34 lpw (175 watts)	46 lpw (pulse) (100 watts)	59 lpw (70 watts)
High-bay	37 lpw (400 watts)	61 lpw (pulse) (250 watts)	83 lpw (200 watts)

Performance Parameters. 40 lumens per watt for mercury vapor; 70 lumens per watt for metal halide; and 90 lumens per watt for high pressure sodium.

3.2.5 Sources

(1) BT Appliances and Commercial Equipment Standards web site, accessible at: http://www.eere.energy.gov/buildings/appliance_standards/commercial/high_intensity_lamps.html.
(2) High-Intensity Discharge Lamps Analysis of Potential Energy Savings, December 2004, accessible at: http://www.eere.energy.gov/buildings/appliance_standards/commercial/pdfs/hid_energy_savings_report.pdf.

3.3 Distribution Transformers

Project Description. Distribution transformers convert high-voltage electricity from distribution centers to lower-voltage electricity for use at the household level. During this conversion process, a small fraction of heat is lost. The Energy Policy and Conservation Act (EPCA) of 1975 established an energy conservation program for major household appliances. The National Energy Conservation Policy Act of 1978 amended EPCA to add Part C of Title III, which established an energy conservation program for certain industrial equipment. The Energy Policy Act of 1992 amended EPCA to add certain commercial equipment, including distribution transformers.

The department is currently conducting two rulemakings for Distribution Transformers: an energy conservation standard and a test procedure.

3.3.1 Significant Changes from FY06

For the FY07 effort, the effective date of the standard was changed from 2008 to 2010 based on the current rule-making schedule.

3.3.2 Target Market

Market Description(3). Over one million new distribution transformers are purchased annually. Utility distribution transformers account for an estimated 61 billion kWh of the annual energy

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[i] Source is the ktech.wk1 spreadsheet containing cost and performance characteristics for the NEMS commercial module used for the 2006 AEO reference projection.

lost in the generation and delivery of electricity. Additional transformer losses in non-utility applications are estimated to be 79 billion kWh.

Baseline Technology Improvements. There are no technology improvements assumed apart from what appears in the Energy Information Administration (EIA) baseline.

3.3.3 Key Factors in Shaping Market Adoption of EERE Technologies

Price. BT assumed a 10-year payback period on investment to develop incremental investment costs (i.e., an annual energy cost savings of $1 implies an initial investment of $10).

Key Consumer Preferences/Values. The following nonenergy characteristics were not considered in developing energy output estimates:

- Reduced CO_2 and SO_X emissions

3.3.4 Methodology and Calculations

Inputs to Base Case. BT did not provide inputs to change the base case assumptions for the program markets. BT's calculations were based on a baseline that was developed from the Energy Information Administration's (EIA's) Commercial Buildings Energy Consumption Survey (CBECS), Residential Energy Consumption Survey (RECS), and the Annual Energy Outlook (AEO).

Technical Characteristics

Performance Target. Savings estimates for a distribution transformer standard were based on the DOE Draft ANOPR Analysis for Distribution Transformers Rulemaking (January 6, 2004).(1) The analysis assumed the following:

- Average savings of 140 watts per unit
- A transformer sales forecast (see **Table G-9**).
- 0% sales complying with the new level without the standard (this was taken into account in calculating the 140 watts average savings)
- 8,760 annual operating hours per unit
- 30-year life of equipment.

BT assumed that the distribution transformer standard would not go into effect until 2010, based on the BT 2006 Multi-Year Program Plan indicating that the final rule would be issued September 2007, with the standard going into effect three years later.(2) The savings estimate of 140 watts per unit installed was multiplied by the estimated hours of operation and then by the forecasted number of units installed.

Expected Market Uptake

Table G-9. Distribution Transformer Market Penetration (# of units)

Year	Transformer Sales Forecast
2010	1,582,000
2011	1,614,000
2012	1,646,000
2013	1,673,000
2014	1,701,000
2015	1,729,000
2016	1,756,000
2017	1,782,000
2018	1,810,000
2019	1,840,000
2020	1,870,000
2021	1,898,000
2022	1,929,000
2023	1,960,000
2024	1,994,000
2025	2,025,000
2026	2,058,000
2027	2,090,000
2028	2,124,000
2029	2,158,000
2030	2,192,000

3.3.5 Sources

(1) DOE Draft ANOPR Analysis for Distribution Transformers Rulemaking, January 6, 2004.
(2) "Building Technologies Program: 2006 Multi-Year Program Plan." Draft. U.S. DOE, March 29, 2005.
(3) Barnes, P.R., S. Das, B.W. McConnell, J.W. Van Dyke, 1997. *Supplement to the "Determination Analysis" (ORNL-6847) and Analysis of the NEMA Efficiency Standard for Distribution Transformers*. ORNL-6925, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

4.0 Emerging Technologies

The Emerging Technologies subprogram seeks to develop cost effective technologies (e.g., lighting, windows, and space heating and cooling) for residential and commercial buildings that can reduce the total energy use in buildings by 60% to 70%. The improvement in component and system energy efficiency, when coupled with research to integrate onsite renewable energy supply systems into the commercial building, can result in marketable net zero energy designs.

4.1 Analysis Tools and Design Strategies

Project Description.(1) The Analysis Tools and Design Strategies project researches the interrelationship of energy systems and building energy performance, develops various building analysis tools to more accurately model energy use in new and existing buildings, and provides recommendations and strategies to cost effectively lower energy use and improve building performance. The project focuses on whole-building software tools for evaluating energy efficiency and renewable energy. The project also focuses on non-software solutions such as improved standards, guidelines, and performance measurements, all of which bring about excellence in designing new buildings. The project's long-term goal is to improve energy designs for all building types through a number of widely used analytical tools and guidance documents.

4.1.1 Significant Changes from FY06

BT estimates that Analysis Tools and Design Strategies would accelerate the adoption of relevant energy-savings products, technologies and designs by 5 years. This estimate is a revision from a 10 year period (assumed in FY06).

4.1.2 Target Market

Market Description: Although this project does not explicitly exclude any particular building type, the types of commercial buildings that most likely will be impacted by the technologies developed by this project include those with relatively higher energy use intensities such as assembly, education, health care, lodging, and office buildings.

Market Introduction(1,3): BT assumed that this project accelerates the introduction and market penetration of the advanced building energy tools and design strategies by 5 years. Historically, there have been a number of building energy tools that have been developed privately; however, most of these tools use algorithms, code, and modules developed by DOE. BT estimated that a proportion of these activities (50%) would not occur without DOE funding. These assumptions are necessary in the absence of citable sources documenting DOE's influence on building energy tool adoption and algorithm attribution.

Baseline Technology Improvements. There are no technology improvements assumed apart from what appears in the Energy Information Administration (EIA) baseline.

Baseline Market Acceptance. In 1998, Pacific Northwest National Laboratory (PNNL) conducted a study examining the historical market penetration for 10 energy-efficient products related to the buildings sector. The results of this study are documented by PNNL(5). The study suggested several generic penetration curves based on the type of equipment of interest. BT used the curve related to design products to model this project.

4.1.3 Key Factors in Shaping Market Adoption of EERE Technologies

Price(3,4)**.** Although the tools supported by this project are distributed free of charge, users must invest a certain amount of time to learn the tools. Without a user-friendly interface, approximately one person-month is required to be come proficient with the tools. Analysis Tools and Design Strategies is currently developing energy-simulation tools without a user-friendly interface. This allows the private sector to contribute its knowledge of user needs and market competition to design their own user-friendly interface.

Key Consumer Preference/Values – Nonenergy Benefits. The following nonenergy characteristics were not considered in developing energy output estimates:

- Improved indoor environmental quality, such as thermal comfort and ventilation adequacy
- Improved indoor air quality
- Fire safety
- Overall environmental sustainability (i.e., Green Buildings).

4.1.4 Methodology and Calculations

Inputs to Base Case. BT did not provide inputs to change the base case assumptions for the program markets. BT's calculations were based on a baseline that was developed from the Energy Information Administration's (EIA's) Commercial Buildings Energy Consumption Survey (CBECS), Residential Energy Consumption Survey (RECS), and the Annual Energy Outlook (AEO).

Technical Characteristics(2)**.** In concert with Commercial Buildings R&D project, the performance goals are to reduce heating and cooling loads by 50% in new small commercial construction and by 30% in existing buildings.[j]

Expected Market Uptake(3)**.** The market penetration goal is to accelerate the penetration of high-performance building design, such that 55% of new commercial and multifamily construction and 20% of existing construction incorporates the products supported by this project by 2025. BT assumes that this project accelerates the adoption of relevant energy-savings products, technologies and designs by 5 years.

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[j] The percentage of the load reduction attributed between Commercial R&D and Analysis Tools and Design Strategies is in proportion with their respective budget requests.

4.1.5 Sources

(1) "Building Technology Program: Research, Development and Demonstration Plan, Planned Program Activities for 2004-2010." Final Draft. U.S. DOE, January 9, 2004.

(2) Torcellini, Paul, et. al. *Lessons Learned from Field Evaluation of Six High-Performance Buildings,* NREL/CP-550-36290, National Renewable Energy Laboratory, June 2004.

(3) E-mail correspondence with project manager, Dru Crawley, June 2003 and June 2004.

(4) Kats, Greg (Capital E), et. al. "The Costs and Financial Benefits of Green Buildings," A Report to California's Sustainable Building Task Force. October 2003.

(5) Elliott, D.B., D.M. Anderson, D.B. Belzer, K.A. Cort, J.A. Dirks, D.J. Hostick. 2004. *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort*. PNNL-14697. Pacific Northwest National Laboratory, Richland, Washington.

4.2 Appliances and Emerging Technologies R&D: Solid State Lighting Market Acceptance

Project Description(1)**:** The purpose of this program is to accelerate the market acceptance of solid-state lighting technologies. This will be accomplished through a variety of methods potentially including:

- Competitive technology procurements
- Late-stage technology refinement in conjunction with influential product users
- Field performance evaluation and verification for the benefit of large-scale buyers
- Product performance testing
- Product design competitions in cooperation with major market actors
- Voluntary product guidelines and conventions

4.2.1 Significant Changes from FY06

The activities modeled for Appliances and Emerging Technologies R&D changed for FY07. The only activity modeled for FY07 is Solid State Lighting Acceptance, which is a new activity.

4.2.2 Target Market

Market Description: The market is the entire market for solid-state lighting.

Size of Market: Lighting consumes 26% (3.9 QBtu) of the primary energy used in commercial buildings, which had building stock of about 69 billion ft^2 in 2000.[k]

4.2.3 Key Factors in Shaping Market Adoption of EERE Technologies

Price. Given that this is a market acceptance program there will be no direct cost borne by the consumers.

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[k] According to a report completed for DOE by Navigant Consulting ("U.S. Lighting Market Characterization, Volume I: National Lighting Inventory and Energy Consumption Estimate," September 2002), the amount of energy used for lighting is greater than EIA has traditionally estimated. The report estimates that commercial lighting requires 4.2 QBtu and residential lighting requires 2.2 QBtu.

Key Consumer Preferences/Values(1)**:** This program recognizes that market acceptance is determined by the buyers' perspective and needs. Price, reliability, and performance are key consumer values for lighting.

4.2.4 Methodology and Calculations

As advanced appliance, equipment, and envelope technologies emerge, the AET program plays a key role in expanding and accelerating the market acceptance of technologies that are not only on the critical pathway to ZEB in the future but also relevant to the broader new and retrofit residential and commercial building sectors in the near term.(1)

Market Introduction: It is projected that this program will accelerate the market penetration of the technology by 2 years.

Expected Market Uptake: Figure G-3 (with largely hypothetical numbers) illustrates the market uptake concept. In the graph it is assumed that the Emerging Technologies R&D Program accelerates the penetration of SSL technologies by 2 years. Hence the benefit of the emerging technology program is captured by the yellow line (the difference between the purple line and the blue line).

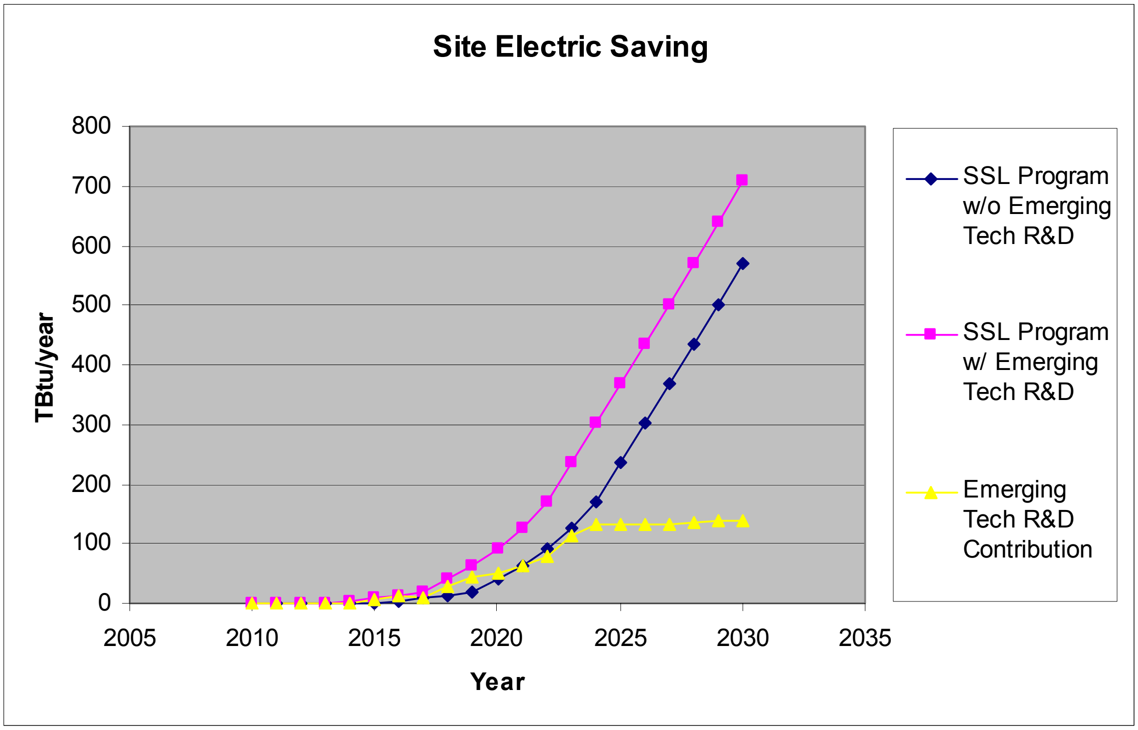

Figure G-3. Solid State Lighting Market Uptake Concept

4.2.5 Sources

1) "Building Technologies Program: 2006 Multi-Year Program Plan." Draft. U.S. DOE, March 29, 2005.

4.3 Envelope Research and Development: Windows

Project Description(1)**.** Windows typically contribute about 30 percent of overall building heating and cooling loads with an annual impact of about 3.7 quads, with an additional potential savings of 1 quad from daylight use. The BT approach is to first convert windows from their current role as significant thermal losses to the point where they are energy neutral, and then move to a higher level of performance, where they contribute to a net energy surplus in a ZEB, thus offsetting other energy costs.

About 60 percent of window sales are to the residential sector and 40 percent to commercial, so that this program targets both sectors. Sales are evenly distributed between new construction and existing buildings, so both markets are included in the R&D program. Because the energy needs of residential users differ from commercial, and new construction and renovation/retrofit are different, and because all performance is strongly influenced by climate and orientation, the development of a single "silver bullet R&D solution" that solves all problems is not possible. Furthermore, window impacts on building energy use are linked to other building systems. Therefore the technical approach of the Windows activity is built around three themes:

1. The need for a broad portfolio of cost-effective advanced technologies to address the disparate heating, cooling and daylighting needs of these different conditions;
2. Recognition that these advanced glazing and façade technologies will perform best when they are optimized as part of fully integrated building systems to address competing performance needs as a function of time, climate, building type and orientation; and
3. The need for decision-support infrastructure to rate and label products, and tools to select and optimize window selection and design solutions. For existing energy efficient products, rating and labeling an entire suite of products with a strong focus on commercial building applications will remove barriers for product specification and promotion by industry and non-profit organizations.

4.3.1 Significant Changes from FY06

No significant changes were made to this program for the FY07 effort.

4.3.2 General Target Market

Market Description: The market includes new and existing commercial and residential buildings in all climate zones.

Size of Market: 500 million square feet of windows for commercial buildings and approximately 55 million manufactured units sold each year for residential and light commercial.

Baseline Technology Improvements. There are no technology improvements assumed apart from what appears in the Energy Information Administration (EIA) baseline.

4.3.3 Key Factors in Shaping Market Adoption of EERE Technologies

Key Consumer Preferences/Values. The following nonenergy characteristics were not considered in developing energy output estimates:

- Reduced utility and building peak loads
- Reduced HVAC Requirements and first costs
- Improved indoor comfort and aesthetics.

4.3.4 Electrochromic Windows

Project Description.(1) Windows are capable of providing solar heat when it is needed, rejecting solar gain to reduce cooling loads, and offsetting most of a building's lighting needs during daylight hours. To fully accomplish these functions, windows and skylights must continuously and dynamically control their transmittance of sunlight and daylight. In commercial buildings the dynamic tradeoffs between cooling load reductions and daylight utilization are particularly complex. Glazings whose solar optical properties can be varied rapidly over a wide dynamic range are needed to address these performance needs. Research activities include development of durable chromogenic coatings, emphasizing electrochromic technology for the first generation of products and the exploration of other switchable coating mechanisms with lower cost, faster switching and wider dynamic range over time. Work includes fundamental coating technology, characterization, durability testing, prototype testing, and controls integration and optimization including field-testing.

4.3.4.1 Target Market

Market Introduction: 2010; This project was assumed to accelerate the introduction of this technology into the marketplace by 10 years.

4.3.4.2 Key Factors in Shaping Market Adoption of EERE Technologies

Price. Incremental Installed Cost over competing technology (Low-e Double-Pane Windows)

- 2010: \$54.42/ ft^2
- 2011: \$44.42/ ft^2
- 2012: \$34.42/ ft^2
- 2013: \$24.42/ ft^2
- 2014: \$19.42/ ft^2
- 2015: \$14.42/ ft^2
- 2016: \$9.42/ ft^2
- 2017: \$7.42/ ft^2
- 2018: \$5.42/ ft^2
- 2019: \$3.42/ ft^2
- 2020: \$1.42/ ft^2

4.3.4.3 Methodology and Calculations

Inputs to Base Case. BT did not provide inputs to change the base case assumptions for the program markets. BT's calculations were based on a baseline that was developed from the Energy Information Administration's (EIA's) Commercial Buildings Energy Consumption Survey (CBECS), Residential Energy Consumption Survey (RECS), and the Annual Energy Outlook (AEO). Note that the base technology to which this technology is being compared is that of low-e double pane windows.

Technology Characteristics

Performance Parameters: Performance parameters for Electrochromic Windows are presented in **Table G-10**.

Table G-10. Performance Parameters for Electrochromic Windows

End Use	Shading Coefficient	U-Value
Heating	0.6	0.25 Btu/ft2·°F
Cooling	0.1	0.25 Btu/ft2·°F

Performance Target: Performance characteristics vary by building type and climate zone. The estimated savings per building were determined by simulating residential and commercial buildings in all climate zones (see **Table G-11**). Commercial lighting savings are estimated to be 5% in all regions.

Table G-11. Performance Targets for Electrochromic Windows

Region	Sector	End Use	New Building Savings	Existing Building Savings	Units
Northern	Commercial	Heating	1.83	1.61	MMBtu/ksf
		Cooling	4.62	4.58	MMBtu/ksf
North Central	Commercial	Heating	1.88	1.66	MMBtu/ksf
		Cooling	5.80	5.52	MMBtu/ksf
South Central	Residential	Heating	3.91	4.38	MMBtu/HH
		Cooling	11.16	11.30	MMBtu/HH
	Commercial	Heating	0.94	0.88	MMBtu/ksf
		Cooling	5.75	5.51	MMBtu/ksf
Southern	Residential	Heating	3.00	3.61	MMBtu/HH
		Cooling	7.51	7.76	MMBtu/HH
	Commercial	Heating	0.56	0.53	MMBtu/ksf
		Cooling	3.05	2.92	MMBtu/ksf
Weighted National Average (Southern and South Central for Residential)	Residential	Heating	3.65	4.16	MMBtu/HH
		Cooling	10.13	10.28	MMBtu/HH
	Commercial	Heating	1.43	1.28	MMBtu/ksf
		Cooling	4.96	4.81	MMBtu/ksf

Note: MMBtu is millions of Btus; Ksf is thousand square foot; HH is household

Window Lifetime: 20 years.

Expected Market Uptake. The goal is to obtain 50% of window sales by 2020 in the commercial sector, and 20% of window sales by 2020 in the residential sector. Penetration curves were developed and documented based on market diffusion curves developed by

PNNL(2). The "Accelerated" penetration curve represents the percent of electrochromic window sales with the DOE project; the "Net" penetration curve represents the percent of sales attributable to DOE, as BT assumed that the DOE project would accelerate market acceptance by 10 years. See penetration curves in **Figures G-4 through G-7**.

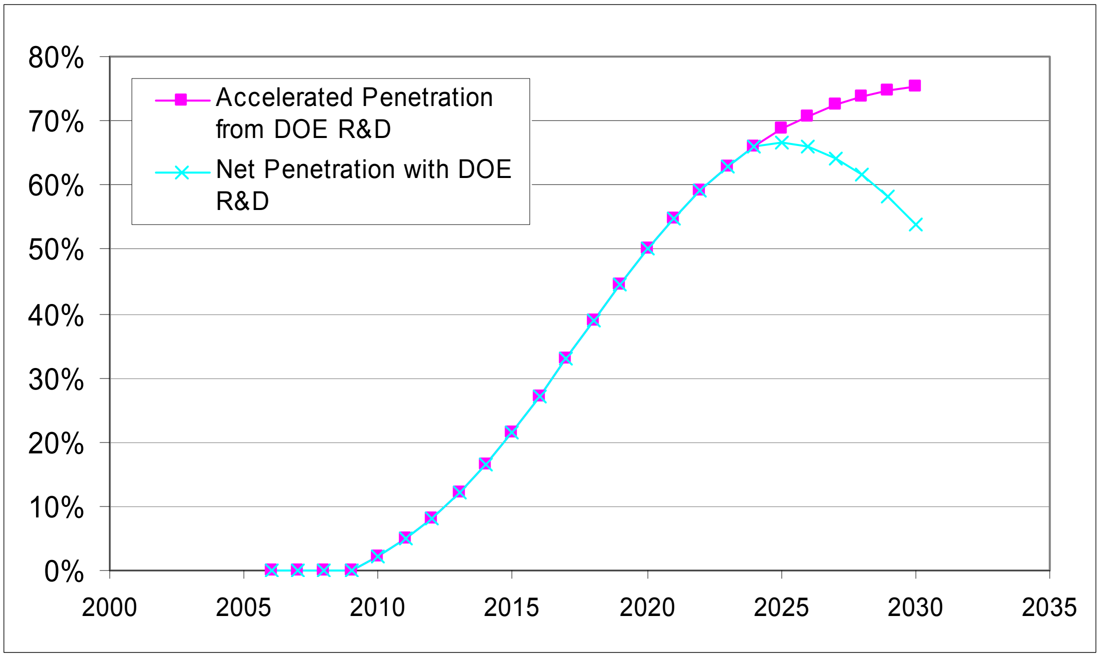

Figure G-4. Electrochromic Windows – New Commercial Buildings Percent of Sales

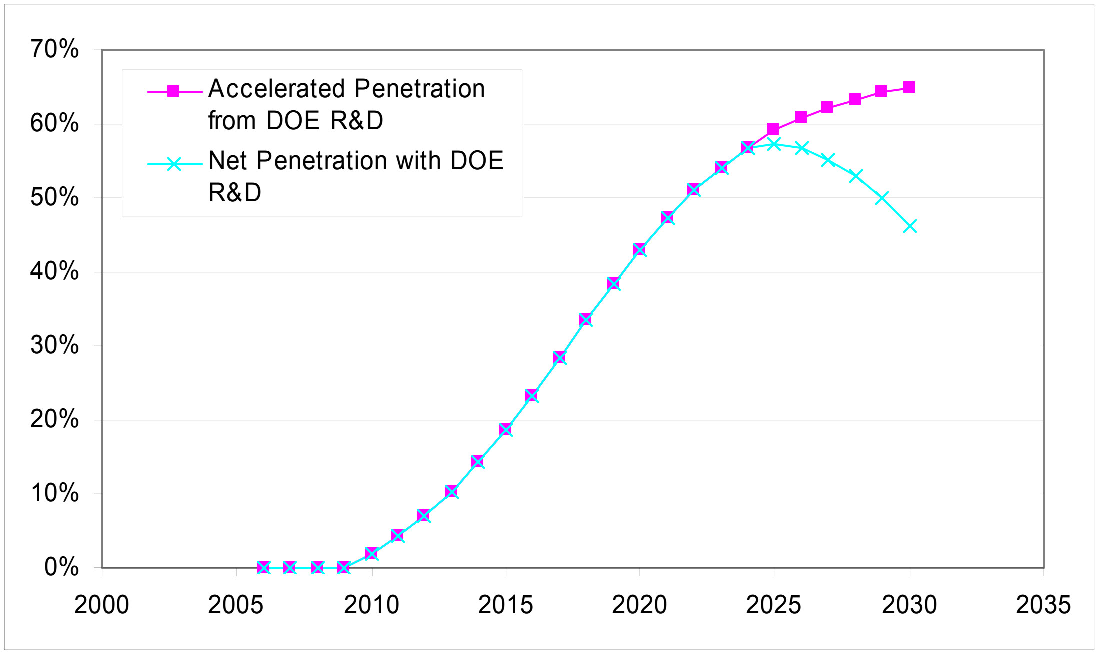

Figure G-5. Electrochromic Windows – Existing Commercial Buildings Percent of Sales

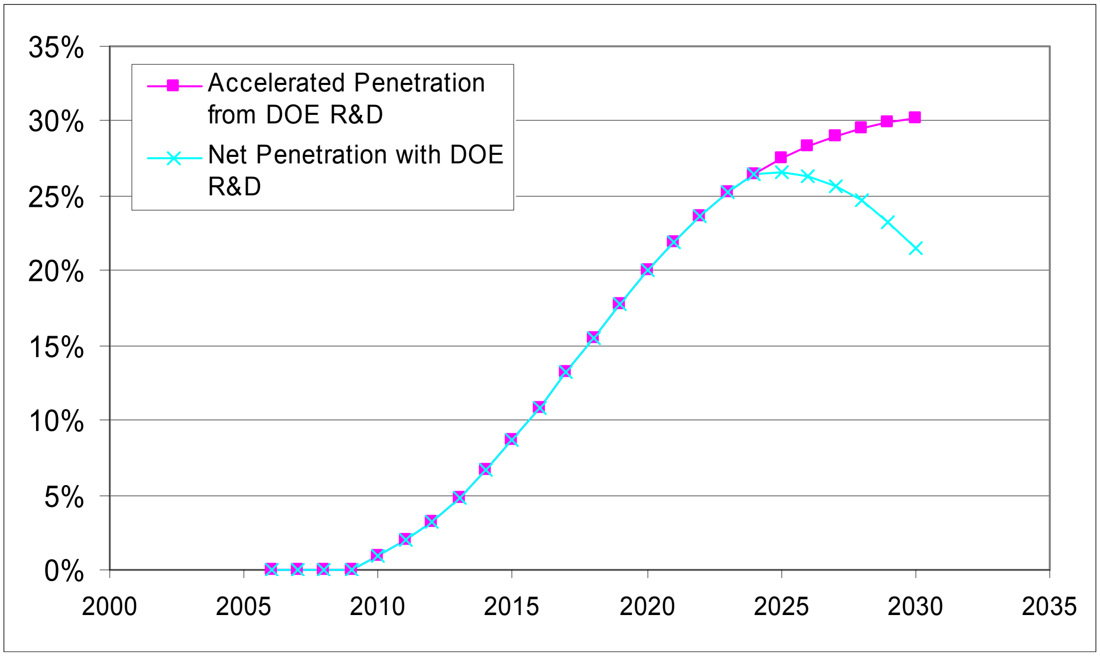

Figure G-6. Electrochromic Windows – New Residential Buildings Percent of Sales

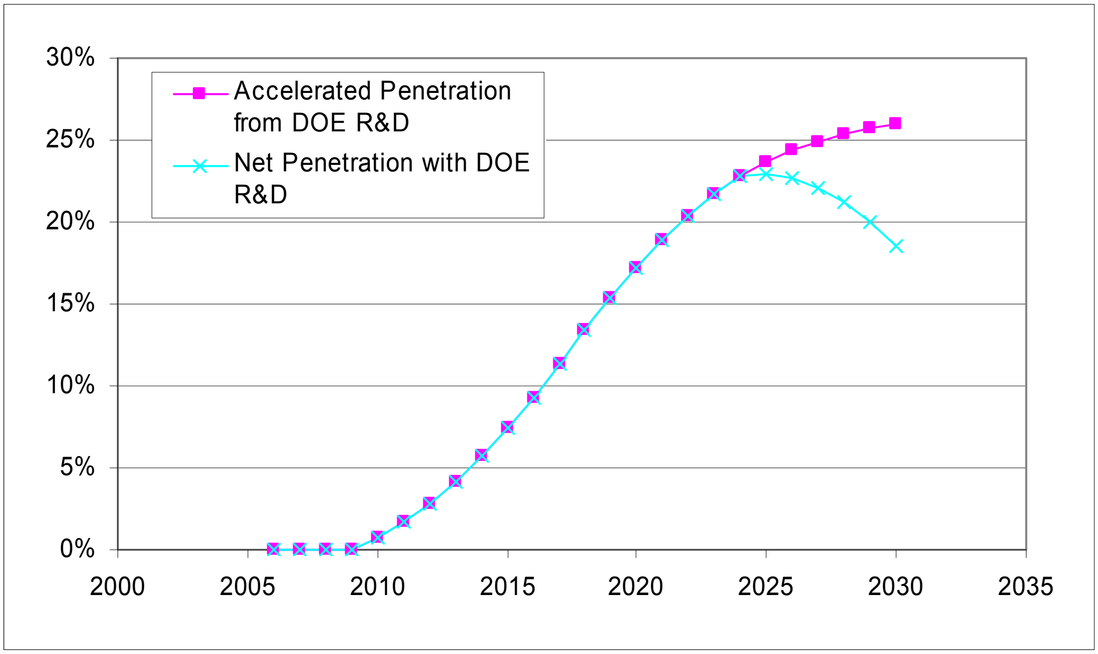

Figure G-7. Electrochromic Windows – Existing Residential Buildings Percent of Sales

4.3.5 Superwindows

Project Description. (1) With heating loads being the largest end-use impact, improving winter performance has the potential for large energy savings. Low-E gas-filled windows introduced in the 1980s have now captured more than 40% of the residential market. But, heat loss rates for whole windows must be reduced by at least a factor of 2 to approach levels needed for zero-energy buildings. Highly leveraged competitive R&D will be conducted towards achieving these impacts. Research activities will include basic and exploratory research on advanced optical coatings, gas filled and evacuated cavities, microporous transparent insulating materials, improved edge and frame materials; and applied research to support rating, design tools, and implementation of efficient window technologies.

4.3.5.1 Target Market

Market Introduction: 2007; BT assumed that this project would accelerate the introduction of this technology into the marketplace by 10 years.

4.3.5.2 Key Factors in Shaping Market Adoption of EERE Technologies

Price. Incremental Installed Cost Over competing technology (Low-e Double-Pane Windows)

- 2007: $6.00/ft^2
- 2020: $4.00/ft^2
- 2030: $3.00/ft^2

4.3.5.3 Methodology and Calculations

Inputs to Base Case. BT did not provide inputs to change the base case assumptions for the program markets. BT's calculations were based on a baseline that was developed from the Energy Information Administration's (EIA's) Commercial Buildings Energy Consumption Survey (CBECS), Residential Energy Consumption Survey (RECS), and the Annual Energy Outlook (AEO). Note that the base technology to which this technology is being compared is that of low-e double pane windows.

Technical Characteristics

Performance Parameters: Superwindows have maximum U-value[l] and solar heat gain coefficient (SHGC)[m] for four climate zones. These climate zones do not directly correspond to the traditional climate zones used in CBECS or RECS; they also do not correspond to the census divisions used in NEMS. These new climate zones are based on the eight climate zones that were developed as part of the IECC 2003 code change cycle or Residential IECC Code Change (RICC). In general, the Superwindow zones map from the RICC zones **(Table G-12)**.

Table G-12. Mapping of RICC Zones to Superwindow Zones

RICC Zone	Superwindow Zone
1	Southern
2	Southern
3	South/Central
4	North/Central
5	Northern
6	Northern
7	Northern
8	Northern

To construct the four Superwindow zones there was a fair amount of smoothing required due to geo-political boundaries, existing codes, and commercial regions. For example, a strict

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[l] U-Value is defined as the rate of heat loss, in Btu per hour, through a square foot of surface.

[m] SHGC is the fraction of solar radiation admitted through a window.

adherence of the eight RICC zones to four Superwindow zones shown above would have portions of California in all four Superwindow zones and would result in discontinuities in the zones across the country. The final result is that California is wholly within the South/Central zone and all four Superwindow zones are continuous across the country. Performance parameters are listed in **Table G-13**.

Table G-13. Performance Parameter Maximums for Superwindows

Region	End Use	Shading Coefficient	U-Value
Northern	Heating	0.6087	0.10 Btu/ft2·°F
	Cooling	0.2609	0.10 Btu/ft2·°F
North Central	Heating	0.6807	0.10 Btu/ft2·°F
	Cooling	0.2609	0.10 Btu/ft2·°F
South Central	Heating	0.1304	0.20 Btu/ft2·°F
	Cooling	0.1304	0.20 Btu/ft2·°F
Southern	Heating	0.1304	0.20 Btu/ft2·°F
	Cooling	0.1304	0.20 Btu/ft2·°F

Performance Target: Performance characteristics vary by climate zone. The estimated savings per building were determined by simulating residential buildings in all climate zones (see **Table G-14**).

Table G-14. Performance Targets for Superwindows

Region	Sector	End Use	New Building Savings	Existing Building Savings	Units
Northern	Residential	Heating	10.80	11.15	MMBtu/HH
		Cooling	4.29	4.31	MMBtu/HH
North Central	Residential	Heating	8.83	9.18	MMBtu/HH
		Cooling	5.05	5.15	MMBtu/HH
South Central	Residential	Heating	-0.08	0.02	MMBtu/HH
		Cooling	10.10	10.32	MMBtu/HH
Southern	Residential	Heating	1.64	1.90	MMBtu/HH
		Cooling	6.32	6.66	MMBtu/HH
Weighted National Average	Residential	Heating	6.24	6.51	MMBtu/HH
		Cooling	6.34	6.44	MMBtu/HH

Lifetime: 30 years

Expected Market Uptake. The goal is to obtain 65% of window sales in new residential buildings and 33% in existing residential buildings by 2020. Penetration curves were developed based on market diffusion curves developed by PNNL and documented in the 2004 PNNL report, *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort* (Elliott, et. al). The "Accelerated" penetration curve represents the percent of superwindow sales with the DOE project; the "Net" penetration curve represents the percent of superwindow sales attributable to DOE, as BT assumed that the DOE project would accelerate market acceptance by 10 years. See penetration curves in **Figures G-8 and G-9**.

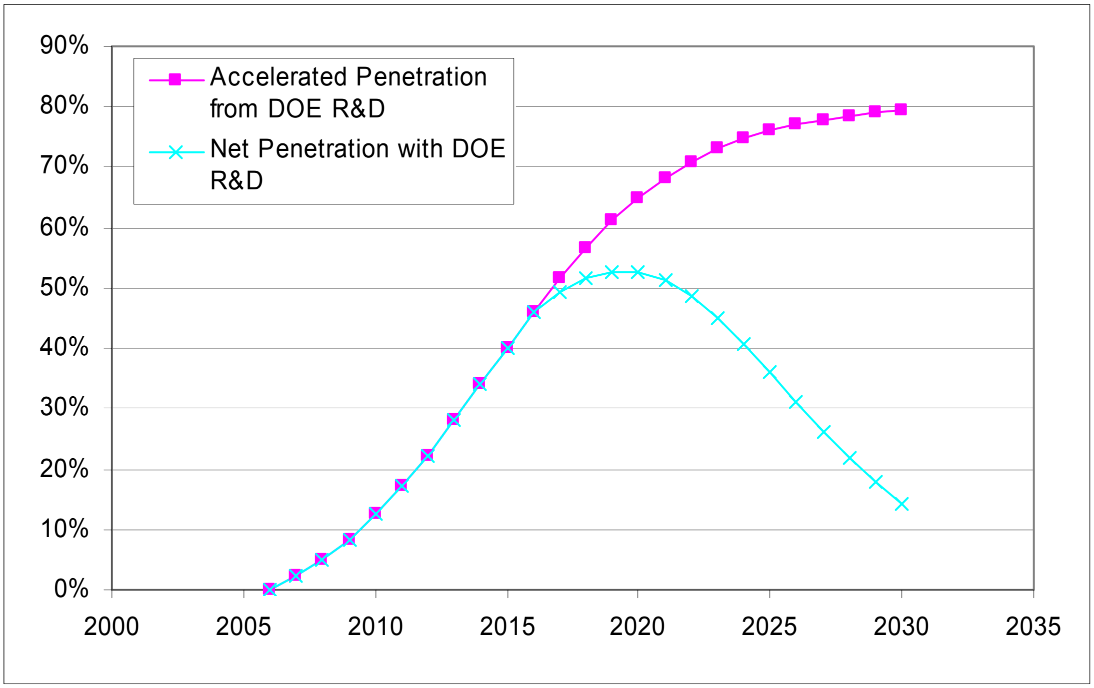

Figure G-8. Superwindows – New Residential Buildings Percent of Sales

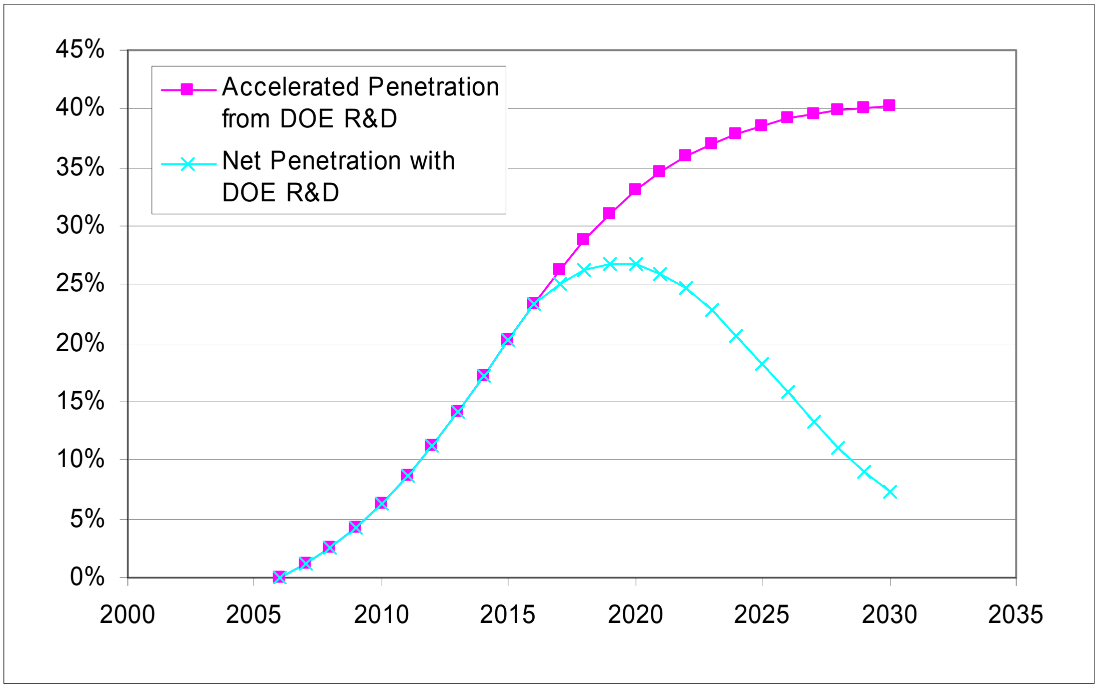

Figure G-9. Superwindows – Existing Residential Buildings Percent of Sales

4.3.6 Low-Emissivity Glass Acceptance

Project Description. (1) Low-e windows have at least one surface coated with a thin, nearly invisible, metal oxide or semiconductor film that reduces the heat transfer through windows. The conventional windows that they replace have no coating. Currently low-e windows represent less than 20% of the commercial market and are not the default product for builders in the residential market, constituting about 40% of that market. Additional research that supports industry and nonprofit energy efficiency programs from FY07 through FY09 can significantly increase the penetration of these energy-efficient products. The purpose of the program is to increase the penetration of low-e glass from 40% in the residential market and 10% in the commercial market to 100% in both markets by 2020. Two programs, Low-e Market Acceptance and Energy Star Windows, form the joint means to achieving the low-e penetration goal; hence, the savings will be split equally. The performance of the low-e glass is as described for the Electrochromic and Super Windows baseline.

4.3.6.1 Target Market

Market Introduction: The technology is commercially available. BT assumed that this project would accelerate the penetration in the marketplace by 10 years.

4.3.6.2 Key Factors in Shaping Market Adoption of EERE Technologies

Price. Incremental Installed Cost over Conventional Double-Pane Windows

- 2005: \$1.00/ft^2
- 2015: \$0.50/ft^2

4.3.6.3 Methodology and Calculations

Inputs to Base Case. BT did not provide inputs to change the base case assumptions for the program markets. BT's calculations were based on a baseline that was developed from the Energy Information Administration's (EIA's) Commercial Buildings Energy Consumption Survey (CBECS), Residential Energy Consumption Survey (RECS), and the Annual Energy Outlook (AEO).

Technical Characteristics

Performance Parameters: Low-e Windows have maximum U-value and SHGC for four different climate zones. These climate zones do not directly correspond to the traditional climate zones used in CBECS or RECS; they also do not correspond to the census divisions used in NEMS. These new climate zones are based on the eight climate zones that were developed as part of the IECC 2003 code change cycle or Residential IECC Code Change (RICC). In general the Low-e zones map from the RICC zones as follows in **Table G-15**.

Table G-15. Mapping of RICC Zones to Low-e Zones

RICC Zone	Low-e Zone
1	Southern
2	Southern
3	South/Central
4	North/Central
5	Northern
6	Northern
7	Northern
8	Northern

To construct the four Low-e zones, there was a fair amount of smoothing required due to geo-political boundaries, existing codes, and commercial regions. For example, a strict adherence of the eight RICC zones to four Low-e zones shown above would have portions of California in all four Low-e zones and would result in discontinuities in the zones across the country. The final result is that California is wholly within the South/Central zone and all four Low-e zones are continuous across the country. Performance parameters are listed in **Table G-16**.

Table G-16. Performance Parameter Maximums for Low-e Windows

Region	Shading Coefficient	U-Value
Northern	0.60	0.35 Btu/ft2·°F
North Central	0.55	0.40 Btu/ft2·°F
South Central	0.40	0.40 Btu/ft2·°F
Southern	0.40	0.65 Btu/ft2·°F

Performance Target: Performance characteristics vary by building type and climate zone. The estimated savings per building were determined by simulating residential and commercial buildings in all climate zones (see **Table G-17**).

Table G-17. Performance Targets for Low-e Windows

Region	Sector	End Use	New Building Savings	Existing Building Savings	Units
Northern	Residential	Heating	8.17	8.30	MMBtu/HH
		Cooling	0.06	0.19	MMBtu/HH
	Commercial	Heating	6.24	5.73	MMBtu/ksf
		Cooling	-0.45	-0.58	MMBtu/ksf
North Central	Residential	Heating	2.88	2.94	MMBtu/HH
		Cooling	1.72	1.79	MMBtu/HH
	Commercial	Heating	2.98	2.77	MMBtu/ksf
		Cooling	0.74	0.68	MMBtu/ksf
South Central	Residential	Heating	0.09	0.00	MMBtu/HH
		Cooling	10.50	10.39	MMBtu/HH
	Commercial	Heating	0.75	0.66	MMBtu/ksf
		Cooling	5.91	5.62	MMBtu/ksf
Southern	Residential	Heating	-1.48	-1.77	MMBtu/HH
		Cooling	9.18	8.77	MMBtu/HH
	Commercial	Heating	-0.14	-0.14	MMBtu/ksf
		Cooling	5.21	4.98	MMBtu/ksf
Weighted National Average	Residential	Heating	3.82	3.82	MMBtu/HH
		Cooling	4.43	4.42	MMBtu/HH
	Commercial	Heating	3.36	3.08	MMBtu/ksf
		Cooling	2.25	2.07	MMBtu/ksf

Expected Market Uptake. The purpose of the program is to increase the penetration of low-e glass from 40% in the residential market and 10% in the commercial market to 100% in the residential market by 2020 and in the commercial market by 2025. Both programs, Low-e Market Acceptance and Energy Star Windows, form the joint means to achieving the low-e penetration goal – the savings are to be split equally. Penetration curves were developed based on market diffusion curves developed and documented by PNNL(2). The "Accelerated" penetration curve represents the percent of superwindow sales with the DOE project; the "Net" penetration curve represents the percent of sales attributable to DOE, as BT assumed that the DOE project would accelerate market acceptance by 10 years. The penetration rates are shown in **Figures G-10 and G-11**. For Low-e Market Acceptance/ Energy Star Windows, BT assumed that these projects would accelerate the acceptance of this technology in the marketplace by 10 years.

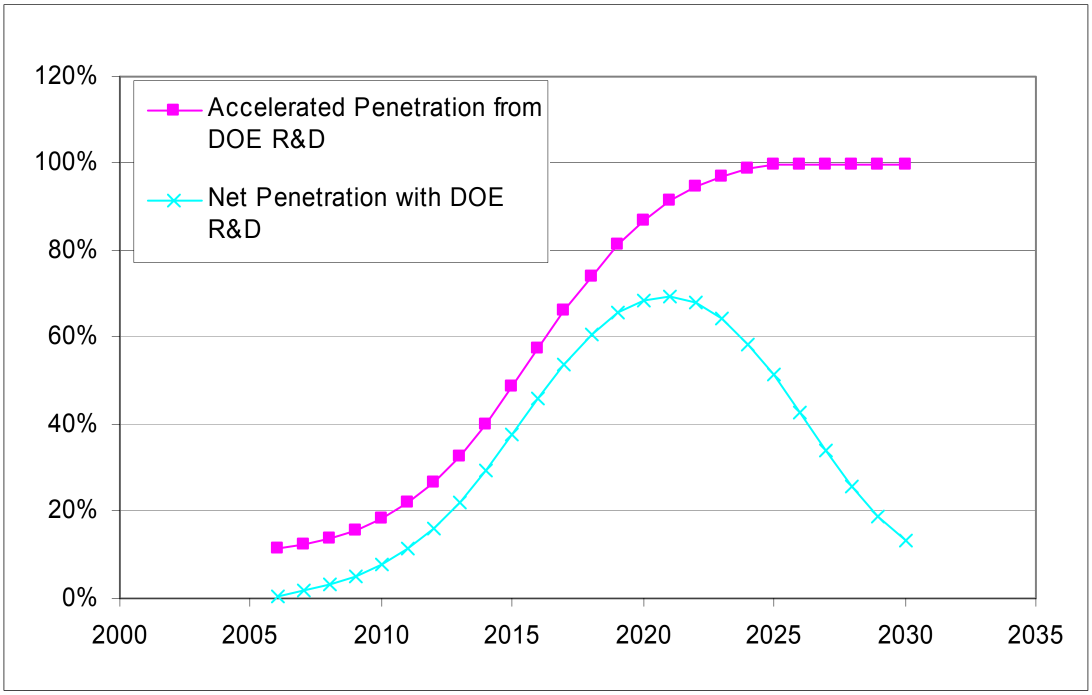

Figure G-10. FY07 Low-e Windows – Commercial Buildings Percent of Sales

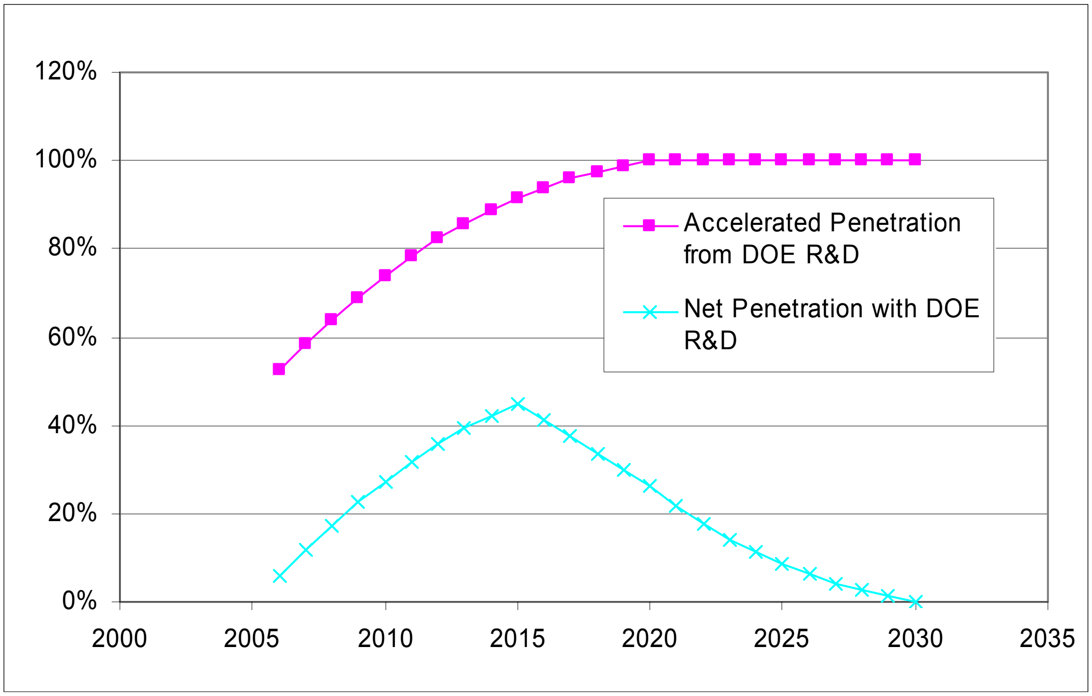

Figure G-11. FY07 Low-e Windows – Residential Buildings Percent of Sales

4.3.7 Sources

(1) "Building Technology Program: Research, Development and Demonstration Plan, Planned Program Activities for 2004-2010." Final Draft. U.S. DOE, January 9, 2004.

(2) Elliott, D.B., D.M. Anderson, D.B. Belzer, K.A. Cort, J.A. Dirks, D.J. Hostick. 2004. *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort*. PNNL-14697. Pacific Northwest National Laboratory, Richland, Washington.

4.4 Envelope Research and Development: Thermal

The Building Technology Program's long range goal of developing Zero Energy Buildings (ZEB) by 2025 will require more cost effective, durable and efficient building envelopes. Reducing envelope heat transfer will significantly facilitate attainment of a practical ZEB since a significant amount of space heating and cooling energy is lost through inefficient envelopes.(1)

To make ZEB affordable, efforts to reduce the energy required for the building are a necessary complement to efforts to reduce the cost of renewable, on-site power. Forty-three percent of the primary energy used in a residence is spent on space heating and cooling. (2)

4.4.1 Significant Changes from FY06

The thermal activities are new for FY07.

4.4.2 Advanced Wall Systems

Project Description(1)**:** Develop new types of regionally optimized wall systems that are inexpensive and are insensitive to moisture ingress. Additionally, invent and evaluate new techniques for window/wall interface. The goal for the advanced wall systems project is to make these systems constructed by 2010 twice as efficient as Building America's regional benchmarks with no additional envelope failure risk.

4.4.2.1 Target Market

Market Description: The market is new single family residential home.

Size of Market: In 2003, 1,386,300 new single-family homes were built.

4.4.2.2 Key Factors in Shaping Market Adoption of EERE Technologies

Price. At market introduction: 30% above conventional insulation and window material costs or about \$1980/single family house[n]. At maturity (10 years): equal to conventional.

Key Consumer Preferences/Values(1)**:** A market resistance to increased wall thickness has jeopardized opportunities to improve the energy efficiency of this envelope component in many regions. Therefore, advanced materials and systems are needed that deliver significant improvements in energy performance without increasing wall thickness.

4.4.2.3 Methodology and Calculations

Technology Characteristics
Market Introduction: 2010

Performance Parameters: Performance and design parameters for baseline and Advanced Wall Systems are presented below.
Baseline: Wall has R-value of 10 Btu/hr·ft^2·F° (U-value = 0.1 hr·ft^2·F°/Btu) and includes fenestration.

- Windows
    - 15% of wall area
    - Double pane wood or vinyl
    - U-value = 0.36 Btu/hr·ft^2·F°
    - Shading coefficient = 0.48
- Opaque Wall
    - 85% of wall area
    - Wood siding on wood frame
    - U-value = 0.054118 Btu/hr·ft^2·F°

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[n] Based on a new 2,349 ft^2 house (NAHB—2004 single family home) with roughly 470 ft^2 of window area (20% of floor area and 15% of wall area) and 1,666 ft^2 of insulated ceiling area (RECSS 2001—average number of stories is 1.41)

Advanced: Wall has R-value of 20 Btu/hr·ft^2·F° (U-value = 0.05 hr·ft^2·F°/Btu) and includes fenestration.

- Windows
  - 15% of wall area
  - Advance window
  - U-value = 0.18 Btu/hr·ft2·F°
  - Shading coefficient = 0.48
- Opaque Wall
  - 85% of wall area
  - Wood siding on wood frame
  - U-value = 0.027059 Btu/hr·ft^2·F°

Performance Target: Tables G-18 and G-19 present the changes in heating and cooling loads by regions for Advanced Wall Systems. These data are presented in both absolute and percentage terms.

Table G-18. Heating and cooling load decrease per household per year (MMBtu/year)

		New England	*Middle Atlantic*	*East North Central*	*West North Central*	*South Atlantic*	*East South Central*	*West South Central*	*Mountain*	*Pacific*	*National*
MBtu/year	Heat	13.1	13.1	15.0	15.6	5.8	7.5	5.2	9.4	5.2	9.2
MBtu/year	Cool	-1.2	-1.2	-1.1	-1.0	-0.9	-0.7	-0.3	0.8	-2.3	-0.7

Table G-19. Heating and cooling load decrease per household per year (% decrease)

		New England	*Middle Atlantic*	*East North Central*	*West North Central*	*South Atlantic*	*East South Central*	*West South Central*	*Mountain*	*Pacific*	*National*
% Decrease	Heat	30.4%	30.4%	28.2%	27.6%	38.2%	37.1%	43.7%	33.9%	45.8%	32.3%
% Decrease	Cool	-10.5%	-10.5%	-12.0%	-9.8%	-2.9%	-2.5%	-0.7%	2.7%	-14.8%	-2.8%

Lifetime: Same as baseline or longer.

4.4.3 Next Generation Attic Systems

Project Description(1)**:** Develop and regionally optimize the next generation of attic systems (e.g., insulation, ventilation strategy, component location, ducts). Also investigate new attic structural systems that will allow for automated construction and develop reliable consensus-based rating methods to assess energy efficiency options for roofing systems. The goal for the next generation attic systems project is to make these systems constructed by 2013 twice as efficient as Building America's regional benchmarks with no additional envelope failure risk.

4.4.3.1 Target Market

Market Description: The market is new single family residential homes.

Size of Market: In 2003, 1,386,300 new single-family homes were built.

4.4.3.2 Key Factors in Shaping Market Adoption of EERE Technologies

Price. At market introduction: 30% above conventional insulation material costs or about $165/single family house.[o] At maturity (10 years): equal to conventional.

Key Consumer Preferences/Values: Consumers largely ignore attics and are mostly concerned about envelope failure.

4.4.3.3 Methodology and Calculations

Market Introduction: 2013

Performance Parameters: Performance and design parameters for baseline and Next Generation Attic Systems are presented below.

Baseline: Roof has R-value of 30 Btu/hr·ft^2·F° (U-value = 0.0333 hr·ft^2·F°/Btu).

- Shingle or shake roof with attic
- Unconditioned

Next Generation: Roof has R-value of 45 Btu/hr·ft^2·F° (U-value = 0.0222 hr·ft^2·F°/Btu).

- Shingle or shake roof with attic
- Conditioned

Performance Target: Tables G-20 and G-21 present changes in heating and cooling loads by regions for Next Generation Attic Systems. These data are presented in both absolute and percentage terms.

Table G-20. Heating and cooling load decrease per household per year (MMBtu/year)

		New England	*Middle Atlantic*	*East North Central*	*West North Central*	*South Atlantic*	*East South Central*	*West South Central*	*Mountain*	*Pacific*	*National*
MBtu/year	Heat	3.0	3.0	3.5	3.7	1.2	1.5	1.0	2.1	1.1	2.1
MBtu/year	Cool	0.3	0.3	0.2	0.2	0.8	0.8	1.1	1.2	0.6	0.7

Table G-21. Heating and cooling load decrease per household per year (% decrease)

		New England	*Middle Atlantic*	*East North Central*	*West North Central*	*South Atlantic*	*East South Central*	*West South Central*	*Mountain*	*Pacific*	*National*
% Decrease	Heat	7.1%	7.1%	6.7%	6.5%	8.0%	7.6%	8.2%	7.6%	10.0%	7.3%
% Decrease	Cool	2.4%	2.4%	1.7%	2.4%	2.4%	2.7%	2.9%	4.1%	3.6%	2.9%

Lifetime: Same as baseline or longer.

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[o] Based on a new 2,349 ft^2 house (NAHB—2004 single family home) with roughly 1,666 ft^2 of insulated ceiling area (RECSS 2001—average number of stories is 1.41)

4.4.4 Next Generation Envelope Materials

Project Description(1)**:** Develop a portfolio of new insulation and membrane materials, including the exterior finishes, having residential and commercial application. The major components of strategy are:

- Develop next generation of low density thermal insulation materials.
- Develop reflective exterior wall finishes.
- Develop smart membrane materials with climatically tuned properties.
- Develop thermochromic roofing surfaces using microstructures down to the nanoscale.

4.4.4.1 Target Market

Market Description: The market is new single family residential home.

Size of Market: In 2003, 1,386,300 new single-family homes were built.

4.4.4.2 Key Factors in Shaping Market Adoption of EERE Technologies

Price. At market introduction: 30% above conventional insulation material costs or about \$535/single family house.[p] At maturity (10 years): equal to conventional.

Key Consumer Preferences/Values(1)**:** Roofing products and wall finishes for cooling dominated climates need to be aesthetically pleasing to the consumer but reflect large percentages of solar radiation.

4.4.4.3 Methodology and Calculations

Market Introduction: 2015

Performance Parameters: Performance and design parameters for baseline and Next Generation Envelope Materials are presented below.

Baseline: Wall has R-value of 10 Btu/hr·ft^2·F° (U-value = 0.1 hr·ft^2·F°/Btu) and includes fenestration. Roof has R-value of 30 Btu/hr·ft^2·F° (U-value = 0.0333 hr·ft^2·F°/Btu).

- Windows
    - 15% of wall area
    - Double pane wood or vinyl
    - U-value = 0.36 Btu/hr·ft^2·F°
    - Shading coefficient = 0.48
- Opaque Wall
    - 85% of wall area
    - Wood siding on wood frame
    - U-value = 0.055118 Btu/hr·ft^2·F°

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[p] Based on a new 2,349 ft^2 house (NAHB—2004 single family home) with roughly 470 ft^2 of window area (20% of floor area and 15% of wall area), 2,662 ft^2 of opaque wall area, and 1666 ft^2 of insulated ceiling area (RECSS 2001—average number of stories is 1.41)

- Roof
    - Shingle or shake roof with attic
    - Unconditioned
    - Insulation R-value is 29.2

Next Generation: Wall has R-value of 11.1 Btu/hr·ft^2·F° (U-value = 0.090031 hr·ft^2·F°/Btu) and includes fenestration. Roof has R-value of 43.8 Btu/hr·ft^2·F° (U-value = 0.022834 hr·ft^2·F°/Btu).

- Windows (unchanged)
    - 15% o f wall area
    - Double pane wood or vinyl
    - U-value = 0.36 Btu/hr·ft^2·F°
    - Shading coefficient = 0.48
- Opaque Wall
    - 85% of wall area
    - Wood siding on wood frame
    - U-value = 0.042389 Btu/hr·ft^2·F°
- Roof
    - Shingle or shake roof with attic
    - Unconditioned

Performance Target: Tables G-22 and G-23 present changes in heating and cooling loads by regions for Next Generation Envelope Materials. These data are presented in both absolute and percentage terms.

Table G-22. Heating and cooling load decrease per household per year (MMBtu/year)

		New England	*Middle Atlantic*	*East North Central*	*West North Central*	*South Atlantic*	*East South Central*	*West South Central*	*Mountain*	*Pacific*	*National*
MBtu/year	Heat	5.5	5.5	6.4	6.7	2.3	2.9	1.9	3.9	2.2	3.8
MBtu/year	Cool	0.2	0.2	0.1	0.2	0.9	0.9	1.4	1.8	0.5	0.9

Table G-23. Heating and cooling load decrease per household per year (% decrease)

		New England	*Middle Atlantic*	*East North Central*	*West North Central*	*South Atlantic*	*East South Central*	*West South Central*	*Mountain*	*Pacific*	*National*
% Decrease	Heat	12.7%	12.7%	12.0%	11.7%	15.2%	14.5%	16.3%	13.8%	19.0%	13.3%
% Decrease	Cool	2.1%	2.1%	1.0%	2.1%	2.9%	3.2%	3.7%	5.9%	3.4%	3.5%

Lifetime: Same as baseline or longer.

4.4.5 Sources

1) "Building Technology Program: Research, Development and Demonstration Plan, Planned Program Activities for 2004-2010." Final Draft. U.S. DOE, January 9, 2004.
2) D&R International, Ltd., The 2005 Building Energy Databook," Silver Spring MD, August 2005

4.5 Lighting Research and Development

4.5.1 Significant Changes from FY06

No significant changes were made to this program for the FY07 effort.

4.5.2 Solid-State Lighting

Project Description. The Solid-State Lighting activity develops and accelerates the introduction of solid-state lighting and seeks to achieve the following for lighting:

- Significantly greater efficacy than conventional sources, such as T8 fluorescents
- Easy integration into building systems of the future
- Ability to provide the appropriate color and intensity for any application
- Ability to last 20,000 to 100,000 hours
- Ability to readily supplement natural sunlight.

4.5.2.1 Target Market

Market Description: The market includes all commercial buildings, with some technologies being introduced into residential buildings.

Size of Market(1): Lighting consumes 26% (3.9 QBtu) of the primary energy used in commercial buildings, which had building stock of about 69 billion ft^2 in 2000.[q]

Baseline Technology Improvements. There are no technology improvements assumed apart from what appears in the Energy Information Administration (EIA) baseline.

4.5.2.2 Key Factors in Shaping Market Adoption of EERE Technologies

Key Consumer Preferences/Values. The following nonenergy characteristics were not considered in developing energy output estimates:

- Helps maintain U.S. semiconductor leadership
- Develops U.S. leadership in lighting technology
- Reduces pollution and contributes to U.S. climate-change goals
- Improves U.S. productivity from better lighting in work environments
- Coordinates with and receives technical advice from an industry consortium of for-profits companies representing the traditional lighting and semiconductor industries.

4.5.2.3 Methodology and Calculations

Technical Characteristics. Key assumptions concerning the likely dates of introduction and the expected efficacies were influenced by two sources: 1) "The Case for a National Research

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[q] According to a report completed for DOE by Navigant Consulting ("U.S. Lighting Market Characterization, Volume I: National Lighting Inventory and Energy Consumption Estimate," September 2002), the amount of energy used for lighting is greater than EIA has traditionally estimated. The report estimates that commercial lighting requires 4.2 QBtu and residential lighting requires 2.2 QBtu.

Program on Semiconductor Lighting,"(2) a white paper prepared by Hewlett-Packard and Sandia National Laboratories and presented in late 1999 at an industry forum; and 2) a more extended study(3) conducted by Navigant Consulting for BT in late 2003; the study presented price and performance improvement curves for solid-state lighting that were developed in close consultation with industry experts.
NEMS characterizes each lighting technology by source efficacy level (lumens/watt), capital cost ($/1000 lumens or $/kLumen), and annual maintenance cost of lamps. For new technologies, the capital costs can be reduced along a logistic-shaped curve. The NEMS model divides the commercial lighting market into five major groups: 1) incandescent CFL (point source), 2) 4-foot fluorescent, 3) 8-foot fluorescent, 4) high-intensity discharge (HID) low bay and 5) HID high bay. Solid-state lighting was assumed to compete in all market groupings with different color rendition index lamps.

Given the cost and efficacy assumptions, the NEMS model chooses among these technologies for each building type in each census division. For each group, the market is assumed to be further segmented, with each segment characterized by a different discount rate in its decision-making criteria. Within each segment, a lighting technology is selected based on minimum annualized cost.

Solid-state lighting was also assumed to be available in the residential lighting market, where it competes with conventional incandescent and compact fluorescent options.

Table G-24 summarizes the cost and performance inputs for the solid state lighting technologies used in NEMS-GPRA07 for FY 2007.

Table G-24. Solid-State Lighting Cost and Efficiency Assumptions – FY 2007 GPRA

	Efficacy				Price (2004$/klm)			
	Low CRI	Med CRI	High CRI	V.High CRI	Low CRI	Med CRI	High CRI	V.High CRI
2005	55	39	24	8	$ 70.85	$ 132.15	$ 182.88	$ 288.17
2006	60	44	28	11	$ 62.22	$ 123.45	$ 172.51	$ 269.09
2007	65	49	32	14	$ 50.87	$ 110.25	$ 156.40	$ 240.15
2008	70	54	37	17	$ 40.17	$ 95.23	$ 137.43	$ 207.21
2009	75	59	41	20	$ 30.79	$ 79.33	$ 116.59	$ 172.35
2010	79	65	45	23	$ 23.07	$ 63.75	$ 95.37	$ 138.20
2011	85	71	49	25	$ 17.05	$ 49.60	$ 75.37	$ 107.17
2012	90	77	54	28	$ 12.56	$ 37.60	$ 57.82	$ 80.85
2013	96	84	60	31	$ 9.31	$ 28.00	$ 43.39	$ 59.81
2014	102	90	65	37	$ 7.01	$ 20.69	$ 32.15	$ 43.78
2015	107	96	72	42	$ 5.41	$ 15.31	$ 23.74	$ 32.00
2016	113	102	78	47	$ 4.31	$ 11.47	$ 17.66	$ 23.58
2017	118	108	84	53	$ 3.56	$ 8.78	$ 13.36	$ 17.68
2018	123	114	91	58	$ 3.05	$ 6.93	$ 10.37	$ 13.61
2019	129	118	97	65	$ 2.70	$ 5.65	$ 8.31	$ 10.82
2020	133	123	103	72	$ 2.47	$ 4.79	$ 6.91	$ 8.92
2021	137	128	109	80	$ 2.32	$ 4.20	$ 5.96	$ 7.64
2022	141	133	114	87	$ 2.21	$ 3.81	$ 5.32	$ 6.77
2023	144	136	119	94	$ 2.14	$ 3.54	$ 4.89	$ 6.19
2024	147	140	124	101	$ 2.10	$ 3.36	$ 4.59	$ 5.80
2025	150	143	129	107	$ 2.06	$ 3.24	$ 4.40	$ 5.54
2026	152	146	132	113	$ 2.04	$ 3.16	$ 4.27	$ 5.36
2027	155	149	135	120	$ 2.03	$ 3.11	$ 4.18	$ 5.24
2028	158	151	139	123	$ 2.02	$ 3.07	$ 4.12	$ 5.16
2029	159	152	142	127	$ 2.01	$ 3.05	$ 4.08	$ 5.11
2030	160	153	145	131	$ 2.01	$ 3.03	$ 4.05	$ 5.07

4.5.2.4 Sources

(1) *Annual Energy Outlook 2002*. 2002. Energy Information Administration, Washington, D.C..

(2) Haitz, R., and F. Kish (Hewlitt-Packard Co) and J. Tsao and J. Nelson (Sandia National Laboratories). 1997. "Case for a National Research Program on Semiconductor Lighting," White paper presented at the 1999 Optoelectronics Industry Development Association forum in Washington D.C., October 6, 1999.

(3) Navigant Consulting, 2003. *Energy Savings Potential of Solid-State Lighting in General Illumination Applications*. Prepared for DOE's Office of Building Technologies by Navigant Consulting, Washington D.C.

4.5.3 Lighting Controls

4.5.3.1 Target Market

Market Description: The market includes all commercial buildings, with some technologies being introduced into residential buildings.

Size of Market: Lighting consumes 26% (3.9 quadrillion Btu) of the primary energy used in commercial buildings, which had a building stock of about 69 billion ft^2 in 2000$^{(1)}$.

Baseline Technology Improvements. There are no technology improvements assumed apart from what appears in the Energy Information Administration (EIA) baseline.

4.5.3.2 Key Factors in Shaping Market Adoption of EERE Technologies

Price. BT assumed a 4-year payback period on investment to develop incremental investment costs (i.e., an annual energy cost savings of $1 implies an initial investment of $4).

Key Consumer Preferences/Values. The following nonenergy characteristics were not considered in developing energy output estimates:

- Develops U.S. leadership in lighting technology
- Reduces pollution and contributes to U.S. climate-change goals
- Improves U.S. productivity from better lighting in work environments

4.5.3.3 Methodology and Calculations

Inputs to Base Case. BT did not provide inputs to change the base case assumptions for the program markets. BT's calculations were based on a baseline that was developed from the Energy Information Administration's (EIA's) Commercial Buildings Energy Consumption Survey (CBECS), Residential Energy Consumption Survey (RECS), and the Annual Energy Outlook (AEO).

Technical Characteristics. Various field studies$^{(2)}$ have shown a very large energy savings potential for lighting controls, primarily using occupancy and daylighting controls. These studies have shown that aggressively implementing controls can save 20% to 40% of lighting energy use. BT supports the development of more advanced systems—through both research and field testing—that will further reduce energy used for lighting in commercial buildings. BT support of research to evaluate the interrelationship between human vision and efficient light use will also contribute to future energy savings.

For FY 2007, the impact of the BT activities in lighting controls and efficient lighting practices was assumed to yield an incremental 5% reduction in lighting energy use compared with current practice. (By *incremental*, the BT activities are assumed to lead to further savings over and above the control technologies that the private sector offers now and are likely to offer.)

Expected Market Uptake. BT assumed that up to 60% of new commercial buildings could incorporate these technologies and that 20% of the existing stock could be retrofitted with these systems by 2020. A time profile of penetration rates was based on the historical pattern of market penetration observed for electronic ballasts. An S-shaped penetration curve was fit to historical market shares for electronic ballasts and then applied to project future adoption of advanced lighting distribution systems and controls. This curve indicated that nearly 50% of the ultimate market penetration was achieved after nine years.

4.5.3.4 Sources

(1) *Annual Energy Outlook 2002*. 2002. Energy Information Administration, Washington, D.C.

(2) See http://eande.lbl.gov/btp/450gg/publications.html and www.cmpco.com/services/pubs/lightingfacts/controls.html

(3) Elliott, D.B., D.M. Anderson, D.B. Belzer, K.A. Cort, J.A. Dirks, D.J. Hostick. 2004. *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort*. PNNL-14697. Pacific Northwest National Laboratory, Richland, Washington.

4.6 Space Conditioning and Refrigeration R&D

The Building Technology Program's long range goal of developing Zero Energy Buildings (ZEB) by 2025 will require more efficient and less expensive HVAC equipment if ZEBs are going to be widespread and affordable. Equipment integration (waste heat from one appliance is beneficially used by another) and new approaches to providing space conditioning are integral to this goal.

4.6.1 Significant Changes from FY06

For FY07, new activities for Space Conditioning R&D were characterized for the GPRA estimates.

4.6.2 Hy-Pak MA

To make ZEB affordable, efforts to reduce the energy required for the building are a necessary complement to efforts to reduce the cost of renewable, on-site power.(1) Eleven percent of the primary energy used in commercial buildings is spent on space cooling. (2)

Project Description: Develop a cost-effective, hydronic rooftop HVAC unit that reduces energy consumption 50% and delivers 0 to 100% ventilation air

4.6.2.1 Target Market

Market Description: The market is commercial buildings. Because of the evaporative nature of the device the market is limited to dry west coast climates only.

Size of Market: The applicability varies by census region. This technology takes advantage of evaporative cooling and therfore is applicable only in dry and marine climates. **Table G-25** contains the portion of the census region to which this technology could be applied:

Table G-25. Percentage of census region to which Hy-Pak MA technology is applicable

New England	Middle Atlantic	East North Central	West North Central	South Atlantic	East South Central	West South Central	Mountain	Pacific	National
0%	0%	0%	0%	0%	0%	8.87%	100%	97.31%	23.02%

Market Introduction: 2008

4.6.2.2 Key Factors in Shaping Market Adoption of EERE Technologies

Price.

- Cost at market introduction: 2 times cost of conventional technology (Simple payback: 2-3 years).
- Cost at maturity (10 years): 1.5 times cost of conventional technology (Simple payback: 1-1.5 years)

Key Consumer Preferences/Values: Because this technology uses evaporative cooling in the condenser and indirect evaporative cooling of the ventilation air it is not likely to be accepted by consumers in areas of high relative humidity.

4.6.2.3 Methodology and Calculations

Performance Parameters: Performance parameters for baseline and rooftop AC and HyPak-MA are presented below.

- Baseline: Conventional rooftop air conditioning—11.2 EER
- HyPak-MA: 16.8 EER

Lifetime: Same as baseline.

Expected Market Uptake: Anticipated market share in 2018 is 20% of rooftop AC market in applicable regions.

4.6.3 Thermotunneling Based Cooling

To make ZEB affordable, efforts to reduce the energy required for the building are a necessary complement to efforts to reduce the cost of renewable, on-site power.(1) Eleven percent of the primary energy used in buildings is spent on space cooling.(2) In addition, refrigeration uses seven percent of the primary energy used in buildings.(2) Savings associated with refrigeration are not considered here.

Project Description: Develop high efficiency, compact, quiet, environmentally friendly, reliable cooling without the use of moving parts or refrigerants. Cooling using themortunneling technology involves the transport of hot electrons across a gap between two low work function electrodes[r], from the object to be cooled (the cathode) to the heat rejection electrode (the anode).

4.6.3.1 Target Market

Market Description: The market is all residential and commercial cooling.

Size of Market: All commercial and residential air conditioning equipment in new and existing residential and commercial buildings.

Market Introduction: 2010

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[r] A work function is the energy needed to extract an electron from a material; a low work function ≡ <1.0eV (where eV is electron-volt).

4.6.3.2 Key Factors in Shaping Market Adoption of EERE Technologies

Price.

- Cost at market introduction: 75% of the cost of conventional technology
- Cost at maturity (10 years): 25% of the cost of conventional technology

Key Consumer Preferences/Values: Quieter, more reliable air conditioning equipment should have a market advantage.

4.6.3.3 Methodology and Calculations

Performance Parameters: Performance and design parameters for baseline and Thermotunneling Based Cooling are presented below.

- Baseline: COP ~ 40-45% of Carnot efficiency
- Thermotunneling Based Cooling: 65% of Carnot efficiency; including ancillary equipment the net results is a 35% increase in cooling efficiency.

Lifetime: Same as baseline or longer.
Expected Market Uptake: Anticipate market share of 70% at maturity

4.6.4 Integrated Heat Pump

To make ZEB affordable, efforts to reduce the energy required for the building are a necessary complement to efforts to reduce the cost of renewable, on-site power. Thirty-one percent of the primary energy used in a residence is spent on space heating, cooling, and water heating.(2)

Project Description: Develop an integrated, multifunction heat pump that provides space heating, cooling, water heating and dedicated dehumidification.(3)

4.6.4.1 Target Market

Market Description: The market is new single family residential homes.

Size of Market: In 2003, 1,386,300 new single-family homes were built.

Market Introduction: 2010

4.6.4.2 Key Factors in Shaping Market Adoption of EERE Technologies

Price.

- Cost at market introduction: 2.5 times cost of conventional heat pump without water heating capability ($2700 versus $1100 for a 1.5 ton unit)
- Cost in 5 years: 1.7 times cost of conventional heat pump without water heating capability ($1900 versus $1100 for a 1.5 ton unit)

Key Consumer Preferences/Values: Dedicated dehumidification should enhance sales in high humidity markets.

4.6.4.3 Methodology and Calculations

Performance Parameters: Annual operating cost savings of $400/year over conventional unit due to higher efficiency and dual production (simultaneous cooling and hot water production)

Lifetime: Same as baseline.

Expected Market Uptake: Anticipate market share is 8% in 5 years and 30% ultimately.

4.6.5 Sources

1) "Building Technology Program: Research, Development and Demonstration Plan, Planned Program Activities for 2004-2010." Final Draft. U.S. DOE, January 9, 2004.
2) D&R International, Ltd., The 2005 Building Energy Databook," Silver Spring MD, August 2005
3) Building Technologies Program Fiscal Year 2006 Annual Operating Plan: Project Proposal for Residential ZEB-Enabling Equipment. CEBT002

5.0 Technology Validation and Market Introduction

This effort seeks to accomplish effective delivery of the full menu of efficiency and renewable resources aligned with community and customer focus. The activities focus on the end-user needs, rather than individual EERE programs, and provide easier access to EERE's array of technologies and resources to ensure they are part of the economic solutions for communities across the country.

5.1 Rebuild America

Project Description. Rebuild America accelerates energy-efficient improvements in existing buildings through community-level partnerships and focuses on K-12 schools, colleges, and universities, State and local governments, public and multi-family housing, and commercial buildings. Rebuild America connects people, resources, proven ideas, and innovative practices to solve problems. The project provides one-stop shopping for information and assistance on how to plan, finance, implement, and manage retrofit projects to improve buildings energy efficiency and helps communities find other resources on renewable energy applications, efficient new building designs, energy education, and other innovative energy conservation measures.

5.1.1 Significant Changes from FY06

This project was previously included in the program structure under Weatherization and Intergovernmental Programs. For FY07, the project was moved under BT. For modeling purposes, the characterization of the project did not change.

5.1.2 Target Market

Market Description. The general target market includes new and existing multifamily housing; public/assisted single-family residential units; and commercial buildings, particularly new and existing assembly, health-care, lodging, office, and education buildings.

Size of Market.(4) The primary market is the commercial-building sector, which includes nearly 68 billion square feet of building space; however, the five commercial building types that this project targets make up a total of nearly 32 billion square feet. The public assistance(5) and multifamily housing that this project also targets make up an additional 27 billion square feet.

Baseline Technology Improvements. For this analysis, BT did not suggest any changes in technology improvements apart from the EIA baseline.

5.1.3 Key Factors in Shaping Market Adoption of EERE Technologies

Price.
Cost of Conventional Technology:(4) Average of \$101/ ft^2 for new commercial and multifamily; \$0 for existing buildings.

Cost of BT Technology:(7) \$103.00/ ft^2 for new commercial and multifamily; \$3/ ft^2 (2007 to 2009), increasing to \$4/ ft^2 (2010 to 2030) for existing buildings.
Incremental Cost: 2% above base for new buildings; \$3/ft^2 (2007 to 2009), \$4/ ft^2 (2010 to 2030) for existing buildings.

Key Consumer Preference/Values -- Nonenergy Benefits.(5) The following nonenergy characteristics were not considered.

- Revitalized neighborhoods and business districts
- Improving school facilities
- Better low-income housing
- Positive economic impact from keeping dollars locally and increasing property values.

5.1.4 Methodology and Calculations

Inputs to Base Case. BT did not provide inputs to change the base case assumptions for the program markets.

Technical Characteristics. The project displaces current design/building practices with the target of reducing heating, cooling, water heating, and lighting energy use in retrofitted and new buildings by 18%/ft^2 in 2007 (1) and 25%/ft^2 by 2010 (3).

Expected Market Uptake. BT assumed that this activity would not occur in the absence of DOE funding, therefore, no acceleration of market acceptance was modeled. The penetration rates shown in **Table G-26** are based on project goals of committing 2.24 billion square feet by 2010.

Table G-26. Penetration Goals for Rebuild America (2,6)

	Penetration Rate %			
Building Type*	**2007**	**2010**	**2020**	**2030**
Targeted Commercial Buildings & Multi-Family Existing	0.7	1.9	2.3	2.3
Targeted Commercial Buildings & Multi-Family New	0.7	1.9	0.0	0.0
Single-Family Existing	0.0	0.02	0.04	0.04
Single-Family New	0.2	0.24	0.0	0.0

* Unless otherwise specified, the building vintage is both new (Post 2007) and existing (2007 and prior construction).

5.1.5 Sources

(1) *Weatherization and Intergovernmental Activities Funding Profile by Subprogram.* FY 2006 Corporate Review Budget, U.S.DOE, May 2004.
(2) *DRAFT Weatherization and Intergovernmental Program Multi*-Year Program Plan, U.S.DOE, September 30, 2003.
(3) *Rebuild America 2002,* Rebuild Annual Report, 2002, U.S.DOE, Washington D.C.
(4) Commercial building and multifamily square footage numbers come from Energy Information Administration. 2001. Annual Energy Outlook 2002. DOE/EIA-0383 (2002). U.S. Department of Energy, Washington, D.C.
(5) *FY 2002 Budget Request – Data Bucket Report for Rebuild America Program* (includes Energy Smart Schools and Competitively Selected Community Program) (internal WIP document).
(6) Rebuild America Key Metric Totals from Oct 2003; Dec 2003; Mar 2004; April 2004; May 2004, Spreadsheet used to document key metrics. (internal WIP document).
(7) RS Means Company, Inc. 2002. *"RS MEANS Square Foot Costs,"* 23rd Edition. Kingston, MA.

5.2 Energy Star Program

Project Description. Energy Star was introduced by the Environmental Protection Agency in 1992 as a voluntary labeling program designed to identify and promote energy efficient products, with the goal of reducing carbon dioxide emissions. Through its partnership with more than 7,000 private and public sector organizations, Energy Star delivers the technical information and tools that organizations and consumers need to choose energy-efficient solutions and best management practices.

5.2.1 Significant Changes from FY06

This project was previously included in the program structure under Weatherization and Intergovernmental Programs. For FY07, the project was moved under BT. The characterization of the project did not change.

5.2.2 General Target Market

Market Description. The market is determined by the project equipment. For FY 2007, the following residential equipment is characterized:

- Clothes washers
- Refrigerators
- Room air conditioners
- Dishwashers
- Compact Fluorescent Lamps (CFLs)
- Windows
- Home Performance

Baseline Technology Improvements. There are no technology improvements assumed apart from what appears in the Energy Information Administration (EIA) baseline.

5.2.3 Key Factors in Shaping Market Adoption of EERE Technologies

Key Consumer Preferences/Values and Manufacturing Factors. The following nonenergy characteristics were not considered.

- Increased comfort for residential homeowners
- Decreased time spent changing incandescent lamps
- Water and water-bill savings from higher efficiency dishwashers and clothes washers
- Increased amenities with clothes washers, also decreased time required for dryer cycle
- Higher profits for manufacturers.

5.2.4 General Methodology

Market transformation projects, such as Energy Star, attempt to accelerate market penetration of existing high-efficiency technologies. The information provided by these programs is designed to influence the consumer's awareness of future energy cost savings as compared to the initial cost of the technology. From a modeling standpoint, these efforts are assumed to be represented by a reduction in the consumer's implicit discount rate or hurdle rate. The implicit discount rate for a technology is assumed to capture the perceived risk in the purchase of new products. For Energy Star technologies, most of the costs are incurred at the time the technology is purchased, while most of the energy-saving benefits occur in the future. If the implicit discount rate for a given technology is particularly high, the value a consumer places on these future energy-saving benefits will be low relative to the weight the consumer places on present costs – reflecting the consumer's uncertainty about future benefits. Therefore, to facilitate project modeling, one goal of the Energy Star project is to reduce implicit discount rates by providing additional information about the potential benefits to the consumer.

Within NEMS-PNNL[s], the two modeling parameters determining the implicit discount rate are labeled Beta1 and Beta2(1). Beta1 is used as multiplicative factor with the initial cost of the appliance, and Beta2 is used to multiply the annual energy cost. The sum of the two products (i.e., Beta1 * initial cost + Beta2 * operating cost) is used in the logit specification to yield market shares for each technology. As a rough approximation, the ratio of Beta1/Beta2 can be interpreted as the consumer discount rate for a specific technology. In the residential NEMS-PNNL module, the Beta1 and Beta2 coefficients vary among technologies, as do the resulting discount rates. For example, the implied discount rate for refrigerators is 16%, while the discount rate is estimated to be more than 80% for electric water heaters. Because the Beta parameters must be modified through an iterative process to achieve the discount rate goal for each technology, and because the Energy Star program goals have not changed significantly since the FY 2004 effort when the original NEMS-PNNL modifications were made, BT has not repeated this iterative process using the latest version of NEMS. References to AEO 2001 reflect the original NEMS model inputs on which the Energy Star program inputs are based.

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[s] Any modification or alteration to the official NEMS model must be called out as such; for PNNL's effort, the modified version used is referred to as NEMS-PNNL

The modifications to the NEMS input file (RTEKTY)—required to estimate energy savings in NEMS-PNNL for each technology in an Energy Star project—are described in the following sections. The assumed reduction in the discount rate (from Energy Star support) is modeled by reducing the Beta1 parameter. The baseline assumptions made by the EIA, the changes in the Beta1 coefficients, and the resulting changes in the market shares for the most energy-efficient products are documented by technology.

General Expected Market Uptake. BT modeled clothes washers, refrigerators, electric water heaters, gas water heaters, room air conditioners, and dishwashers using input from EIA's *Annual Energy Outlook 2001,*(2) based on a project goal of Energy Star appliances achieving 20% of the market share by 2010.

5.2.5 Clothes Washers

5.2.5.1 Target Market

Market Description. This project targets new clothes-washer sales.

5.2.5.2 Methodology and Calculations

Inputs to Base Case and Technical Characteristics. Modeling the energy savings of clothes washers is complex, because energy can be saved by reducing the consumption of the motor, hot water use, or dryer energy use. The most efficient new technology is the horizontal-axis design, which achieves the bulk of its energy savings by reducing hot water use.

The residential NEMS input file (RTEKTY) includes a column of factors that relate to hot water. The (unitless) factors can be used to adjust the hot water load associated with clothes washers and dishwashers. .

Expected Market Uptake. With the support of the Energy Star project, the Beta1 parameter, which impacts the resulting market share of each clothes-washer technology, was modified from -0.03811 to -0.0101, based on this product's project goals.

5.2.6 Refrigerators

5.2.6.1 Target Market

Market Description. This project targets new refrigerator sales.

5.2.6.2 Methodology and Calculations

Inputs to Base Case and Technical Characteristics. EIA uses four separate models to represent the range of energy efficiencies in the refrigerator market. The first three models are conventional top-mount freezer models with a total capacity of 18 cubic feet. The fourth is a through-the-door model (for water and ice) and does not compete with the first three models. .

Expected Market Uptake. The *Annual Energy Outlook 2001*(2) baseline parameters that determined the market share for high-efficiency refrigerators are described as follows:

$$\frac{Beta_1}{Beta_2} = \frac{-0.0229}{-0.1207} \approx implicit\ discount\ rate = 19\%$$

With the support of the Energy Star project, the parameters impacting market share were assumed by BT to change in the following manner, based on project goals:

$$\frac{Beta_1^{E-Star}}{Beta_2^{E-Star}} = \frac{-0.0040}{-0.1207} \approx implicit\ discount\ rate^{E-Star} = 3\%$$

This was modified so that the implied discount rate was 6%. The resulting market share for the most efficient unit (400 kWh per year for the AEO2005) was roughly 17% greater than in the Baseline.

5.2.7 Room Air Conditioners

5.2.7.1 Target Market

Market Description. This project targets sales of new room air conditioners.

5.2.7.2 Methodology and Calculations

Inputs to Base Case and Technical Characteristics. For 2005, EIA assumed that efficiencies of room air conditioners will range from a low of 2.83 COP (seasonal energy efficiency ratio) to a high of 3.52 COP.

Expected Market Uptake. The baseline parameters that determined the market share for high-efficiency room air conditioners are described as follows:

$$\frac{Beta_1}{Beta_2} = \frac{-0.0170}{-0.0120} \approx implicit\ discount\ rate > 100\%$$

With the support of the Energy Star project, the parameters impacting market share were assumed to change in the following manner, based on project goals:

$$\frac{Beta_1^{E-Star}}{Beta_2^{E-Star}} = \frac{-0.0070}{-0.0120} \approx implicit\ discount\ rate^{E-Star} = 58\%$$

The lower hurdle rate was phased in over a 5 year period.

5.2.8 Dishwashers

5.2.8.1 Target Market

Market Description. This project targets sales of new dishwashers.

5.2.8.2 Methodology and Calculations

Inputs to Base Case and Technical Characteristics. The NEMS baseline includes three levels of efficiency for dishwashers

Expected Market Uptake. The *Annual Energy Outlook 2001*(2) baseline parameters that determined the market share for high-efficiency dishwashers are described as follows:

$$\frac{Beta_1}{Beta_2} = \frac{-0.02738}{-0.02413} \approx implicit\ discount\ rate > 100\%$$

With the support of the Energy Star project, the parameters impacting market share were assumed to change in the following manner, based on project goals:

$$\frac{Beta_1^{E-Star}}{Beta_2^{E-Star}} = \frac{-0.01338}{-0.02413} \approx implicit\ discount\ rate^{E-Star} = 55\%$$

5.2.9 Energy Star CFLs

5.2.9.1 Target Market

Market Description. The target market for this technology is residential non-can and non-R-Lamp Edison socket lights, which would not otherwise switch to Compact Fluorescent Lamps (CFLs).

5.2.9.2 Key Factors in Shaping Market Adoption of EERE Technologies

Price. BT assumed that the cost of the conventional incandescent technology is $0.75, and that there is no incremental cost associated with a comparable Energy Star CFL.

Baseline market acceptance. In 1998, PNNL conducted a study examining the historical market penetration for 10 energy-efficient products related to the buildings sector. The results of this study are documented in the PNNL report, *Methodological Framework for Analysis of GPRA Metrics: Application to FY04 Projects in BT and WIP* (2003, PNNL-14231). The resulting data were used to develop a set of generic diffusion curves. These curves were used to generate market penetration estimates for projects that do not have a forecast of annual sales targets. For the Energy Star CFL activity, the lighting diffusion curve was used.

5.2.9.3 Methodology and Calculations

Technical Characteristics. Energy Star-qualified CFLs are assumed to be 66 percent more efficient than incandescent lamps (25 W compared to 75 W)

Expected Market Uptake. Future market share growth for CFLs was extrapolated from historical sales data (see **Table G-27**). On average the CFLs are assumed to be used 4 hours per day and have a lifetime of 8000 hours.

Table G-27. Estimated CFL Sales Share and Incremental Savings

	CFL Sales Share	Incremental Savings (Billion kWh)
2005	2.3%	0.0
2010	3.5%	3.2
2015	4.5%	9.9
2020	5.5%	18.3
2025	7.0%	27.5

Due to their longer lifetimes and use in high use sockets, CFL's provide roughly 20 percent of general residential lighting demand by 2025.

5.2.10 Windows

5.2.10.1 Target Market

Market Introduction. The technology is commercially available. BT assumed that this project would accelerate the penetration in the marketplace by 10 years.

5.2.10.2 Methodology and Calculations

Performance Parameters: Energy Star Windows have maximum U-value and SHGC for four different climate zones. These climate zones do not directly correspond to the traditional climate zones used in CBECS or RECS; they also do not correspond to the census divisions used in NEMS. These new climate zones are based on the eight climate zones that were developed as part of the IECC 2003 code change cycle or Residential IECC Code Change (RICC). In general the Energy Star zones map from the RICC zones as follows in **Table G-28**.

Table G-28. Mapping of RICC Zones to Energy Star Zones

RICC Zone	Energy Star Zone
1	Southern
2	Southern
3	South/Central
4	North/Central
5	Northern
6	Northern
7	Northern
8	Northern

To construct the four Energy Star zones there was a fair amount of smoothing required due to geo-political boundaries, existing codes, and commercial regions. For example, a strict adherence of the eight RICC zones to four Energy Star zones shown above would have portions of California in all four Energy Star zones and would result in discontinuities in the zones across the country. The final result is that California is wholly within the South/Central zone and all four Energy Star zones are continuous across the country. Performance parameters are listed in **Table G-29**.

Table G-29. Performance Parameter Maximums for Low-e Windows

Region	Shading Coefficient	U-Value
Northern	0.60	0.35 Btu/ft2·°F
North Central	0.55	0.40 Btu/ft2·°F
South Central	0.40	0.40 Btu/ft2·°F
Southern	0.40	0.65 Btu/ft2·°F

Performance Target: Performance characteristics vary by building type and climate zone. The estimated savings per building were determined by simulating residential and commercial buildings in all climate zones (see **Table G-30**).

Table G-30. Performance Targets for Low-e Windows

Region	Sector	End Use	New Building Savings	Existing Building Savings	Units
Northern	Residential	Heating	8.17	8.30	MMBtu/HH
		Cooling	0.06	0.19	MMBtu/HH
	Commercial	Heating	6.24	5.73	MMBtu/ksf
		Cooling	-0.45	-0.58	MMBtu/ksf
North Central	Residential	Heating	2.88	2.94	MMBtu/HH
		Cooling	1.72	1.79	MMBtu/HH
	Commercial	Heating	2.98	2.77	MMBtu/ksf
		Cooling	0.74	0.68	MMBtu/ksf
South Central	Residential	Heating	0.09	0.00	MMBtu/HH
		Cooling	10.50	10.39	MMBtu/HH
	Commercial	Heating	0.75	0.66	MMBtu/ksf
		Cooling	5.91	5.62	MMBtu/ksf
Southern	Residential	Heating	-1.48	-1.77	MMBtu/HH
		Cooling	9.18	8.77	MMBtu/HH
	Commercial	Heating	-0.14	-0.14	MMBtu/ksf
		Cooling	5.21	4.98	MMBtu/ksf
Weighted National Average	Residential	Heating	3.82	3.82	MMBtu/HH
		Cooling	4.43	4.42	MMBtu/HH
	Commercial	Heating	3.36	3.08	MMBtu/ksf
		Cooling	2.25	2.07	MMBtu/ksf

Installed Cost:—Incremental Cost Over Conventional Double-Pane Windows

- 2005: \$1.00/ft^2
- 2015: \$0.50/ft^2

Expected Market Uptake. The purpose of the program is to increase the penetration of low-e glass from 40% in the residential market and 10% in the commercial market to 100% in the residential market by 2020 and in the commercial market by 2025. Both programs, Low-e Market Acceptance and Energy Star Windows, form the joint means to achieving the low-e penetration goal – the savings are to be split equally. Penetration curves were developed based on market diffusion curves developed and documented by PNNL(10). The "Accelerated" penetration curve represents the percent of superwindow sales with the DOE project; the "Net" penetration curve represents the percent of sales attributable to DOE, as BT assumed that the

DOE project would accelerate market acceptance by 10 years. The penetration rates are shown in **Figures G-13 and G-14**. For Low-e Market Acceptance/ Energy Star Windows, BT assumed that these projects would accelerate the acceptance of this technology in the marketplace by 10 years.

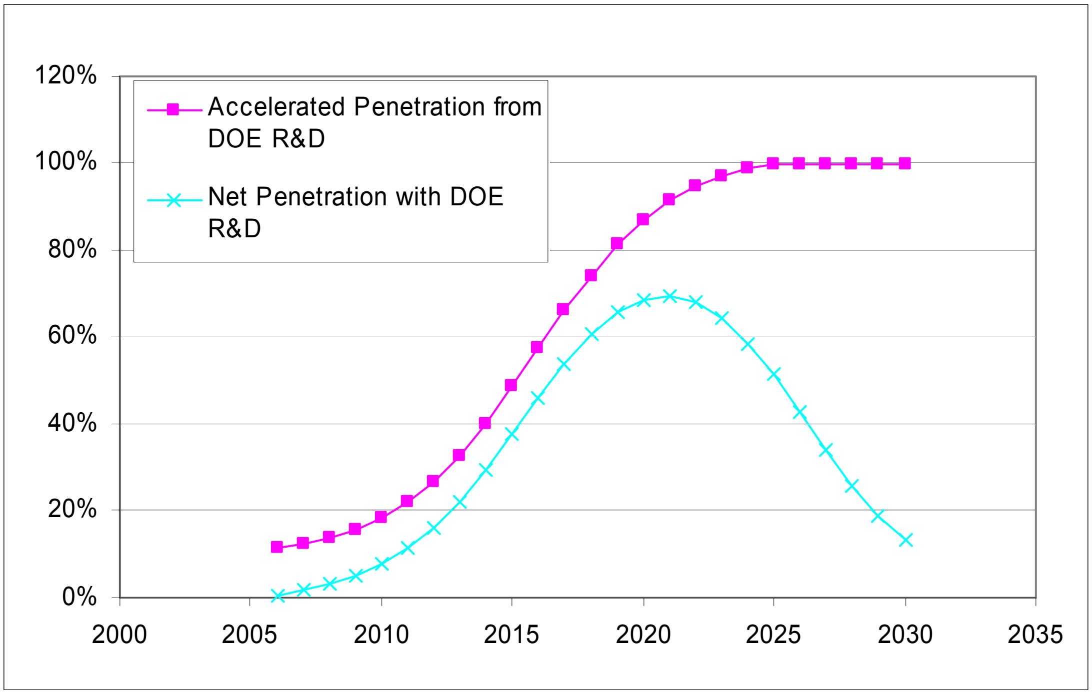


Figure G-13. FY07 Energy Star Windows – Commercial Buildings Percent of Sales

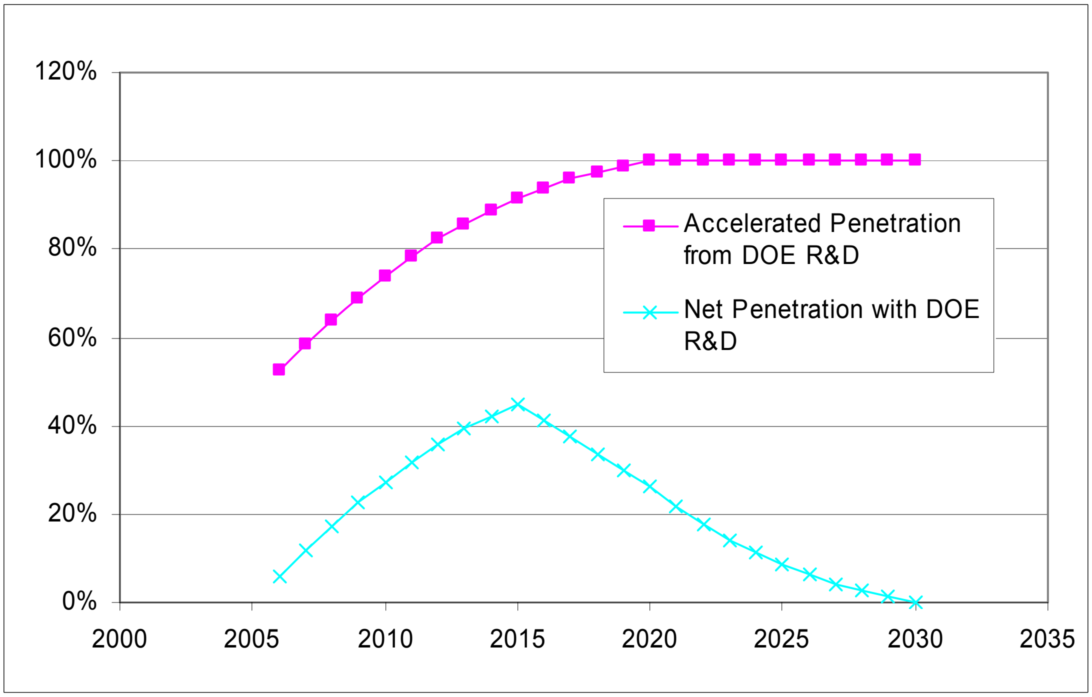


Figure G-14. FY07 Energy Star Windows – Residential Buildings Percent of Sales

5.2.11 Energy Star Home Performance

5.2.11.1 Target Market

Home Performance with Energy Star is a joint effort with the Environmental Protection Agency to develop and support pilot projects that promote whole-house retrofits for existing homes in order to save energy. Home Performance's three main components include whole-house inspections, marketing efforts, and quality assurance.

5.2.11.2 Key Factors in Shaping Market Adoption of EERE Technologies

Price. BT assumed that the cost of Home Performance pilot projects (the average price per household) would be \$5,000—in FY05, Pilot Project homeowners were spending between \$4,000 and \$6,000 in retrofits through the Pilot Project program.(9)

5.2.11.3 Methodology and Calculations

Inputs to Base Case. BT did not provide inputs to change the base case assumptions for the program markets. BT's calculations were based on a baseline that was developed from the Energy Information Administration's (EIA's) Commercial Buildings Energy Consumption Survey (CBECS), Residential Energy Consumption Survey (RECS), and the Annual Energy Outlook (AEO).

Technical Characteristics. BT assumed that Home Performance with Energy Star activities would primarily impact the space conditioning load of existing buildings, as most of the retrofit measures involve the building shell (e.g., insulation, windows); however, water heating and lighting loads are also reduced. Because these retrofits are occurring due to the programmatic builder certification, marketing efforts and financing options, BT assumed the activity would reap all benefits associated with the retrofits, roughly a 20% load reduction.

Expected Market Uptake. The penetration rates for Home Performance with Energy Star was developed using a diffusion model based on Fisher and Pry (1971)(11). The equation for determining market diffusion over time is:

$$N(t) = \frac{\kappa}{1 + \exp(-\frac{\ln(81)}{\Delta t}(t - t_m))}$$

Where K = Maximum market share potential

t_m = year in which 50% of potential is reached

Δt = time to grow from 10% to 90% of potential (years)

For Home Performance with Energy Star, k=0.0002%, t_m=17, and Δt=20. These values were developed through trial and error to achieve the expected annual household impact in 2007 and in "out" years, based on discussions with the program manager. **Table G-31** displays the resulting estimated number of homes impacted based on the penetration curve developed.

Table G-31. FY 2007 Market Penetration for Energy Star Home Performance

Year	Annual No. Homes
2007	700
2008	859
2009	1,052
2010	1,284
2011	1,562
2012	1,891
2013	2,279
2014	2,729
2015	3,245
2016	3,828
2017	4,474
2018	5,177
2019	5,927
2020	6,709
2021	7,503
2022	8,291
2023	9,053
2024	9,771
2025	10,434
2026	11,031
2027	11,557
2028	12,010
2029	12,395
2030	12,714

BT assumed that the portion of the Energy Star Home Performance activity funded by DOE would not occur without DOE funding, because it allocates money for builder training and certification, program marketing support, and program-specific financing options; therefore, no acceleration of market acceptance was modeled.

5.2.12 Sources

(1) *Model Documentation Report: Residential Sector Demand Module of the National Energy Modeling System*. 2003. Energy Information Administration, Washington, D.C. DOE/EIA-M067(2003) http://tonto.eia.doe.gov/FTPROOT/modeldoc/m067(2003).pdf
(2) *Annual Energy Outlook 2001*. 2001. Energy Information Administration, Washington, D.C.
(3) "Clothes Washer Technical Support Document" source: www.eere.energy.gov/buildings/appliance_standards/residential/clwash_0900_r.html.
(4) Arthur D. Little, Inc. (ADL). 1998. "EIA Technology Forecast Updates – Residential and Commercial Building Technologies, Reference Case."
(5) Vineyard, E.A. and J.R. Sand. 1998. "Fridge of the Future: Designing a One Kilowatt-Hour/Day Domestic Refrigerator Freezer." In *1998 ACEEE Summer Study Proceedings*.
(6) National Appliance Energy Conservation Act of 1987, Public Law 100-12.
(7) http://www.energystar.gov/products/cfls/EnergyStarCFLSpecification_Final_8.9.01.pdf p.5.

(8) http://eetd.lbl.gov/btp/papers/43782.pdf *Creating Markets For New Products To Replace Incandescent Lamps: The International Experience.* Presented at the 1998 ACEEE Summer Study on Energy Efficiency in Buildings, August 23-28, 1998, Pacific Grove, CA, and published in the Proceedings. Figure 2.

(9) Based on results documented in article, "Energy Star Tackles Existing Homes," Energy Design Update, Volume 23, No. 8, August 2003 as well as discussions with Kyle Andrews, Project Manager, June 2004 and Lana Nirk, Project Manager, May, 2004.

(10) Elliott, D.B., D.M. Anderson, D.B. Belzer, K.A. Cort, J.A. Dirks, D.J. Hostick. 2004. *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort*. PNNL-14697. Pacific Northwest National Laboratory, Richland, Washington.

(11) Fisher, J.C., and R.H. Pry, (1971) "A Simple Substitution Model of Technological Change." Technological Forecasting and Social Change, 3, 75-88.

Appendix H – GPRA07 Industrial Technologies Program Documentation

1 Introduction

The information provided in this appendix is consistent with the Industrial Technologies Program (ITP) draft report of the GPRA07 process, “GPRA07 Quality Metrics – Methodology and Results,” Energetics Incorporated, December, 2005. The draft report includes additional methodological details and the detailed fuel-specific off-line energy savings metrics results submitted to the Office of Energy Efficiency and Renewable Energy (EERE).

The GPRA07 calculation of future program impacts was performed separately for each planning unit and summed to produce the total ITP program impact. The planning units are: technology development (described as R&D planning units) and technology deployment (described as Technology Delivery planning units).

Within planning units, impacts were calculated differently for R&D planning units than for Technology Delivery planning units. Impacts for R&D planning units were calculated at the project level, using a uniform methodology embodied in a spreadsheet-based computer tool called the Technology Impact Projections Model. Impacts for Industrial Assessment Center (IAC) and Best Practices planning units were calculated for subprogram element activities using historical data, estimates, and assumptions documented in tabular format; and summed to produce the Technology Delivery planning unit impacts. ITP’s subprogram structure includes:

R&D Planning Units

1. Aluminum Industry Vision
2. Chemicals Industry Vision
3. Forest Products Industry Vision
4. Glass Industry Vision
5. Metal-Casting Industry Vision
6. Steel Industry Vision
7. Mining Industry Vision
8. Supporting Industry Vision
9. Industrial Materials Crosscut
10. Sensors and Automation Crosscut
11. Combustion Crosscut

Technology Delivery Planning Units

1. Industrial Assessment Center (IAC) Program
2. Best Practices Program

1.1 Target Markets (The Baseline Case)

- **Target Market Description**

Advanced industrial energy efficiency technologies under development with program support will enter a variety of specialized markets for production equipment, plant energy conversion, distribution, heat recovery, and waste-reduction equipment. Underlying fuel prices, the electricity generation and distribution fuel mix and heat rates, and sector economic growth rates —which were used in the NEMS-GPRA07 runs that produced the ultimate results from ITP's energy-savings inputs—were consistent with the reference case in the Department of Energy's (DOE/EIA) *Annual Energy Outlook 2005*. ITP's off-line calculation of fuel and electricity savings for individual projects and program-element activities did not refer explicitly to macro-baseline projection of energy consumption quantities; rather, a unique market growth rate was specified in each of the 105 Technology Impact Projections Model runs. This permitted the analysts to differentiate among highly varied market outlooks in the various industries. Except for several chemicals industry market targets with short-term growth rates of more than 5.0%, the range of these annual market growth rates was from -1.0% to 5.0%, with an average close to 1.5%.

Due to differences in the analytical framework of the NEMS-GPRA07 model and ITP's bottom-up energy-savings projection methodology, it was not possible to definitively match those models' base-case assumptions with the implicit base case in the GPRA study. NEMS-GPRA07 addresses the entire industry group in a top-down manner, assigning energy intensities to a comprehensive set of activities to project total industry energy use under alternative assumptions. The bottom-up ITP GPRA study specified the unit energy savings of a particular set of 105 advanced technologies, each in comparison to a best-available commercial technology alternative. ITP GPRA savings are only those savings attributable to these technologies in their primary intended markets. The two approaches are not inconsistent. The NEMS-GPRA07 model provides the context for benefit measurement in the overall economic framework.

The target market for each of 105 R&D technologies included in the ITP study was described qualitatively and quantitatively in a spreadsheet-based Technology Impact Projections Model run. The technologies were grouped based on common production activity Impact Targets. This specification of target markets was done to facilitate the identification of potentially overlapping markets. Where potentially overlapping markets were found, either the market was split between the two competing technologies or only one spreadsheet model run was used to represent both technologies.

Markets were initially defined in terms of the total number of technology units potentially in use at the year of introduction. This number was then reduced to the fraction of those units considered technically and economically accessible, and then further reduced to the likely achievable technology market share accessible to the technology, as compared to other advanced technologies. And, finally, the target market was reduced to the savings potential attributable to the program. The market size was adjusted annually by the spreadsheet logic, based on the specified annual percentage market growth rate.

- **Baseline Technology Improvements**

Continued baseline improvement in energy productivity was accounted for in the ITP methodology. ITP's method essentially subtracted a fixed "next best" baseline technology from a fixed advanced technology to obtain unit technology savings. The energy savings of a new technology were determined by the number of years the technology's market introduction is accelerated by the Federal program involvement. The energy savings associated with the program were explicitly projected to occur without the EERE R&D after a period of years known as the "acceleration period." Only the slice of energy savings attributable to the program's effort to accelerate technology development was counted as GPRA savings. In this way, the methodology incorporated an assumption (consistent with NEMS GPRA07) that the energy intensity of industrial production will steadily improve, and that specific Federal interventions in cofunding R&D only temporarily accelerate the rate of improvement in the targeted production activities. Acceleration periods varying from one year to 42 years were found in the GPRA07 runs, with an average close to 9 years.

Likewise, in the ITP off-line study, the conventional technology with which each new technology was compared was generally the best currently available technology—not a projected technology that might exist at the time of market introduction. Therefore, the comparison excludes future sales of the new technology, and the average technology in use, and uses only current best technology as the baseline for assessing impact.

While the industry-level rate of improvement in production energy intensity tends to follow fairly smooth curves of monotonic improvement, it is very difficult to predict the future energy performance of as-yet unidentified technologies to perform specific functions. In addition, the best currently available technology is often not yet widely adopted in the market, so that when the ITP technology enters the market, the current best-available technology may still represent the next-best decision alternative for many cases. As a result, the use of next best technology as a comparison point for new technology investment would have the tendency to understate rather than overstate the impact of a new technology savings. As well, taking credit for only that slice of savings due to the presumed acceleration of the new technology's market introduction date was intended to minimize any overestimation of savings due to the underlying rate of technology improvement.

The commercial introduction of a technology normally occurs after a significant demonstration, use of an operating prototype, and after an adequate test and evaluation period along with allowances for the beginnings of production, dissemination of information, initial marketing and sales, and other "start-up" factors. To capture this lengthy process, users of the Technology Impact Projections Model were asked to indicate the timeline for developing and introducing the technology into the market. This timeline includes the years for when an initial prototype, refined prototype, and commercial prototype of the technology has or will be completed; and the year when the technology will be commercially introduced. An initial prototype is the first prototype of the technology. A refined prototype represents changes to the initial prototype, based on testing and field tests but not a commercially scaled-up version. A commercial prototype is a commercial-scale version of the technology. Commercial introduction occurs when the first unit beyond the commercial prototype is operating. Prototype and commercial introduction years, consistent with the technology development program plans, are estimated; and two values for a commercial introduction year were requested. One estimate reflects when the technology is projected to be introduced, if the program proceeds as expected (“With ITP” case). The other year estimate reflects when the technology would have entered the market, if the program had not been involved (“Without ITP” case). The difference in commercial introduction years for the “With ITP” and “Without ITP” cases is referred to as the “acceleration period.”

- **Baseline Market Acceptance**

The rate of market penetration of novel technologies in industrial production markets is captured explicitly in the methodology.

Based on historical data, new technologies normally penetrate a market following a familiar S-curve—the lower end representing the uncertainties overcome by “early adopters.” The curve tails off at the far future, where some may never adopt the new technology. The steepest portion of the S-curve is where the new technology is most rapidly penetrating the market and producing new savings. The rate at which technologies penetrate their markets varies significantly. The actual penetration rate varies due to economic, environmental, competitive, productivity, regulatory, and other factors. For example, penetrations of long-lived assets associated with industrial technologies generally occur over decades, while simple process or control changes can penetrate much more rapidly.

In a 1998 study by Arthur D. Little Inc. (“Streamlining of OIT’s GPRA Process - Draft,” Arthur D. Little Inc., Reference 33550-01, May 27, 1998), data was presented on a number of actual penetration rates of past and present technologies. These penetration rates were analyzed, normalized, and grouped into five classes, based on a number of characteristics and criteria. These criteria were then used to classify technologies, based on their characteristics and the characteristics of the target markets where the technologies are expected to penetrate. Each technology was matched to the most similar one of five generic technology classifications to represent a specific technology’s market adoption profile. The process is described below.

Users of the ITP Technology Impact Projections Model were asked to complete **Table H-1** for each project by selecting a technology-impact value for each technology characteristic as a, b, c, d, or e in the right-hand column for those characteristics for which they could make a judgment. Based on the strength of these characteristic scores, the overall technology market-penetration curve selection was entered in the first row at the right under “Score.” The table was copied onto the spreadsheet model run at the “Background” tab. Note that the characteristics (rows) are relatively independent, and a given technology will likely fit best in different classes for different characteristics. By examining the pattern, however, it is possible (based on best judgment and experience) to select the most likely class (rate) at which the new technology may penetrate the market. This may be a “subjective average” of the characteristics, or it is possible that one or two characteristics are expected to dominate future adoption decisions that a particular class of penetration rate is justified. There also may be “windows of opportunity,” where significant replacements of existing equipment may be expected to occur in the future for other reasons. The user was asked to insert into the spreadsheet the class of penetration rate believed most likely—all things considered—and provide a narrative of the rationale for selection, if not obvious from **Table 1.** The GPRA07 study included projects with curve selections a, b, c, and d, with b and c being the most common selections.

For additional context, **Table H-2** shows actual technologies and the class of their historical penetration rates. Comparison of the new technology, by analogy or similarity, with these examples provided additional insight into selecting the appropriate penetration rate that might be expected for the new technology. The actual technologies' historical market penetrations are shown graphically in **Figure 1,** falling within the market-penetration rate classes used by the model.

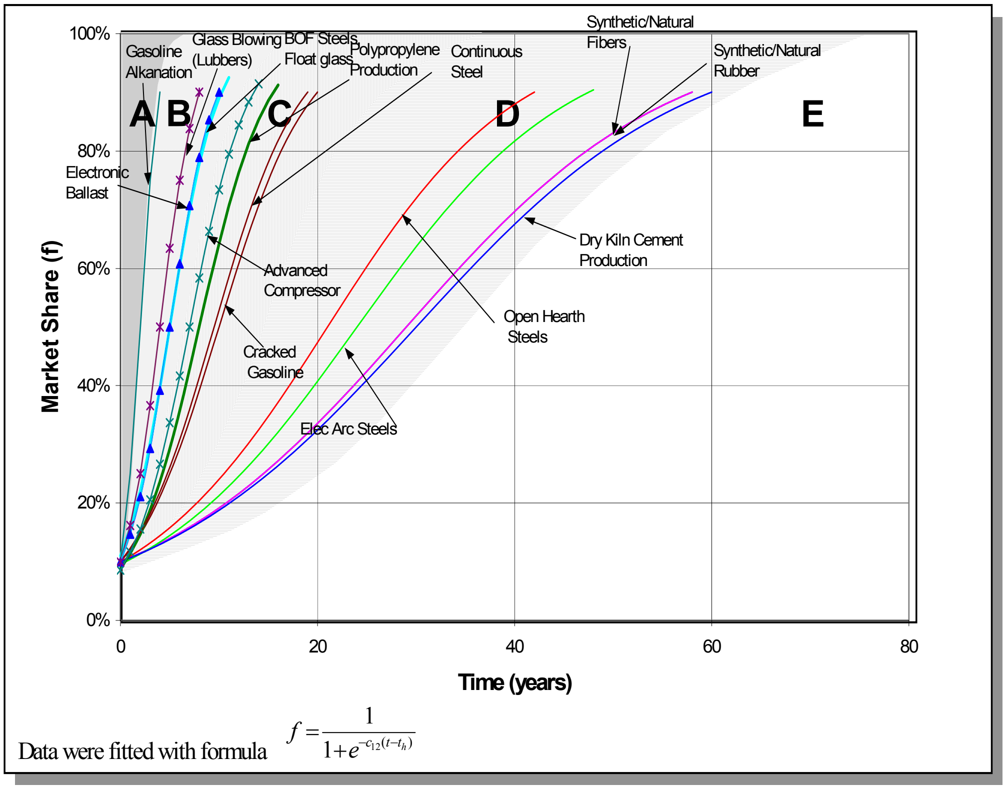
Table H-1. Selecting the Market-Penetration Rate Class

Technology/project						**Score (a,b,c,d,e)**
Characteristic	**a**	**b**	**c**	**d**	**e**	
Time to saturation	5 yrs	10 yrs	20 yrs	40 yrs	>40 yrs	
Technology factors						
Payback discretionary	<<1 yrs	<1 yr	1-3 yrs	3-5 yrs	>5 yrs	
Payback non-discretionary	<<1 yr	<1 yr	1-2 yrs	2-3 yrs	>3 yrs	
Equipment life	<5 yrs	5-15 yrs	15-25 yrs	25-40 yrs	>40 yrs	
Equipment replacement	none	minor	unit operation	plant section	entire plant	
Impact on product quality	$$	$$	$$	$	0/-	
Impact on plant productivity	$$	$$	$$	$	0/-	
Technology experience	new to U.S. only	new to U.S. only	new to industry	new	new	
Industry factors						
Growth (% per annum)	>5%	>5%	2-5%	1-2%	<1%	
Attitude to risk	open	open	cautious	conserv-ative	averse	
External factors	forcing	forcing	driving	none	none	
Gov't regulation						
Other						

Table H-2. Examples of Technologies

Class	A	B	C	D	E
Aluminum		Treatment of used cathode liners	Strip casting, VOC incinerators		
Chemicals	New series of dehydrogenation catalyst (incremental change)	CFCs -> HCFCs, incrementally improved catalysts, membrane-baed chlor-alkali	Polypropylene catalysts, solvent to water-based paints, PPE-based AN	Synthetic rubber and fibers	
Forest Products			Impulse drying, de-inking of waste newspaper	Kraft pulping, continuous paper machines	
Glass		Lubbers glass blowing, Pilkington float glass	Particulate control, regenerative melters, oxygenase in glass furnaces		
Metals Casting	New shop floor practice				
Petroleum	New series HDS catalysts	Alkylation gasoline	Thermal cracking, catalytic cracking	Residue gasification, flexicoking	
Steel	Improved EAF operating practice (e.g. modify electric/ burner heating cycle to minimize dust generation)	BOF steel making	Oxyfuel burners for steel, Level II reheat furnace controls, continuous casting, particulate control on EAF, high-top pressure blast furnace	Open-hearth technology, EAF technology	
Other		Advanced refrigerator compressors, oxygen flash copper smelting, solvent extraction with liquid ion exchange	Fluegas desulfurization (coal-fired utilities), low Nox industrial burners, industrial gas turbines, ore beneficiation		Dry-kiln cement, industrial ceramic recuperators Industrial heat pumps

Figure 1. Market Penetration Rate Classes



1.2 Key Factors in Shaping Market Adoption of EERE Technologies

- **Price**

ITP methodology places little emphasis on cost-based estimation of market penetration, because useful cost information on industrial technologies in the R&D stage of development is, in nearly all cases, impossible to obtain. Instead, relative costs in the form of the expected payback period were one of numerous market-driving factors in matching the market-penetration schedule with each innovative technology (see previous section). These market-penetration schedules are typical of historical industrial-sector technology innovations, whose characteristic payback period, scale, equipment lifetime, impact on product quality, relevant experience level, market growth rate, attitude to risk, and other factors were matched to each innovative technology to select the best market-penetration schedule.

- **Nonprice Factors**

- **Key Consumer Preferences/Values.**

Several consumer-preference/value issues were incorporated in the ITP market-penetration curve selection technique. These include factors such as technology scale, equipment lifetime, impact on product quality, etc. listed above.

- **Manufacturing Factors.**

The benefits-estimation approach requested the analyst to estimate the year in which the technology is expected to be successfully developed at the successive stages of (1) completion of initial R&D, (2) initial system prototype, (3) refined prototype, (4) commercial prototype, and finally (5) commercial introduction, given the push provided by the ITP program support. These estimates were documented as part of each spreadsheet model run.

- **Policy Factors.**

In the great majority of cases, no policy factors were considered significant to the market introduction and acceptance of ITP technologies. However, for cases where a regulation or other policy will drive the market to accept a new technology solution, the market-penetration curve selection procedure was set up to accept this information and allow it to play a role in the analysis. Any such influence was discussed in documentation provided in the spreadsheet model run.

1.3 Methodology and Calculations

- **Changes in Inputs to Base Case**

ITP did not provide inputs that changed the base case assumptions for the industrial markets.

- **Technical Characteristics of the Program Case**

ITP did not provide specific changes to the NEMS-GPRA07 industrial-sector characteristics.

ITP's estimates of the energy savings of its advanced technologies were based on information provided to the analysts through the proposal review and contracting process, which includes industry participation and review, followed by program review of these estimates. ITP analysis by sector has focused on assessing the industrial processes where energy is actually consumed and understanding current and best practices for each proposed technology. The participation of industry experts in this process has been critical to helping refine the estimates.

- **Expected Market Uptake**

- **R&D Planning Units**

GPRA07 energy savings in the ITP off-line study were projected for individual projects within planning units and summed to total results for planning units and for ITP as a whole. Active projects were selected by the ITP program managers for GPRA07; thus, the FY 2006 program portfolio was used as a surrogate for the (as-yet unknown) FY 2007 portfolio. The number of study projects in each planning unit was controlled to represent an aggregate nominal funding level not greater than 100% of the FY 2006 budget request.

This prospective assessment was carried out with the aid of an experience-based market-penetration model designed to estimate the national energy, economic, and environmental impacts of innovative industrial technologies. ITP's off-line calculations for GPRA07 did not utilize the model's capabilities to project environmental and cost impacts, so the results will focus only on energy savings. EERE guidance for GPRA07 was to project the energy impacts of the FY 2007 program, which subsequently were used by others to specify scenario projections by the NEMS-GPRA07. The resulting NEMS-GPRA07 runs (reported elsewhere) produce environmental and cost results using integrated demand and supply assumptions consistent across the demand sectors.

The Technology Impact Projections Model was used to estimate the potential energy savings resulting from research, development, and demonstration projects funded by the Industrial Technologies Program (ITP). Benefit estimates are critical for evaluating projects and presenting the merits of both individual projects and the overall RD&D portfolio.

The Technology Impact Projections Model has been used by proposers responding to a Solicitation or Request for Proposals to estimate program impacts. Where not provided in proposals, principal investigators were asked to provide inputs for their active projects. Use of the model across all projects allows ITP to estimate the impacts of its projects in a consistent manner.

Users were asked to provide their best estimate for each piece of information required for the spreadsheet model. A description of the advanced technology was required to provide an overview of the project/technology. This includes the project name, project number (once project is funded), estimates preparer, program manager, planning unit, lab and industry contacts, and data sources. A narrative summary of the technology on which benefit estimates are based was required. This described what constitutes a typical process unit for the technology, in terms of annual output (production capacity multiplied by duty factor). For simplicity, the analysis assumed that all units in the industry have the same capacity. An average, or typical, unit capacity was chosen, particularly for situations where the unit size may vary in different installations. By convention and to enable comparisons, units for the new technology and the current state-of-the-art were equal in output capacity; even if, in reality, the new technology might have a different unit capacity for various reasons.

The new technology also might not be a physical item of hardware. Rather, it could be a process change, a computer model or control system, operational change, or other nonphysical technique. In such cases, a unit was defined as the typical or average process or plant that would utilize the new technique. The annual energy inputs, based on the expected energy consumption of the process or plant with the new technique, were then compared with annual energy consumption required by existing techniques.

Key information was provided on the performance of single installed units or applications of the advanced technology. For comparison, information was required on the performance of the best-available technology for the application, not the average of all in-place technology units.

Users were required to provide energy use per year for the new and conventional units, by fuel:

Electricity - Includes direct electricity.

Natural Gas - Includes pipeline fuel natural gas and compressed natural gas.

Petroleum - Includes residual fuel, distillate fuel, and liquid petroleum gas.

Coal - Includes metallurgical coal, steam coal, and net coal coke imports.

Feedstock - Includes fossil fuels consumed in nonenergy uses such as process feedstocks.

Biomass - Includes the use of biomass (for energy or as feedstock).

Wastes - Includes the use of fuels that are generated as wastes or process byproducts. Examples of such fuels are refinery fuel gas, blast furnace gas, hog and bark fuel, and sewage sludge.

Other - Includes any fuels that may not be included in those listed above.

Total Primary Energy - Is calculated from individual energy inputs. The primary equivalent of direct electricity consumption includes losses in electricity generation and distribution. For GPRA07, fuel and electricity savings were used as inputs to specify NEMS-GPRA07 runs that themselves applied heat rates, etc., varying over time to produce primary energy savings.

Energy use was entered in physical units (e.g., billion cubic feet of natural gas) or primary units (trillion Btu). The exception was electricity use, which has to be entered as site energy consumption (either in billion kWh or trillion Btu).

To determine the potential impact of the new technology as it becomes adopted, it was necessary to estimate the total market for the technology, reduce that to the likely actual market, and estimate when—and the rate at which—the new technology will penetrate the market.

Users were required to estimate the number of installed units in the U.S. market in a specified year. That market was defined as narrowly as possible: the smallest group of applications that covers all potential applications for which the user may have some data. Users could apply their own data on energy use of the state-of-the-art technology. Other potential data sources include ITP’s Energy and Environmental Profile for the relevant industry, EIA’s MECS (Manufacturing Energy Consumption Survey) data, or industry sources.

The annual market growth rate was specified by the model user, based on an EIA or industry growth projection for the relevant industry and process. A source for the growth rate was called for in the comments section.

Market share was specified as a function of the potential accessible market share and the likely market share. The Potential Accessible Market Share was defined as the market that the new technology could reasonably access given technical, cost, and other limitations of the technology. For example, certain technologies may be applicable only to a certain scale of plant, certain temperature-range processes, certain types of existing equipment or subsystems, or only certain segments of the industry.

A further delimiting fraction was called the “Likely Market Share.” In some instances, in addition to technical and cost factors, the technology may compete with other new technology approaches (or with other companies) for the market. The user was asked to use current market-share information or base their estimated market share on the number of competitors in the market, assuming they are using different technologies not resulting from this project. This market-share estimate is different than the possibility of “copycats,” which should not be considered as competing uses; the reason is, if others adopt essentially the same (or slightly modified) technology due to this new technology, that additional adoption was triggered by the project being described and that project should be “credited” with causing that trend. This mechanism encompasses the case for techniques where the intellectual property cannot be, or is not, protected and becomes general knowledge throughout the industry.

In some instances, a program may be developing a technology in conjunction with another ITP, EERE, or DOE program. In these cases, the analysts were asked to provide an estimate of the percentage of savings that is attributed to the program. The attribution percentage should be similar to the percentage of Federal funds provided to the project by the program. A default value of 100% was entered in the model and the principal investigator could provide additional information.

As previously described under Baseline Technology Improvements, the market penetration of the technology was projected based on two estimates: the technology development and commercialization timeline, and the market-penetration curve. The technology development and commercialization timelines were determined first. The commercial introduction of a technology normally occurs after a significant technology demonstration or by a lengthy field testing of an operating prototype and after an adequate test-and-evaluation period. To capture this lengthy process, the analyst indicated the timeline for developing and introducing the technology into the market. This includes the years for when an initial prototype, refined prototype, and commercial prototype of the technology has or will be completed, as well as the year when the technology will be commercially introduced. An initial prototype is the first prototype of the technology. A refined prototype represents changes to the initial prototype but not a commercially scaled-up version. A commercial prototype is a commercial-scale version of the technology.

Commercial introduction occurs when the first unit beyond the commercial prototype is operating. Prototype and commercial-introduction years were estimated to be consistent with the technology-development program plans. Two values for a commercial introduction year were requested. One reflected when the technology is projected to be introduced, if the program proceeds as expected (“With ITP” case). The other reflected when the technology would have entered the market if the program had not been involved (“Without ITP” case). If the technology would not have been commercially introduced without the program, then a year of 2050 for the “Without ITP” case was entered. The difference in commercial introduction years for the “With ITP” and “Without ITP” cases is referred to as the acceleration period. Only the slice of energy savings attributable to the program’s effort to accelerate technology development was counted as GPRA savings.

As previously described, new technologies are estimated to penetrate a market following a familiar S-curve, the lower end representing the above uncertainties overcome by “early adopters." The curve tails off where some may never adopt the new technology. The major portion of the S-curve that is most important is where the new technology is penetrating the market, and benefits are being reaped. The rate at which technologies penetrate their markets varies significantly. The actual penetration rate varies due to economic, environmental, competitive, productivity, regulatory, and other factors. Penetrations of new technologies with long-lived assets often associated with heavy industrial technologies generally take place over decades, while simple process or control changes can penetrate much more rapidly.

Technology impact projections-model runs for individual R&D projects receiving R&D support were aggregated to obtain energy savings associated with each R&D planning unit. In aggregating the savings, market targets were examined explicitly to avoid double-counting the same potential savings in the infrequent instances when the same energy efficiency market is clearly addressed by multiple projects. Where possible, market overlaps were found; and, in these cases, the markets were either assigned to only one technology or divided among the competing technologies under development. This process increases confidence that any systemic double-counting within planning units has been minimized. Nevertheless, some double-counting across planning units within ITP or with other EERE programs is assumed to remain, and this residual was handled as described below.

The approximate portion of the FY 2006 budget represented by the analysis for each planning unit was noted, but the results were not scaled to 100% of the FY 2006 budget. Typically, the projects analyzed represented 80% to 99% of the FY 2006 budget for the various planning units. Projected benefits for these planning units do not include the effects of R&D projects completed prior to the current year.

The justification for assuming that all of the projects analyzed will succeed is twofold. First, projects that fail will likely be replaced with new projects using different technical approaches to achieve similar goals. However, this rationale requires that the program is continuously funded. Second, the projects analyzed do not comprise 100% of the FY 2006 budget. Therefore, although there is no explicit estimation of risk, the aggregate benefits are discounted, which is equivalent to an allowance for some risk. In addition, there are benefits that are excluded from the program estimates. These include: the knowledge benefits of ITP's R&D portfolio; this scientific and technical knowledge can help to underpin additional production technology innovations in the future, and spin-off applications in both the near and longer terms.

- Technology Delivery Planning Units

The Industrial Analysis Center program and the Best Practices program were assessed, based on retrospective analysis of performance data accumulated over a period of years. ITP's off-line Quality Metrics study for these planning units is based on the premise that continuation of the programs will result in beneficial impacts proportional to documented experience at historical budget levels. These analyses did not count as "savings" any continuing contributions from prior program expenditures, but only assumed that future expenditures will produce results proportionate to those reported for past expenditures.

The approaches for calculating the impacts of the IAC and best-practices planning units were similar. In each case, those program activities associated with historic documented energy savings were projected into the future based on assumed continuation at the FY 2006 budget level. Outreach is measured in a number of ways including the numbers of assessments, Web site visitors, and trained individuals. The activity levels performed in each future year were used to arrive at the future energy savings attributable to the activity, given continued performance at historical levels of effectiveness. Each quantity and assumption was explicitly shown in a tabular format intended to show the contribution of each step of the calculation to the final result and to make the entire analytical process repeatable.

The IAC program benefits were supported by more than 20 years of actual assessment and implementation data. Among other assumptions, the effects of assessments were projected to last for seven years. The effects of student training were projected to persist for 11 years. The effects of the Web site information activity were projected to last for seven years.

Best Practices program benefits were based on findings of an Oak Ridge National Laboratory study of program effects, and on a FY 2004 peer review that focused on ORNL's outcome evaluation study. The basic methodology used in each of four best-practices activity areas was very similar. First, the activity reach was estimated by calculating the number of individuals "touched" by best-practices information. This number was then scaled back to calculate the number of plants taking action, due to this information dissemination. The scale-back factors included accounting for duplicate "touches" within the same company, the percentage of companies actually taking action, and a reduction factor to discount program credit due to it being but one of multiple sources of influence. To obtain the total program energy savings, reported rates of energy savings were applied to the number of plants estimated to be affected by best-practices activities in each future year.

Best Practices activity areas evaluated for GPRA07 were Plant-wide Assessments, Training, Software, and Qualified Specialists. Total annual energy savings attributed to Best Practices were the sum of the subtotals estimated for these four delivery channels.

1.4 Sources

"GPRA07 Quality Metrics – Methodology and Results," Energetics Incorporated, draft, December, 2005.

DOE/EIA, *Annual Energy Outlook 2005.*

"Streamlining of OIT's GPRA Process (Draft),"Arthur D. Little Inc. Reference 33550-01, May 27, 1998.

Appendix I – GPRA07 Federal Energy Management Program Documentation

Project Description. The mission of the Federal Energy Management Program (FEMP) is to promote energy security, environmental stewardship, and cost reduction through energy efficiency and water conservation; report progress toward the Executive Order goals at Federal sites; and support energy management activities of the Department of Energy.[1]

Through the Federal Government's own actions, FEMP's target is to facilitate energy efficiency and renewable energy investments in FY 2007 that will result in life-cycle energy savings of 17.1 trillion Btus. This target includes only those investments at Federal agencies that can be quantified and directly related to FEMP activities.[2]

FEMP's spreadsheet model is not integrated into the larger FY 2007 GPRA models (NEMS-GPRA07 and MARKAL-GPRA07). However, the delivered energy savings are used as inputs for the integrated modeling. The projected savings are subtracted from the Baseline Case for commercial-building energy consumption. Analysts use NEMS-GPRA07 to compute the other benefits metrics of primary energy savings, carbon emission reductions, and energy expenditure savings. This appendix provides an outline of how the delivered energy savings estimates were calculated. The specific mathematical calculations are available in two spreadsheet files which are available through the FEMP program.

Background: Note that the FY 2007 GPRA benefits were calculated during a transitional period in FEMP. In 2005, at the time the GPRA calculations had already been completed for the Corporate Review Budget, FEMP was in the midst of changing its metrics and benefits calculations as part of the OMB Program Assessment Rating Tool (PART) process. To ensure consistency between the GPRA benefits and the PART metrics, the final GPRA methodology for FY 2007 represents a somewhat disjointed approach, combining both a bottom-up approach to reflect PART and the existing GPRA top-down model. As part of the FY 2008 budget development process, FEMP will employ a more unified methodology to calculate GPRA benefits.

Target Market

Target Market Description. The target market is the Federal sector, the Nation's 3.0 billion square feet of standard Federal buildings (e.g., military bases, post offices, hospitals, courthouses) and the Nation's 300 million square feet of Federal energy-intensive operations (e.g., laboratories, check-processing facilities, and linear accelerators). The Federal Government's actions—via leadership, awards, influence, and raw purchasing power—may well influence private-sector and state and local government decisions with respect to energy-related decisions, but any such "spillover" impact is not estimated in this GPRA process.

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[1] Department of Energy FY 2007 Congressional Budget Request. Vol. 3. p. 407.

[2] Department of Energy FY 2007 Congressional Budget Request. Vol. 3. p. 408.

Key Factors in Shaping Market Adoption of EERE Technologies

Policy Factors. FEMP's mission is to assist the 32 Federal agencies in attaining the goals set by Executive Order and other legislation for the Federal government. Strictly speaking, these are not goals for FEMP but goals for each individual agency, and their involvement is essential. Executive Order 13123 establishes that the goal for all Federal agencies is to reduce energy intensity in "standard" Federal buildings by 35% by 2010 (relative to the 1985 statutory baseline level of 138,610 Btu per gross square foot).[3] Additionally, Executive Order 13123 contains a goal for energy-intensive operations, which is to reduce energy per square foot by 25% in 2010 relative to a 1990 baseline.

The Energy Policy Act of 2005 (EPACT 2005) establishes the following goals: to reduce energy consumption per square foot by 20% by 2015 compared to the baseline year of FY 2004 at a rate of 2% per year; and to ensure that at least 3% of Federal electricity consumption is generated by renewables in the years FY 2007 through FY 2009, by 5% in the years FY 2010 through FY 2012, and by 7.5% in FY 2013 and each fiscal year thereafter.[4]

Methodology and Calculations

FEMP used a combination of a "bottom-up" and "top-down" approach in calculating GPRA benefits that accrue due to its activities. For activities through FY 2010, FEMP estimated the energy savings that will result from only its quantifiable activities and then summed these savings to generate a comprehensive savings estimate. Quantifiable activities are limited to project financing projects, technical assistance projects, and departmental energy management projects.

Note that the comprehensive savings estimate does not take into account additional savings that likely result from FEMP's non-quantifiable activities (e.g., product specifications, outreach, training, reporting). Furthermore, the Federal Government's actions—via leadership, awards, influence, and raw purchasing power—may well influence private-sector and state and local government decisions with respect to energy-related decisions, but any such "spillover" impact is not estimated in this GPRA process.

For years FY 2011 through FY 2013, FEMP relied on a model and supporting research that estimates the government-wide energy savings for these years, and then approximated FEMP's contribution to this savings based on prior performance. Finally, for years 2014 and beyond, FEMP assumed a 1% annual decrease in the overall energy intensity of Federal facilities. Then, as with years FY 2011 through FY 2013, FEMP approximated its contribution to this reduction based on past performance.

Inputs to Base Case. FEMP did not provide inputs to change the Base Case assumptions for the program markets. FEMP's calculations were based on a baseline that was developed from Federal building historical energy-use data, per Executive Order and legislation.

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[3] Department of Energy FY 2007 Congressional Budget Request. Vol. 3. p. 409.

[4] Department of Energy FY 2007 Congressional Budget Request. Vol. 3. p. 409.

Technical Characteristics. FEMP maintains a database with information on all of the projects it assists—both through its technical assistance and project financing efforts. The database includes information regarding engineering estimates of energy and cost savings for individual projects among other important data. FEMP relied on this database, as well as written contracts, to develop annual energy savings estimates for projects it assisted in FY 2002, FY 2003, and FY 2004. These engineering estimates were used to develop a savings projection for FY 2007.

Annual energy savings projections attributable to quantifiable FEMP activities were calculated for five FEMP sub-programs using the following sources and assumptions. Life-cycle energy savings were estimated by multiplying the annual savings by 15 years, the average life span of installed energy-efficient equipment.

Project Financing Activities:

(1) Energy Savings Performance Contracts (ESPC)
Annual savings for these contracts were obtained directly from FEMP Super ESPC Delivery Order schedules. Savings are assumed to begin accruing in the year of the delivery order award. In instances where annual savings were not available for a particular delivery order, the average savings per dollar of project investment (9,000 Btu/dollar) was used to estimate annual savings.

(2) Utility Energy Savings Contracts (UESC)
These savings were obtained directly from UESCs awarded with direct assistance from FEMP.

(3) Energy Markets/Shared Energy Savings Support
These estimates were derived from projects in which FEMP directly assisted Federal agencies in successfully applying for public benefit funds or other energy efficiency funds.

Technical Assistance Activities:

(4) Technical Assistance Projects (TA)
These estimates reflect the savings potential from projects for which FEMP provided technical assistance, including both energy efficiency and renewable energy support. The estimates do not credit FEMP with the full energy savings potential by the projects, but rather for the incremental savings that would be accrued if FEMP's technical recommendations were followed. In the case of renewable energy projects, energy savings are presumed to equal the amount of energy generated from the on-site renewable project and used by the federal facility.

Departmental Energy Management Activities:

(5) Departmental Energy Management (DEMP)
These estimates were derived directly from engineering estimates of energy savings reported by DOE sites that received funding from FEMP for energy efficiency and renewable energy projects.

FEMP Project Financing: Estimated Savings. FEMP Project Financing performance measures were derived from the average annual energy savings (in billion Btu) for projects signed in fiscal years 2002 through 2004. **Table I-1** details the annual FEMP-facilitated savings for the three project financing programs: Super ESPCs, Utility Energy Service Contracting support, and Energy Markets, including support for the United States Postal Service's shared energy savings projects.

Table I-1. Annual Savings (Billion Btu)

	2002	2003	2004	2002-2004
Super ESPC	517	2,634	215	3,366
UESC	204	163	140	507
Energy Markets	0	66	142	208
Project Financing Total	720	2,863	498	4,081

FEMP divided the average annual energy savings by the total project financing annual budgets (**Table I-2**) for the three years to determine "Annual Energy Savings per FEMP Dollar of Funding" shown in **Table I-3**.

Table I-2. Project Financing Dollars (Thousand $)

2002	2003	2004	2002-2004
$8,700	$7,839	$7,830	$24,369

Table I-3. Annual Energy Savings per FEMP Dollar of Funding (Site-Delivered Btu/$)

2002	2003	2004	2002-2004
82,813	365,224	63,550	167,469

The "Annual Energy Savings per FEMP Dollar of Funding" for 2002-2004 was multiplied by the approximate project financing budget request for FY 2007 ($6 million) to estimate annual savings from the project financing program for that year, yielding an estimate of 1,005 billion Btu.

FEMP's performance measure target for project financing in 2007 is 80% of the annual estimate for FY 2007 (or 804 billion Btu) based on the average performance of the fiscal years 2002 through 2004. FEMP used the 80% multiplier to ensure that the projected savings estimates were conservative and attainable.

FEMP calculated life-cycle energy savings by taking the estimated annual savings and multiplying by 15 to reflect an average project life of 15 years, for a total life-cycle energy savings of 12,060 billion site-delivered Btu.

FEMP Technical Assistance: Estimated Savings. Program performance measures for these activities were derived first from the estimated annual savings from all TA projects facilitated by FEMP (**Table I-4**) whether or not those projects are ultimately implemented by the agency. The estimated annual energy savings in million Btu (MMBtu) for fiscal years 2001 through 2004 were divided by the total TA budget for those years to arrive at "Identified Annual Savings from TA Projects per dollar of TA Funding" (200 MMBtu).

Table I-4. Technical Assistance Project Savings and Funding Levels

	2001	2002	2003	2004	2001 - 2004 4-Year Total	2007 Estimate
Total TA Funding (Thousand $)	$7,896	$7,000	$7,825	$8,140	$30,861	$6,591
Identified Savings from Recommended TA Projects (MMBtu)	824,019	865,590	3,695,862	776,670	6,162,141	1,316,052
Identified Savings per $ of TA funding (MMBtu)	104	124	472	95	200	200

FEMP multiplied the 200 MMBtu value (Identified Annual Savings per dollar of TA Funding) by the budget request for FY 2007 to estimate potential annual savings identified by all TA projects for FY 2007 (illustrated in the far right column of **Table I-4**).

FEMP estimated "Implemented Savings" for FY 2007 by taking 30% of estimated potential annual savings identified by all TA projects, yielding 395 billion Btu. FEMP used the 30% multiplier to reflect that not all projects for which FEMP provides technical assistance are actually implemented. Based on historical implementation rates, FEMP determined the 30% figure to be a reasonable estimate of how many projects would be implemented in the future.

FEMP calculated the target 2007 TA project target performance measure by taking 80% of estimated "Implemented Savings" from TA program facilitated projects yielding 316 billion Btu. FEMP used the 80% multiplier to ensure that the projected savings estimates were conservative and attainable.

FEMP calculated life-cycle energy savings by taking the estimated annual savings and multiplying by 15 to reflect an average project life of 15 years, for a total life-cycle energy savings of 4,740 billion site-delivered Btu.

FEMP Departmental Energy Management: Estimated Savings. FEMP DEMP performance measures were derived from the average annual energy savings (in billion Btu) for projects signed in fiscal years 2002 through 2004. **Table I-5** details the annual FEMP-facilitated savings, the DEMP budget, and the resulting "Annual Energy Savings per FEMP Dollar of Funding."

Table I-5. DEMP Annual Savings and Funding

	2002	2003	2004	2002-2004
Annual Savings (Billion Btu)	26.9	27.2	35.4	89.5
DEMP Budget (Thousand $)	$1,421	$1,445	$1,963	$4,829
DEMP Cost-Share from Sites (Thousand $)	$1,097	$402	$555	$2,054
Annual Energy Savings per Dollar of Funding (DEMP Budget plus Cost-Share)	10,683	14,727	14,059	13,003

The "Annual Energy Savings per FEMP Dollar of Funding" for 2002-2004 was multiplied by the approximate Departmental Energy Management budget request for FY 2007 ($2 million) to estimate annual savings from the Departmental Energy Management activities for that year, yielding an estimate of 26.0 billion Btu.

FEMP's performance measure target for DEMP in 2007 is 80% of the annual estimate for FY 2007 (or 20.8 billion Btu) based on the average performance of the fiscal years 2002 through 2004. FEMP used the 80% multiplier to ensure that the projected savings estimates were conservative and attainable.

FEMP calculated life-cycle energy savings by taking the estimated annual savings and multiplying by 15 to reflect an average project life of 15 years, for a total life-cycle energy savings of 312 billion site-delivered Btu.

Total estimated annual savings for all quantifiable FEMP activities for FY 2007 is 1.14 trillion Btu, which is equivalent to 17.1 trillion Btu life cycle energy savings. FEMP assumed that this target level of savings would remain in effect through 2010, based on the Executive Order goal year.

Projection of Estimated Savings through the Analysis Period. In order to project the estimated savings through the remainder of the analysis period (FY 2011 – FY 2030), FEMP developed an estimate of the reasonably attainable potential of the Federal sector. The method FEMP used to develop the Federal building retrofit potential is outlined in the next section on technical potential. Using this projection, FEMP calculated the amount of the total potential that is attributable to FEMP (based on FEMP's target), and applied that percentage to the projected estimates to obtain out-year FEMP savings. By using the projected Federal building retrofit potential, FEMP could incorporate future baseline changes in energy use intensity, which affect the level of savings.

FEMP used a weighted average for FY 2007 – FY 2010, equal to the sum of the target savings divided by the sum of the potential savings, as the attribution factor for FY 2011 through FY 2030. **Table I-6** provides the projected savings levels, the target levels, and the attribution percentage.

Table I-6. Development of Out-Year Energy Savings Estimates

Year	Potential Total Site Energy Displaced (TBtu)	FEMP Target, FY 2007 – FY 2010 (TBtu)	Attribution Factor
2007	6.68	1.14	17.08%
2008	13.22	2.28	17.25%
2009	19.63	3.42	17.43%
2010	25.91	4.56	17.60%
2015	50.45		17.42%
2020	65.73		17.42%
2025	80.26		17.42%
2030	94.07		17.42%

FEMP allocated the energy savings into savings by fuel type using historical fuel mix data from the Federal sector along with Energy Information Administration (EIA) forecasts, as outlined in the section, "Fuel Mix" within the Technical Potential section below. Energy savings by fuel type, measured in MMBtu, were converted to alternative units for reporting requirements via the conversion factors listed in **Table I-7**.

Table I-7. Energy Conversion Factors[5]

Fuel Oil: 5.825 MMBtu/barrel
Natural Gas: 1.027 MMBtu/1000 cubic feet
Coal: 22.489 MMBtu/short ton
Electricity: 3.412 MMBtu/MWh
LPG: 3.603 MMBtu/barrel

Energy Savings Results. Estimated annual and cumulative energy savings attributable to FEMP resulting from the FY 2007 Budget Request are summarized in **Table I-8** and **Table I-9**.

Table I-8. Annual Energy Metrics for Federal Standard Buildings and Energy-Intensive Operations (FY 2007 Budget Request)

Year	Total Site Energy Displaced (TBtu)	Direct Electricity Displaced (billion kWh)	Direct Natural Gas Displaced (billion CF)	Direct Petroleum Displaced (million barrels)	Direct Coal Displaced (million short tons)	Direct Biomass Displaced (TBtu)	Direct Energy Displaced from Feedstocks (TBtu)	Direct Energy Displaced from Wastes (TBtu)	Other Direct Energy Displaced (TBtu)
2007	1.140	0.114	0.426	0.014	0.009	0	0	0	0
2008	2.280	0.228	0.817	0.037	0.018	0	0	0	0
2009	3.420	0.345	1.240	0.055	0.027	0	0	0	0
2010	4.560	0.459	1.641	0.080	0.035	0	0	0	0
2015	8.790	0.816	3.378	0.181	0.061	0	0	0	0
2020	11.452	0.995	4.540	0.247	0.080	0	0	0	0
2025	13.984	1.183	5.605	0.311	0.098	0	0	0	0
2030	16.392	1.359	6.679	0.365	0.114	0	0	0	0

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[5] Source: Performance Planning Guidance (GPRA Data Call) FY2004-2008 Budget Cycle-Draft. April 1, 2002. U.S. Department of Energy. Office of Energy Efficiency and Renewable Energy.

Table I-9. Cumulative Energy Metrics for Federal Standard Buildings and Energy-Intensive Operations (FY 2007 Budget Request)

Year	Total Site Energy Displaced (TBtu)	Direct Electricity Displaced (billion kWh)	Direct Natural Gas Displaced (billion CF)	Direct Petroleum Displaced (million barrels)	Direct Coal Displaced (million short tons)	Direct Biomass Displaced (TBtu)	Direct Energy Displaced from Feedstocks (TBtu)	Direct Energy Displaced from Wastes (TBtu)	Other Direct Energy Displaced (TBtu)
2007	1.140	0.114	0.426	0.014	0.009	0	0	0	0
2008	3.432	0.344	1.248	0.052	0.028	0	0	0	0
2009	6.886	0.692	2.501	0.108	0.055	0	0	0	0
2010	11.516	1.159	4.167	0.189	0.090	0	0	0	0
2015	47.779	4.633	17.724	0.920	0.346	0	0	0	0
2020	99.769	9.253	38.086	2.026	0.711	0	0	0	0
2025	164.676	14.785	64.058	3.453	1.165	0	0	0	0
2030	241.867	21.226	95.332	5.172	1.704	0	0	0	0

Technical Potential. FEMP estimated the energy savings to the Federal sector that FEMP expects to be reasonably attainable within the analysis period. FEMP estimated the Federal building retrofit potential as one combined effect in the market, measured in terms of energy use per square foot per year.

Actual historical and estimated future energy consumption are characterized in terms of fuel consumption (million Btu or MMBtu), fuel mix (the fractions of total fuel consumption by fuel type), and building floor space (thousand square feet or ksf). A critical derived figure is building energy intensity (MMBtu/ksf). The development of these measures is described in the sections that follow.

Historical Federal Agency Energy Consumption and Cost. Estimates of future Federal agency energy consumption start from the latest data available for actual energy consumption. For the analysis of impacts resulting from the FY 2007 Budget Request, the latest actual data were for FY 2004. These data were provided by the individual Federal agencies to McNeil Technologies, which has the responsibility for collecting and managing these data for FEMP. These data are eventually documented in the *Annual Report to Congress on Federal Government Energy Management and Conservation Programs*[6] for each fiscal year. As of September 2005, the most recent published version of this report covered fiscal year 2002 and was published September 29, 2004.

The historical data available for analysis are energy consumption (MMBtu) by fuel type and building floor space (ksf). These data are reported by each agency. The fuel type categories are electricity, fuel oil, natural gas, liquefied petroleum gas (lpg), coal, purchased steam, and "other." Building energy intensities (MMBtu/ksf) are calculated from these raw data.

Future Federal Agency Energy Consumption. Future Federal energy consumption was estimated by combining estimates of future building energy intensity, fuel mix, and building

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[6] Available on FEMP's Web site at ***http://www.eere.energy.gov/femp/pdfs/annrep02.pdf***

floor space. Total energy consumption (MMBtu) is the product of building energy intensity (MMBtu/ksf) and building floor space (ksf), as defined by Equation 1. Energy consumption by fuel type (MMBtu) is the product of total energy consumption and fuel-mix fraction for each fuel type, as defined by Equation 2.

$$E = EI_B \times SF_B \qquad \text{Eqn. 1.}$$

$$E_f = E \times F \qquad \text{Eqn. 2.}$$

Where E = total energy consumption (MMBtu)
EI_B = building energy intensity
SF_B = building floor space
E_f = energy consumption by fuel type
F = fuel mix fraction

The Department of Defense (DOD), DOE, General Services Administration (GSA), United States Postal Service (USPS), and Veterans Affairs (VA) were selected for specific metric development because they are the five largest agencies measured by annual energy use, consuming nearly 90% of the Federal total in FY 2004; DOD alone is nearly two-thirds of total Federal energy use (see **Figure I-1**). Reduction in MMBtu/ksf from FY 2003 through FY 2013 was estimated for each of these five agencies and all other agencies (27 total) grouped together for standard buildings. Metrics for energy intensive operations were developed for the Federal government as a whole. The following subsections describe the development of building energy intensity, building floor space, and fuel-mix fraction assumptions. In addition, the resulting estimates of building energy intensity reductions are provided.

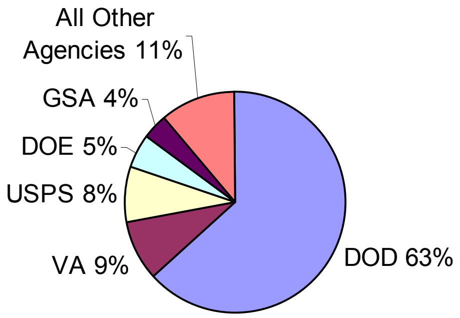

Figure I-1. FY 2004 Federal Agency Standard Building Energy Consumption

Building Energy Intensity. Estimates for agency-specific reductions in MMBtu/ksf by FY 2013 relative to FY 2003 were aggregated from estimates due to a) cost-effective retrofits of building energy systems, b) replacement of equipment upon failure (with generally more efficient equipment), c) cost-effective retrofits of central energy plants and thermal distribution systems (DOD, DOE, and VA only), and d) improvements in O&M practices. These four categories have differing assumptions, and the assumptions for each agency can be different within a particular category. The assumptions are discussed in the text below, and are based on literature referenced in the text. **Table I-10** presents the output estimates of energy intensity reductions derived from the spreadsheet model by category and agency.

Table I-10. Energy Intensity Reduction Estimates

Estimated Reduction in MMBtu/ksf by 2013 from 2003						
	Agency					
Reduction Source	**DOD**	**DOE**	**GSA**	**USPS**	**VA**	**Other**
Building Retrofit	5	8	6	6	6	6
Replace on Failure	4	10	3	3	7	5
CEP and Dist Retrofit	4	4			4	
Improved O&M	3	8	2	2	6	4
Total	16	30	11	11	23	15
FY 2003 MMBtu/ksf	102	238	69	68	186	124

The reduction in MMBtu/ksf from building retrofit was previously based on data developed in two Pacific Northwest National Laboratory (PNNL) reports, *Economic Energy Savings Potential in Federal Buildings,*[7] and *An Assessment of Prospective FORSCOM Energy Intensities.*[8] The former was prepared for FEMP by D. Brown, J. Dirks, and D. Hunt; the latter was prepared for the U.S. Army's Forces Command (FORSCOM) by D. Brown and J. Dirks.

The report for FEMP specifically examined the retrofit potential based on government financing for all government agencies, while the report for FORSCOM examined the retrofit potential for their facilities based on either government or alternative-financing (i.e., private funding) mechanisms.[9] The former report was used as the basis for civilian agencies while the latter was used for the military. The ratio of cost-effective savings found in the FORSCOM report for private and government funding was applied to the civilian results from the FEMP report to estimate civilian agency retrofit potential with private funding. Government-financed retrofit projects were assumed to be minimal, so the private funding potential was used for developing the energy intensity savings estimate. Finally, 50% of the potential was assumed captured over a 10-year period, from 2000 to 2010. This was consistent with the rate of annual alternative-financing investment and the ratio of energy savings per dollar invested from FY 1998 through FY 2000. The report for FORSCOM also looked at the impacts of the natural turnover of HVAC and service hot water (SHW) equipment (called "replace on failure" in **Table I-10**) and improvements to central energy plants (CEPs, i.e., boilers and/or chillers) and thermal-distribution systems.

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[7] D.R. Brown, J.A. Dirks, and D.M. Hunt. 2000. *Economic Energy Savings Potential in Federal Buildings*. PNNL-13332. Pacific Northwest National Laboratory. Richland, Washington.

[8] Distribution of the full report is limited by FORSCOM. The following paper, based on the full report, is publicly available. D.R. Brown and J.A. Dirks. 2002. "Prospective FORSCOM Energy Intensities." *Proceedings of the 25th World Energy Engineering Conference.* Association of Energy Engineers. Atlanta, Georgia.

[9] Alternative financing includes energy-saving performance contracts (ESPC) and utility energy service contracts (UESC).

Battelle, Pacific Northwest Division, and PNNL have since conducted approximately two dozen assessments of energy efficiency retrofit potential at Army facilities.[10] The Army facilities evaluated represent about 9% of total DOD floor space and have a mix of building types generally representative of DOD as a whole. The average retrofit potential via government funding was found to be 14.9 MMBtu/ksf, compared to 21.1 MMBtu/ksf in the prior FORSCOM study. The ratio of energy savings potential for private and government funding averaged 0.76, compared to 0.67 in the FORSCOM study.

The decline in cost-effective retrofit potential from the previous study is believed to be the result of the following three factors.

1. The recent Army results are based on a series of more thorough investigations than the previously cited work done specifically for FORSCOM.
2. Declining building energy intensities generally imply less energy savings potential, following the economic law of diminishing returns.
3. Privately financed projects in the past few years have dropped the Federal building energy intensity by about 3 MMBtu/ksf.

The increase in the ratio of private to government-financed cost-effective retrofit potential is consistent with a greater drop in private real interest rates compared to the government real interest rate. The latter has been limited by statute for the interest rate prescribed for energy projects by NIST to a minimum of 3% even though long-term Treasury bond rates and inflation forecasts suggest a lower real cost of government financing.[11]

Assuming that interest rates rise back toward long-run averages, the prescribed government rate will rise relatively little compared to the private rate. Thus, the cost-effective retrofit potential with government financing will remain the same while the cost-effective potential with private financing will drop. Therefore, the prior (0.67) ratio of private-funded to government-funded retrofit potential was thought to better represent the long-term condition.

The percentage decline in cost-effective retrofit potential collectively found in the more recent Battelle and PNNL studies for the Army was assumed to apply to the civilian agencies too because the latter two of the three explanatory factors cited above apply to both civilian and military agencies. The bottom line result was a 30% reduction in agency energy intensity via cost-effective building retrofits for the period 2004 through 2013 compared to the previous estimates developed for the period 2001 through 2010.

Replacement of HVAC and SHW equipment occurs continuously as equipment ages, fails, and must be replaced. In general, the efficiency of HVAC and SHW equipment has substantially improved because of technology advances, stimulated in part by stricter equipment and appliance standards at the national level. Other factors include building energy codes and the forces of technological innovation. As a result, replacement equipment will usually consume less energy than the equipment being replaced; and, in some cases, much less energy (refrigerators and

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[10] A complete listing of these references is presented at the end of this documentation.

[11] S.K. Fuller and A.S. Rushing. 2005. Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis – April 2005. NISTIR 85-3273-20. National Institute of Standards and Technology. Gaithersburg, MD.

chillers, for example). The estimated energy-intensity reduction from this mechanism was about 4% over a 10-year period in the FORSCOM study; the estimated impact for civilian agencies was judged by FEMP to be the same, since the phenomenon of improving energy efficiency in new equipment and appliances is economy-wide and not restricted to just DOD. More specifically, the estimated impact was judged by FEMP to be similar on a percentage basis (proportional to current energy intensity) rather than similar on a fixed basis (the same MMBtu/ksf impact for all agencies). This latter assumption represents a change from prior year's estimate for this mechanism.

DOD sites often have large central energy plants (CEPs) and accompanying thermal distribution systems. Results from the recent PNNL studies conducted for the Army and cited above indicate a savings potential equivalent to about 8 MMBtu/ksf. Again, it is unlikely that 100% of the potential will be captured. A 50% capture fraction was assumed to be consistent with the building retrofit capture fraction assumption. Among the four civilian agencies considered explicitly, only DOE and VA have a significant number of sites with CEPs, so this projected savings was only applied to these two agencies, in addition to DOD. The estimated energy intensity reduction of 4 MMBtu/ksf is about 50% higher than the previous estimate. The increase can be attributed to consideration of decentralization from central boilers to building-level boilers (eliminating all thermal distribution losses external to a building) as well as improvements in the efficiencies of central boilers and existing thermal distribution systems.

The estimated decrease in MMBtu/ksf from improved O&M practices was previously developed from data presented in *Using Targeted Energy Efficiency Programs to Reduce Peak Electrical Demand and Address Electric System Reliability Problems* by S. Nadel (et al) of American Council for an Energy Efficient Economy (ACEEE); and *Energy and Comfort Benefits of Continuous Commissioning in Buildings* by D. Claridge (et al) of Texas A&M University. Specifically, Nadel estimated cost-effective energy savings via improved O&M practices to be between 5% and 15% of existing energy consumption, with a maximum penetration rate of 50%. A more recent PNNL study[12] conducted for FEMP also concluded that the energy savings potential through improved O&M practices is approximately 10% of existing energy consumption. The authors of the PNNL study agreed that capturing one-third of the O&M potential by 2013 relative to a 2003 baseline were reasonable assumptions. Previously, 25% of the estimated O&M savings potential was assumed captured by 2010 relative to 2000.

The FY 2013 building energy-intensity calculations are defined by Equation 3 for standard buildings. To calculate energy intensity for FY 2013, the estimated reductions in MMBtu/ksf shown in **Table I-10** are subtracted from the actual energy intensities for each agency in FY 2003. Although actual FY 2004 energy consumption data are currently available, the estimated energy intensities for FY 2013 are based on FY 2003 to be consistent with the references (reports for FEMP and the Army described above) supporting the figures in **Table I-10**. As described earlier, the FY 2010 energy intensity for energy-intensive operations was set at the value that exactly meets the energy-intensity goal for these types of facilities.

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[12] W.D. Hunt and G.P. Sullivan. 2002. *Assessing the Potential for a FEMP Operations and Maintenance (O&M) Program to Improve Energy Efficiency*. PNNL-14076. Pacific Northwest National Laboratory. Richland, Washington.

EI_B in FY 2013 = EI_B in FY 2003 – EI_B Reduction Estimate Eqn. 3

Where EI_B = building energy intensity

Energy intensities for years between FY 2004 and FY 2013 were geometrically interpolated between these two endpoints. Energy intensities beyond FY 2013 were assumed to continue declining, with each year 1% less than the previous year. This is a conservative assumption compared to the average compounded rate of decline from 1985 through 2004, which was 1.5%.

Building Floor Space. As Federal floor space is not specifically tracked nor projected by EIA, future Federal building floor space was set equal to the FY 2004 value, i.e. no change in floor space was assumed through FY 2030. Total Federal floor space has been relatively constant since FY 1997 after declining from FY 1985 to FY 1997. The decline through FY 1997 was driven mostly by reductions in DOD. Continued decline in DOD floor space since FY 1997 has been offset by increases in other agencies. Most notably, USPS floor space has increased by 85% from FY 1985 through FY 2004. It is not clear whether an increase or decrease in floor space is more likely during the next 5 years, let alone the next 25 years; therefore, floor space was assumed to remain constant for the duration of the analysis period.

Fuel Mix. Since FY 1985, total site use of coal and fuel oil has declined significantly, while the use of electricity has remained nearly constant and the use of natural gas has declined slightly. As a consequence of these changes, the fractions of fuel use associated with electricity (and to a lesser extent, natural gas) have increased over time (See **Figure I-2**). EIA forecasts from the *Annual Energy Outlook 2005* suggest that this trend will continue, with site use of electricity increasing relative to other energy forms.

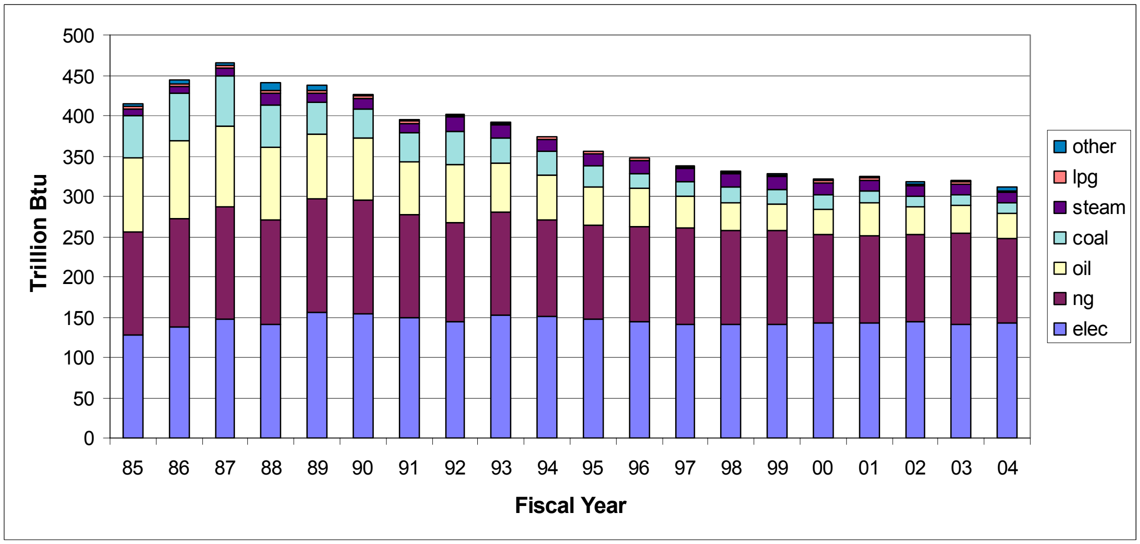

Figure I-2. Historical Energy Use in Standard Federal Buildings

Changes in the forecast fuel mix for the commercial sector from EIA's *Annual Energy Outlook 2005* were applied to the actual Federal fuel mixes in FY 2004 to estimate future federal fuel mixes. Projected changes for the commercial-sector fuel mix were first normalized relative to the existing commercial-sector fuel mix in 2004. For example, the normalized electricity fraction in the commercial sector grew from 1.0 (by definition) in 2004 to 1.17 in 2030. In contrast, the normalized natural gas fraction in the commercial sector fell from 1.0 in 2004 to 0.84 in 2030. The normalized fuel fractions for each fuel and each year were multiplied by the actual Federal fuel fractions in 2004 for each agency or agency group to estimate future Federal fuel mixes.

This procedure was applied to standard buildings, but not to energy-intensive operations. There, it was not so clear what sector (commercial or industrial) would better represent energy-intensive operations or whether the year-to-year volatility in reported data for energy-intensive operations would invalidate the refined approach. Instead, future fuel mixes for energy-intensive operations were assumed to remain as they were in FY 2004.

Federal Agency Energy Consumption Baseline. The estimated FY 2006 Federal agency energy consumption is used as the baseline Federal agency energy consumption. FY 2007 is the first possible year that could be affected by the FY 2007 budget, so FY 2006 is the logical baseline year. As previously described, the latest actual data are from FY 2004. Energy consumption by fuel type is estimated for each year after FY 2004, including the FY 2006 baseline year, via the process described above in the section on Future Federal Agency Energy Consumption.

Future Federal Agency Energy Savings. Annual energy savings were calculated by subtracting the estimated energy consumption in FY 2006 from the estimated energy consumption for FY 2007 and each following year. These calculations were done for each fuel type. Implicitly, if not for activities conducted by FEMP and the Federal agencies, future energy consumption would remain as estimated for FY 2006, and there would be no energy savings. Energy savings were summed across agencies and fuel types to determine total energy savings. Equations 4 through 6 define these calculations.

$$ES_{f,A} \text{ in FY20XX} = E_{f,A} \text{ in FY20XX} - E_{f,A} \text{ in FY2006} \qquad \text{Eqn. 4.}$$

$$ES_{f,F} \text{ in FY20XX} = \Sigma\, ES_{f,A} \text{ in FY20XX} \qquad \text{Eqn. 5.}$$

$$ES_{F} \text{ in FY20XX} = \Sigma\, ES_{f,F} \text{ in FY20XX} \qquad \text{Eqn. 6.}$$

Where $ES_{f,A}$ = energy savings by fuel type and agency
$E_{f,A}$ = energy consumption by fuel type and agency
$ES_{f,F}$ = Federal energy savings by fuel type
ES_{F} = Federal energy savings

The estimated Federal building retrofit potential energy savings are contained in **Table I-6**, in the column titled "Potential Total Site Energy Displaced."

Sources for Building Energy Retrofit Potential

Battelle, Pacific Northwest Division Reports

Brown, D.R., J.A. Dirks, D.L. Hadley, B. Liu, and S.A. Parker. 2004. *Final Assessment Report for Fort Shafter, Hawaii: Western Power Grid Peak Demand and Energy Reduction Program*. PNWD-3412. Battelle—Pacific Northwest Division, Richland, WA.

Brown, D.R., J.A. Dirks, D.L. Hadley, B. Liu, and S.A. Parker. 2004. *Final Assessment Report for Schofield Barracks, Hawaii: Western Power Grid Peak Demand and Energy Reduction Program*. PNWD-3413. Battelle—Pacific Northwest Division, Richland, WA.

Brown, D.R., J.A. Dirks, D.L. Hadley, B. Liu, A.P. Melendez, E.E. Richman, and S.A. Parker. 2003. *Final Assessment Report for Fort Huachuca, Arizona: Western Power Grid Peak Demand and Energy Reduction Program*. PNWD-3411. Battelle—Pacific Northwest Division, Richland, WA.

Dahowski, R.T., D.R. Dixon, D.L. Smith, and S.A. Parker. 2004. *Final Assessment Report for Fort Drum, New York: Western Power Grid Peak Demand and Energy Reduction Program*. PNWD-3368. Battelle—Pacific Northwest Division, Richland, WA.

Hadley, D.L., D.R. Dixon, A.E. Solana, and S.A. Parker. 2004. *Final Assessment Report for Fort Carson, Colorado: Western Power Grid Peak Demand and Energy Reduction Program*. PNWD-3410. Battelle—Pacific Northwest Division, Richland, WA.

Hadley, D.L., B. Liu, J.A. Dirks, and S. A. Parker. 2004. *Final Assessment Report for the Presidio of Monterey, California: Western Power Grid Peak Demand and Energy Reduction Program*. PNWD-3414. Battelle—Pacific Northwest Division, Richland, WA.

Parker, G.B., D.L. Hadley, D.L. Smith, A.E. Solana, and S.A. Parker. 2004. *Final Assessment Report for Sierra Army Depot, California: Western Power Grid Peak Demand and Energy Reduction Program*. PNWD-3417. Battelle—Pacific Northwest Division, Richland, WA.

Parker, G.B., B. Liu, E.E. Richman, A.P. Melendez, and S.A. Parker. 2004. *Final Assessment Report for Parks Reserve Forces Training Area (RFTA), California: Western Power Grid Peak Demand and Energy Reduction Program*. PNWD-3416. Battelle—Pacific Northwest Division, Richland, WA.

Pacific Northwest National Laboratory Reports

Brown, D.R., J.A. Dirks, D.R. Dixon, and G. B. Parker. 2003. *Southeast Region 10-Year Energy Plans; Prospective Energy Savings; Hunter Army Airfield.*_ PNNL-14607. Pacific Northwest National Laboratory. Richland, Washington.

Brown, D.R., J.A. Dirks, D.R. Dixon, and G. B. Parker. 2003. *Southeast Region 10-Year Energy Plans; Prospective Energy Savings; Fort Stewart.* PNNL-14608. Pacific Northwest National Laboratory. Richland, Washington.

Brown, D.R., and J.A. Dirks. 2003. *Southeast Region 10-Year Energy Plans; Prospective Energy Savings; Fort McPherson.*_ PNNL-14606. Pacific Northwest National Laboratory. Richland, Washington.

Brown, D.R., and J.A. Dirks. 2003. *Southeast Region 10-Year Energy Plans; Prospective Energy Savings; Fort Gillem.*_ PNNL-14605. Pacific Northwest National Laboratory. Richland, Washington.

Brown D.R., J.A. Dirks, and R.W. Reilly. 2004. *FORSCOM 10-year Energy Plans - Prospective Energy Savings at Fort Campbell* . PNNL-14598. Pacific Northwest National Laboratory, Richland, WA.

Brown, D.R., J.A. Dirks, and D.R. Dixon. 2005. *Facility Energy Decision System (FEDS) Assessment Report for Anniston Army Depot, Alabama*. PNNL-15216. Pacific Northwest National Laboratory. Richland, WA.

Brown, D.R., J.A. Dirks, and D.R. Dixon. 2005. *Facility Energy Decision System (FEDS) Assessment Report for Fort Bragg, North Carolina*. PNNL-15100. Pacific Northwest National Laboratory. Richland, WA.

Chvala, W.D., B. Liu, D.R. Brown, and D.R. Dixon. 2004. *Facility Energy Decision System (FEDS) Assessment Report for Fort Benning, Georgia*. PNNL-14885. Pacific Northwest National Laboratory. Richland, WA.

Chvala, W.D., A.E. Solana, and D.R. Dixon. 2005. *Facility Energy Decision System (FEDS) Assessment Report for Fort Buchanan, Puerto Rico*. PNNL-15053. Pacific Northwest National Laboratory. Richland, WA.

Chvala, W.D., D.R. Brown, and D.R. Dixon. 2004. *Facility Energy Decision System (FEDS) Assessment Report for Redstone Arsenal, Alabama*. PNNL-14905. Pacific Northwest National Laboratory. Richland, WA.

Hadley, D.L., B. Liu, W.D. Chvala, A.E. Solana, and D.R. Dixon. 2004. *Facility Energy Decision System (FEDS) Assessment Report for Fort Knox, Kentucky.* PNNL-14827. Pacific Northwest National Laboratory. Richland, WA.

Liu, B., G.P. Sullivan, G.B. Parker, E.E. Richman, A.E. Solana, and D.R. Dixon. 2005. Facility Energy Decision System (FEDS) Assessment Report for Military Ocean Terminal (MOT) Sunny Point, North Carolina. PNNL-15090. Pacific Northwest National Laboratory. Richland, WA.

Parker, G.B., A.E. Solana, D.L. Hadley, and D.R. Dixon. 2004. Facility Energy Decision System (FEDS) Assessment Report for Fort Jackson, South Carolina. PNNL-14781. Pacific Northwest National Laboratory. Richland, WA.

Parker, G.B., A.E. Solana, and D.R. Dixon. 2005. Facility Energy Decision System (FEDS) Assessment Report for Blue Grass Army Depot, Kentucky. PNNL-15075. Pacific Northwest National Laboratory. Richland, WA.

Sullivan, G.P., A.E. Solana, E.E. Richman, and D.R. Dixon. 2005. Facility Energy Decision System (FEDS) Assessment Report for Fort Gordon, Georgia. PNNL-15068. Pacific Northwest National Laboratory. Richland, WA.

Appendix J - GPRA07 Weatherization and Intergovernmental Activities Program (WIP) Documentation

Introduction

The Weatherization and Intergovernmental Activities Program (WIP) develops, promotes, and accelerates the adoption of energy efficiency, renewable energy and oil displacement technologies and practices by a wide range of stakeholders. These include State and local governments, weatherization agencies, communities, companies, fleet managers, building code officials, Native American Tribal Governments, and international partners. **Table J-1** outlines the activities characterized for WIP for GPRA07. Characterizations and inputs for these activities were provided to the Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE) as inputs to EERE's integrated modeling effort.

Table J-1. WIP Subprograms, Projects, and Activities

Subprogram	Project	Activity
State Energy Program Grants	State Energy Program Grants	Codes and Standards Energy Audits Rating and Labeling Workshops/Training Incentives Retrofits Loans and Grants Technical Assistance Traffic Signals
Weatherization Assistance Program Grants	Weatherization Assistance	Weatherization Assistance
Intergovernmental Activities	Tribal Energy Activities	Tribal Energy Activities
	International Renewable Energy Program	International Renewable Energy Program

1.0 State Energy Program Grants

Project Description. The State Energy Program provides financial assistance to States, enabling State governments to target their own high priority energy needs and expand clean energy choices for their citizens and businesses. With these funds and the resources leveraged by them, the State and Territory Energy Offices develop and manage a variety of programs geared to increase energy efficiency, reduce energy use and costs, develop alternative energy and renewable energy sources, promote environmentally conscious economic development, and reduce reliance on imported oil.

1.1 State Energy Program Grants

1.1.1 Significant Changes from FY06

Inputs for the State Energy Program Grants were updated, based on more recent and more complete information. The FY06 inputs were derived from the 2003 report, *Estimating Energy and Cost Savings and Emissions Reductions for the State Energy Program Based on Enumeration Indicators Data*;(1) the updated inputs are based on the 2005 report, *An Evaluation of State Energy Program Accomplishments: 2002 Program Year*.(2) For this report, all states and territories were contacted by the SEP program and asked to provide counts of specified SEP activities that were performed during the 2002 program year. All 50 states and four of five territories provided information for activities that used SEP funds. For FY07, the WIP program added a new project area, Traffic Signals, to the analysis.

1.1.2 Target Market

Market Description. The market includes all markets (including buildings, transportation, industry, and power technologies), except new construction and all categories of energy end use.

Baseline Technology Improvements. There are no technology improvements assumed apart from what appears in the Energy Information Administration (EIA) baseline.

1.1.3 Methodology and Calculations

Inputs to Base Case. The WIP program did not provide inputs to change the base case assumptions for the program markets. The WIP program's calculations were based on a baseline that was developed from the Energy Information Administration's (EIA's) Commercial Buildings Energy Consumption Survey (CBECS), Residential Energy Consumption Survey (RECS), and the Annual Energy Outlook (AEO).

Technical Characteristics. For the FY07 GPRA metrics, the State Energy Program (SEP) was characterized based on the budget request and leveraged funds. Based on the report, *An Evaluation of State Energy Program Accomplishments: 2002 Program Year* (Schweitzer and Tonn 2005),(2) nine activities (referred to in the report as project areas) supported by SEP were selected to represent the project. These activities—Codes and Standards, Energy Audits, Rating and Labeling, Workshops/Training, Incentives, Retrofits, Loans and Grants, Technical Assistance, and Traffic Signals—comprised approximately 90% of the total estimated energy savings reported.

In previous years, the SEP has administered funds on behalf of other EERE projects, through "Special Projects" funds. The WIP program has assumed that the energy savings resulting from these funds were captured in the originating project (the project that provided the funding). For FY07, funds previously budgeted through Special Project funds became part of SEP. The WIP program assumed that this new funding would be administered to project areas based on the historical percentages reported in Schweitzer and Tonn. A key assumption in the program's methodology is that benefits are directly proportional to funds expended.

Codes and Standards. The purpose of the SEP Codes and Standards activity is to encourage the adoption of building codes and standards through training and implementation activities. Data was collected on three separate metrics related to building codes: name of new energy-efficiency building code adopted; name of old energy-efficiency building code replaced; and percentage of new construction in state covered by the new code.(2) The information provided by the states on all three metrics combined was used to calculate energy savings achieved by code activity.(2) For consistency, the WIP program based the estimated savings of the Codes and Standards activities funded by the SEP on the savings estimates produced for the Residential and Commercial Energy Codes projects within the Office of Building Technologies (BT). Historically, Codes and Standards activities accounted for almost 19% of SEP funding.(1) Based on the FY 2006 budget request, this would have equated to approximately $7.7 million; with the inclusion of the former Special Projects money (of about $19 million for FY07), the budget for codes and standards would be anticipated to be about $11.3 million, an increase of about $3.6 million. The WIP program assumes that this increase in budget corresponds to an allocation of about 50% of the estimated energy savings for Codes and Standards training/implementation activities.

Energy Audits. The purpose of the SEP Energy Audits activity is to perform energy audits. Energy-audit calculations were based on three indicators: number of audits, square feet retrofit, and reported savings. (2) For this effort, the WIP program converted these three indicators to number of households and square footage of commercial floor space impacted.

The WIP program assumed a savings per audit of 21.7 MMBtu per household and 0.0167 MMBtu per square foot of commercial floor space. (2) The per-unit energy savings estimate for residential retrofits listed in the "An Evaluation of State Energy Program Accomplishments: 2002 Program Year" report (43.3 million source Btu per project) provides the base for the estimate of savings associated with energy audits in the residential sector. An adjustment factor of 0.50 was applied to the retrofit number, based on the conservative assumption that only half of the recommended measures would be installed. Based on Tables 1.2.3 and 1.2.4 of the *Buildings Energy Databook,*(2) approximately 84 MMBtu/HH/yr are used by residential space heating and space cooling, yielding a load reduction attributable to the audits of 26% for residential space heating and cooling. Based on Tables 1.3.3 and 1.3.4 of the *Buildings Energy Databook*, approximately 121 kBtu/SF/yr are used by commercial space heating, space cooling, and lighting, yielding a load reduction attributable to the audits of 14% for commercial space heating, space cooling, and lighting.

States reported to the WIP program a total of 581 residential audits performed, 1,878,809 residential square feet retrofit, and 139,851 MMBtu projected residential source savings. To convert the residential indicators into an estimated number of households, the WIP program assumed that each residential audit represented one household, divided the total residential square feet retrofit by 1,707, which is the average heated square footage for all residential units in the United States from the *2001 Residential Energy Consumption Survey*, and divided the estimated reported annual savings by the 21.7 MMBtu/HH figure.(2) This yielded an estimate of approximately 8,100 households impacted by energy audits in any given year.

In the categories of commercial, industrial, and institutional, States reported to the WIP program a total of 35 audits performed, 67,976,934 square feet retrofit, and 17,551,878 MMBtu projected source savings. To convert the commercial/industrial/institutional indicators into an estimated commercial square footage, the WIP program assumed that each commercial audit represented one building multiplied by 14,500 square feet, which is the average building size taken from the *1999 Commercial Building Energy Consumption Survey*, used the square footage reported, and divided the estimated annual savings by the 0.0167 MMBtu/SF figure.(2) This yielded an estimate of approximately 1.1 billion square feet impacted by energy audits in any given year, or 1.6% of existing commercial floor space, in each year.

The WIP program assumed that the number of energy audits performed would be in direct proportion to the funds available for energy audits. Therefore, the estimated penetration was adjusted upward by 46% to reflect the additional funds from the Special Projects monies that would be funded through SEP in FY07.

Rating and Labeling. The energy savings in this project area describe the amount of energy saved (statewide) as a result of a state’s endorsement of rating and labeling systems for up to 15 different types of energy consuming devices. Because the Energy Star program is the biggest and most successful rating and labeling program operating at this time, and many states use SEP funds to encourage participation in the Energy Star program, savings associated with the Energy Star program were used to represent the savings achieved by all state rating and labeling efforts. The difference in annual energy use between an Energy Star unit and a typical unit for each type of device was identified.(2) The national savings for each type of energy-consuming device was adjusted downward by multiplying by an “attribution factor” of 0.10, which approximates the proportion of Energy Star purchases made as a result of state encouragement.(6) **Table J-2** contains the estimated energy savings from rating and labeling.

Table J-2. Estimated Energy Savings from Rating and Labeling(2)

Device	Energy Star savings per unit (MMBtu source)	Number of Energy Star units sold in U.S., 2002	National Savings, 2002 (MMBtu source)	Adjusted national savings (using 0.10 "attribution factors" (MMBtu source)
Office Computer/Monitor	2.938	22,941,000	67,400,658	6,740,066
Home Computer/Monitor	0.853	11,402,000	9,725,906	972,591
Fax Machine	1.801	2,271,000	4,090,071	409,007
Copier	3.033	209,000	633,897	63,390
Multi-function Device	6.540	1,338,000	8,750,520	875,052
Scanner	2.654	6,810,000	18,073,740	1,807,374
Printer	2.085	7,369,000	15,364,365	1,536,437
TV	0.360	10,446,000	3,760,560	376,056
VCR	0.171	12,028,000	2,056,788	205,679
TV/VCR	0.332	4,643,000	1,541,476	154,148
Audio Equipment	0.171	3,687,000	630,477	63,048
Room AC	0.663	2,195,000	1,455,285	145,529
Dishwasher	0.569	2,262,000	1,287,078	128,708
Refrigerator	1.137	1,956,000	2,223,972	222,397
Clothes Washer	2.464	1,224,000	3,015,936	301,594
Average Savings per Device				933,405

The WIP program used a national per-device estimate for rating and labeling of approximately 933,400 MMBtu per year. (2) While Schweitzer and Tonn allocated these savings to states (based on population) to determine an estimate of savings for states reporting estimates, the WIP program allocated the device savings equally across all states, because no forecast is available for determining which states would fund rating and labeling projects in the future. The equivalent savings per state is about 18,670 MMBtu per device (the national estimate divided by 50).

In 2002, seven states were promoting Energy Star; and 15 widely used energy-consuming devices were characterized in terms of their energy savings.(2) While data underlying the Schweitzer and Tonn report indicate that the seven states make up an average of only 7.7% of sales of the profiled devices, the Energy Star Web site states that more than 40 devices are labeled. There is no forecast available as to which of these 40 devices would be promoted as a result of a state's endorsement of rating and labeling systems, Therefore, while savings per device (for states participating in 2002) are overstated using the averaging methodology that the WIP program used, potential savings from the other 25 labeled devices are not included. The WIP program assumed that the average energy savings are therefore representative of the total potential rating/labeling package. To reflect the additional funds from the Special Projects monies that would be funded through SEP in FY07, the WIP program assumed that 10 states (instead of the reported seven) would provide rating and labeling support in any given year, covering a total of 150 devices (10 × 15). The WIP program assumed that the savings would be effective for 15 years, and that they were attributable to electricity.

Workshops/Training. The purpose of this SEP activity is to promote energy-efficiency measures through workshops and training. The approach to developing a residential sector energy-savings multiplier was to select a package of four common energy-conservation measures that could easily be taught in workshops and training sessions. Consequently, the WIP program modeled the residential training measures as air infiltration sealing, resetting water heater thermostats, attic insulation, and CFLs; and assumed that the average annual savings per household for these four measures was 28.7 source MMBtu, which was derived from the impacts of these measures in four representative cities (Schenectady, New York; Birmingham, Alabama; Moline, Illinois; and Eureka, California) using the *Home Energy Saver* System,[a] a Web-based energy audit system, which is driven by the DOE-2 building simulation program. (2) The WIP program assumed that 3.4 MMBtu of those savings resulted from CFLs; 5.5 MMBtu resulted from resetting water heater thermostats; and that the rest was attributable to space conditioning. (5) Based on the *Building Energy Databook*, (3) Tables 1.2.4 and 1.2.3, total primary household consumption for 2005 is 191.4 MMBtu/HH: 44.1% (or 84.4 MMBtu) is space conditioning, 12.7% (or 24.3 MMBtu) is water heating, and 11.8% (or 22.6 MMBtu) is lighting. Therefore, the estimated savings resulting from residential workshops and training are 23.4% space-conditioning savings, 22.6% water heating savings, and 15% lighting savings. The WIP program assumed that 20% of attendees would implement the measures, based on the findings from three recent studies, (7, 8, 9) and that the average attendee would influence 1.75 homes based on U.S Census Bureau residential construction numbers and conservative estimates formulated in the Schweitzer and Tonn report. (2) There were approximately 49,000 residential workshop attendees in 2002, (2) so the WIP program assumed that this number would continue, resulting in residential workshops/training impacting approximately 17,150 existing residential households, or 0.02% of existing residential homes per year.

Schweitzer and Tonn provided an estimate for both commercial and institutional buildings. Because the savings coefficients reported for commercial (156.8 MMBtu/attendee) and institutional (151 MMBtu/attendee) were within 5% of each other, the two were modeled together by the WIP program. The WIP program assumed estimated commercial savings of 5.25% for HVAC measures and 3.2% for lighting measures based on two reports(10, 11) that identified the percent energy savings possible from HVAC and lighting retrofits in large and small office buildings. (2) Because the buildings evaluated in those reports were selected for their unusually high savings opportunities, the reported savings were divided in half to better represent the potential savings achievable in more typical office buildings, and were then further adjusted by multiplying by an installation rate of 0.20 to reflect the finding noted above, that roughly 20% of workshop attendees implement the measures. The WIP program assumed that HVAC savings equate to both space heating and space cooling. The WIP program used a weighted median number of buildings influenced by each trainee as four buildings per trainee[b]. The total number of attendees in 2002 that had training for commercial

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[a] Accessible at http://hes.lbl.gov/

[b] U.S. Census Bureau 1997 indicates that the average residential construction firm builds an average of eight new homes per year. Schweitzer and Tonn applied the conservative assumption that a residential retrofitter will work on approximately 50% of the mean number of homes constructed annually by firms engaged in new construction

buildings was 19,000 and institutional was 25,000. (2) This is equivalent to 176,000 buildings impacted. The WIP program assumed the average square feet per commercial building is 14,500, based on the *1999 Commercial Buildings Energy Consumption Survey*,(2) so commercial and institutional workshops/training impacts about 0.51 billion square feet of existing commercial floorspace, or 0.74% of existing commercial floorspace per year.

The WIP program assumed that the number of workshops/training sessions performed would be in direct proportion to the funds available for workshops and training. Therefore, the estimated penetration was adjusted upward by 46% to reflect the additional funds from the Special Projects monies that would be funded through SEP in FY07.

Technical Assistance. The WIP program assumed that technical assistance is credited with half the implementation of workshops, and half the savings achieved by workshop attendees (see discussion above for derivation of savings estimates). (2) Because the WIP program assumed that technical assistance savings were half the savings of workshops, (2) the estimated savings resulting from residential technical assistance are 11.7% space-conditioning savings, 11.3% water heating savings, and 7.5% lighting savings. The WIP program assumed that 10% of attendees would implement the measures. (2) This implementation rate is half that of the rate used for workshops and training, based on the assumption that the implementation rate would be substantially lower than workshops and training sessions because technical assistance is less intensive and personal interaction is more limited, providing less detailed instruction, and would therefore be expected to be less motivational. There were approximately 297,350 contacts for residential technical assistance in 2002, (2) so residential technical assistance impacts approximately 29,735 existing residential households, or 0.04% of existing residential homes per year.

Because the WIP program assumed that technical-assistance commercial building savings would be half the savings of workshops, (2) this yielded estimated savings of 2.63% in space conditioning and 1.6% in lighting. The WIP program assumed that HVAC savings equate to both space heating and space cooling. The WIP program assumed that 10% of attendees would implement the measures. (2) The total number of technical assistance contacts in 2002 for commercial buildings was 67,000. (2) The WIP program assumed the average square feet per commercial building is 14,500, from the *1999 Commercial Buildings Energy Consumption Survey*, (2) so commercial and institutional workshops/training impacts about 0.19 billion square feet of existing commercial floorspace, or 0.28% of existing commercial floorspace per year.

The WIP program assumed that the amount of technical assistance provided would be in direct proportion to the funds available for technical assistance. Therefore, the estimated penetration was adjusted upward by 46% to reflect the additional funds from the Special Projects monies that would be funded through SEP in FY07.

Financial Incentives. The purpose of this SEP activity is to provide financial incentives (or rebates) to encourage the installation of energy-efficient equipment. Defensible study results were cited on rebate payments and the associated energy savings for four programs: Anaheim Public Utilities Energy Efficiency Incentives Program, Pacific Gas and Electric (PG&E) Single Family Homes Energy Efficiency Rebate Program, Pacific Gas and Electric Multifamily Energy Efficiency Rebate Program, and Pacific Gas and Electric Express Efficiency Program.(2) These program results provide the basis for assumptions made by sector. The WIP program assumed the estimates of savings per rebate dollar by sector as reported in **Table J-3**. (2) The residential sector estimate is a simple average of the Anaheim, PG&E Single Family, and PG&E Multifamily programs. The commercial-, industrial-, and institutional-sector estimates are a simple average of the Anaheim and PG&E Express Efficiency programs. The agricultural-sector estimate was taken from the PG&E Express Efficiency program.

In 2002, incentive funding of $34.7 million ($0.56 million of SEP funds and $34.1 million in leveraged funds) provided for $21.5 million worth of rebates. (2) The WIP program therefore assumed that SEP leverages $60.87 for each program dollar, and that each dollar of total funding provides $0.62 in rebates. Incentive funding as a percent of total SEP funding reported for all project areas was 1.3% in 2002. (2) The WIP program assumed that this percentage would apply to FY07. The WIP program assumed that leveraged dollars per SEP dollar for incentives was $60.87. (2) Based on the FY 2007 request, the WIP program assumed that approximately $48.2 million dollars (from both SEP and leveraged funds) would be spent on incentive activities, equating to about $29.9 million in rebates. Using the rebate dollar amounts by sector from Schweitzer and Tonn's underlying data, the percentage of the total rebate package per sector was calculated (see **Table J-3**) to determine the proportion of each sector's savings, yielding a total annual savings of about 1.6 TBtu [(78.6% x $29.9M x 0.0281) + (14.9% x $29.9M x 0.1558) + (3.1% x $29.9M x 0.1558) + (2.8% x $29.9M x 0.1558) + (0.5% x $29.9M x 0.1455)]. The WIP program assumed that the savings would be in effect for 15 years.

Table J-3. Percentage of Total Rebate Amount and Savings per Rebate Dollar by Sector

	Residential	Commercial	Industrial	Institutional	Agriculture
% of rebate	78.6%	14.9%	3.1%	2.8%	0.5%
MMBtu/$ rebate	0.0281	0.1558	0.1558	0.1558	0.1455

Retrofits. Energy-savings estimates for retrofits were reported in residential and commercial structures, schools, health-care facilities, government buildings, and industrial applications.(2) Retrofit calculations were based on two indicators: number of retrofits and square feet retrofit. (2) For this effort, the WIP program converted these two indicators to number of households and square feet of commercial floor space impacted.

The WIP program assumed a savings per retrofit of 43.4 MMBtu per household based on an unweighted, nationwide average energy savings for the residential sector. This number was based on primary energy savings per house from residential retrofits for four regions of the country, as developed for the Weatherization Assistance Program.(5) The WIP program assumed a savings per retrofit of 18.8% per square foot of commercial floor space. This number was based on the average savings in retrofits in commercial buildings reported in two studies.(12, 13) The WIP program also applied the commercial number to schools and hospitals. (2) Based on Tables 1.2.3 and 1.2.4 of the *Buildings Energy Databook,* approximately 84 MMBtu/HH/yr are used by residential space heating and space cooling, yielding a load reduction of 54% for residential space heating and cooling. The WIP program applied the 18.8% savings to commercial space heating, space cooling, and lighting.

States reported to the WIP program a total of 683 residential building retrofits and 49.7 million square feet of residential floor-space retrofit. To convert the residential indicators into an estimated number of households, the WIP program assumed that each residential retrofit represented one household, and divided the total residential square feet retrofit by the average square feet per household (1,707, which is the average heated square footage for all residential units in the United States from the *2001 Residential Energy Consumption Survey*). This yielded an estimate of approximately 29,800 households impacted by retrofits in any given year, or 0.067% of existing residential single-family buildings in each year.

States reported to the WIP program a total of 92 commercial/industrial/institutional building retrofits and 206.8 million square feet of commercial/industrial/institutional floor-space retrofit. To convert the indicators into an estimated commercial square footage, the WIP program assumed that each commercial retrofit represented one building multiplied by the average building size (14,500 square feet, from the *1999 Commercial Buildings Energy Consumption Survey*) and used the square footage reported. This yielded an estimate of approximately 0.021 billion square feet impacted by retrofits in any given year, or 0.302% of existing commercial floor space in each year.

The WIP program assumed that the number of retrofits performed would be in direct proportion to the funds available for retrofits. Therefore, the estimated penetration was adjusted upward by 46% to reflect the additional funds from the Special Projects monies that would be funded through SEP in FY07.

<u>Loans and Grants.</u> The WIP program found defensible study results on the amount of loans provided and estimated energy savings associated with those loans for the following three programs: Oregon Low-Interest Loan Program, Texas LoanStar Program, and Nebraska Dollar and Energy Savings Loan Program.(2) The WIP program also found defensible study results on the amount of grants provided and energy savings associated with those grants for the following five programs: Illinois Energy Efficient Affordable Housing Program, California Grants, Louisiana Institutional Conservation Program, Wisconsin Farm Save Energy Project, and New York State Variable Speed Drive

Program.(2) The WIP program assumed the estimates of savings per loan/grant by sector, as reported in **Table J-4**. (2) Because the estimates of savings resulting from loans are more conservative than the estimates of savings from grants, the savings from loans were used to represent the total loan and grant activity. The residential-sector estimate is a simple average of the Oregon and Nebraska programs. The commercial-sector estimate is a simple average of the Oregon, Texas, and Nebraska programs. The industrial-, and institutional-sector estimates are a simple average of the Oregon and Texas programs. The agricultural-sector estimate was based on the an average of the Wisconsin Farm Save Energy Project and New York State Variable Speed Drive Program, adjusted by the average ratio of loan to grant coefficients in all other sectors.

Loan/grant funding as a percent of total SEP funding reported for all project areas was 16.2% in 2002. (2) The WIP program assumed that this percentage would apply to FY07. In 2002, leveraged dollars per SEP dollar for loans/grants was $10.65. (2) Based on the FY 2007 request, the WIP program assumed that approximately $113.2 million dollars (from both SEP and leveraged funds) would be spent on loan/grant activities. Using the loan/grant dollar amounts by sector from Schweitzer and Tonn's underlying data, the percentage of the total loan/grant package per sector was calculated (see **Table J-4**) to determine the proportion of each sector's savings, yielding a total annual savings of about 1.9 TBtu [(22.9% x $113.2M x 0.0148) + (9.1% x $113.2M x 0.0148) + (3.4% x $113.2M x 0.0178) + (63.3% x $113.2M x 0.0178) + (1.2% x $113.2M x 0.0161)]. The WIP program assumed that the savings would be in effect for 15 years.

Table J-4. Percentage of Total Loan/Grant Amount and Savings per Loan/Grant Dollar by Sector

	Residential	Commercial	Industrial	Institutional	Agriculture
% of loan	22.9%	9.1%	3.4%	63.3%	1.2%
MMBtu/$ loan	0.0148	0.0148	0.0178	0.0178	0.0161

Traffic Signals. The WIP program assumed that incandescent bulbs used in traffic signals would be replaced with LEDs. (2) The average traffic light serviced would save 793.9 kWh or 8.64 million source Btu per year, and the total number of traffic signals replaced in 2002 was 94,824. (2) The WIP program assumed that this number would be replaced in FY07. The WIP program also assumed that the savings would be in effect for 15 years.

The WIP program assumed that the number of traffic signals replaced would be in direct proportion to the funds available for signal replacement. Therefore, the estimated penetration was adjusted upward by 46% to reflect the additional funds from the Special Projects monies that would be funded through SEP in FY07.

1.1.4 Sources

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(2) Schweitzer, M, and B. Tonn. June 2005. *An Evaluation of State Energy Program Accomplishments: 2002 Program Year.* ORNL/CON-492, Oak Ridge National Laboratory, Oak Ridge, TN.

(3) *2005 Buildings Energy Databook*. http://www.buildingsdatabook.eren.doe.gov.

(4) Elliott, D.B., D.M. Anderson, D.B. Belzer, K.A. Cort, J.A. Dirks, D.J. Hostick. 2004. *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort*. PNNL-14697. Pacific Northwest National Laboratory, Richland, Washington.

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(7) Reed, J.M., M. O'Drain, and J. Chace, 1999. "Transforming Markets Through Educational Information: A Study of the Pacific Energy Center," *1999 International Energy Program Evaluation Conference*, Denver, CO, August 18-20.

(8) Peters, J.S. and M.R. McRae, 2001. *Market Progress Evaluation Report, Architecture + Energy Program, Final Report*, Report #E01-084, Northwest Energy Efficiency Allowance, Portland, Oregon, June.

(9) Tools of Change, 2004. *Whitney Public School Case Study*, www.toolsofchange.com

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(11) Abraham, M. and J. MacDonald, 1995. *Energy and Conservation Opportunities in Small Commercial Buildings*, ORNL/CON-414, Oak Ridge National Laboratory, Oak Ridge, TN, August.

(12) Greely, K., J. Harris, and A. Hatcher, 1990. "Measured Energy Savings and Cost-Effectiveness of Conservation Retrofits in Commercial Buildings," *ACEEE 1990 Summer Study on Energy Efficiency in Buildings*, American Council for an Energy-Efficient Economy, Washington, DC.

(13) Coates, B., 1995. "Persistence of Energy Savings in Commercial Buildings," *1995 Energy Program Evaluation Conference*, 649-655, Chicago, IL.

2.0 Weatherization Assistance Grants

Project Description. The Weatherization Assistance Project provides cost-effective energy-efficiency services to low-income households that otherwise could not afford the investment, but would benefit significantly from the cost savings of energy efficiency technologies. The project focuses on households that spend a disproportionate amount of their income for energy, giving priority to households with elderly members, persons with disabilities, and children.

Weatherization Assistance provides technical assistance and formula grants to State and local weatherization agencies throughout the United States. A network of approximately 970 local agencies provide trained crews to perform weatherization services for eligible low-income households in single-family homes, multifamily dwellings, and mobile homes. Of the homes weatherized annually, 49% are occupied by an elderly person with special needs. or a person with disabilities. All homes receive a comprehensive energy audit, which is a computerized assessment of a home's energy use and an analysis of which energy-conservation measures are best for the home—and a combination of those energy-saving measures are installed.

2.1 Weatherization Assistance

2.1.1 Significant changes from FY06

No significant changes were made to this program for the FY07 effort.

2.1.2 Target Market

Market Description. The market includes households that are eligible for Federal assistance. Households are categorized as eligible for federal assistance if the household income is below the federal maximum standard of 150% of the poverty line or 60% of Statewide median income, whichever is higher. Individual States can also set the standard at a lower level than the federal maximum.[c] Target measures include air sealing; caulking and weather stripping; furnace and boiler tune-up, repair, and replacement; cooling system tune-up and repair; replacement of windows and doors; addition of storm windows and doors; insulation of building shells; and replacement of air conditioners, whole-house fans, evaporative coolers, screening, and window films.(2) Weatherization *Plus* expands this strategy to include water heating, refrigeration, lighting, and cooling.(1)

Size of Market. About 34 million eligible low-income homes are included in the market.

Baseline Technology Improvements. There are no technology improvements assumed apart from what appears in the Energy Information Administration (EIA) baseline.

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[c] Eligibility requirements for Weatherization Assistance can be found at http://www.eere.energy.gov/weatherization/apply.html

2.1.3 Key Factors in Shaping Market Adoption of EERE Technologies

Price. The WIP program employed the average household weatherization cost of \$1,830;(6) this estimate does not include training, technical assistance, and administrative costs. Incremental investment beyond this amount for Weatherization *Plus* homes, estimated at an average of \$1,400 by the Weatherization project,(6) was assumed by the Weatherization Assistance Program to be provided by leveraging funds from other organizations. **Table J-5** shows the estimated total costs by region for *Plus* homes.

Table J-5. Estimated Regional Costs for Weatherization *Plus* Homes

Region	Cost per "*Plus*"Household
South	\$2861
Northeast	\$3674
West	\$1814
Midwest	\$3429

2.1.4 Methodology and Calculations

Inputs to Base Case. The WIP program did not provide inputs to change the base case assumptions for the program markets. The WIP program's calculations were based on a baseline that was developed from the Energy Information Administration's (EIA's) Commercial Buildings Energy Consumption Survey (CBECS), Residential Energy Consumption Survey (RECS), and the *Annual Energy Outlook* (AEO). For more information about the methodology used by the WIP program, see *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort* (2004)(7).

Technical Characteristics. This project was characterized based on an estimated level of savings per household, cost to weatherize each household, budget request, leveraged funds, and an assumed life expectancy of 15 years for weatherization measures. The basic assumptions were derived from a spreadsheet provided by the Weatherization project in September 2001.(6)

Table J-6 shows the savings per household used for each region.

Table J-6. Savings Per Household for the Weatherization Assistance Project

Region	Regular Household Savings (MMBtu/yr)	*"Plus"* Household Savings (MMBtu/yr)
South	22.25	24.23
Northeast	31.20	46.04
West	19.04	20.31
Midwest	31.20	49.21

The figures in the table were calculated based on the 1997 ORNL meta-evaluation report,(2) the ORNL *Meeting the Challenge* report,(3) and special tabulations from the 1997 "Residential Energy Consumption Survey."(4)

Of the units weatherized in FY 2007, nearly 50% were assumed by the Weatherization Project(3) to have the higher savings rates associated with Weatherization *Plus*. In the *Meeting The Challenge* report,(3) these savings rates were calculated on a regional basis and multiplied by the expected number of *Plus* households in each region.

To develop energy savings by building type, the WIP program evaluated historical Weatherization project data in the 1997 ORNL report(2) concerning the types of households weatherized (see **Table J-7**).

Table J-7. Percent of Weatherized Households by Type

Household Type	% of Weatherized Households
Single Family	64.0%
Mobile Home	20.0%
Multi Family	16.0%

To develop energy savings by fuel type, the WIP program also used the historical primary fuel Weatherization project data in the 1997 ORNL report.(2) Because the GPRA metrics are reported for electricity, natural gas, and fuel oil (but not for LPG and kerosene), other fuels were allocated within those types based on similarities of emissions. **Table J-8** shows the allocation approaches used.

Table J-8. Percent of Weatherized Households by Fuel Type

Primary Heating Fuel	% of Weatherized Households	Categorized As
Natural Gas	50.6	Natural Gas
Liquid Propane Gas	13.2	
Fuel Oil	16.0	Fuel Oil
Kerosene	3.2	
Other (includes wood and coal)	7.5	
Electricity	9.5	Electricity

The Department of Energy (DOE) budget and leveraged funding forecasts were used to determine the number of households weatherized in each category (regular or *Plus*) for each of the four regions (South, Northeast, West, and Midwest) based on the weatherization costs per household and assumptions regarding the use of leveraged funds. **Table J-9** shows the projection for regular and *Plus* households to be weatherized. The WIP program assumed that the number of households weatherized for each category would be constant from 2011 through 2030.

Table J-9. Projected Regular and *Plus* Households to be Weatherized

	2007	2008	2009	2010	2011
Total Households	188,286	186,942	185,618	184,267	182,983
Regular South	18,907	18,758	18,610	18,460	18,318
Regular Northeast	22,524	22,355	22,189	22,020	21,860
Regular West	24,758	24,661	24,567	24,470	24,378
Regular Midwest	27,955	27,697	27,442	27,183	26,936
Plus South	18,907	18,758	18,610	18,460	18,318
Plus Northeast	22,524	22,355	22,189	22,020	21,860
Plus West	24,758	24,661	24,567	24,470	24,378
Plus Midwest	27,955	27,697	27,442	27,183	26,936

The number of households in each category was multiplied by the estimated savings level for each category. The estimated savings level for each household category was further divided by household type and then by fuel type. The WIP program assumed that savings from each household weatherized would last for 15 years; i.e. savings from households weatherized in 2007 were included in the annual total savings estimates for the years 2007 through 2021.

2.1.5 Sources

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(2) Berry, L.G., M.A. Brown, and L.F. Kinney. 1997. *Progress Report of the National Weatherization Assistance Program*, ORNL/CON-450, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

(3) Schweitzer, M. and J.F. Eisenberg. 2000. *Meeting The Challenge: The Prospect of Achieving 30 Percent Energy Savings Through the Weatherization Assistance Program*. ORNL/CON 479, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

(4) Eisenberg, J.F., Oak Ridge National Laboratory. 2001. Special tabulations for the Weatherization Population derived from the 1997 Residential Energy Consumption Survey.

(5) Brown, M.A., L.G. Bery, R.A. Balzer, and E. Faby. 1993. *National Impacts of the Weatherization Assistance Program in Single-Family and Small Multifamily Dwellings*. ORNL/CON-326, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

(6) Eisenberg, J.F., Oak Ridge National Laboratory. 2001. Projections for the Weatherization Assistance Program, provided to the WIP program in file "Projections02d230.xls."

(7) Elliott, D.B., D.M. Anderson, D.B. Belzer, K.A. Cort, J.A. Dirks, D.J. Hostick. 2004. *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort*. PNNL-14697. Pacific Northwest National Laboratory, Richland, Washington.

3.0 Intergovernmental Activities

The Intergovernmental Activities promote the market transfer of clean energy innovations for sustainable development, trade, security, environment, and climate.

3.1 Tribal Energy Activities

Tribal Energy Activities builds partnerships with Tribal governments to help assess Native American energy needs for residential, commercial, and industrial uses. Additionally, it provides technical and financial assistance in energy efficiency and renewable energy project development. Energy projects are competitively awarded on a cost-shard basis for Native American Tribes to implement comprehensive energy plans.

3.1.1 Significant changes from FY06

This program was not modeled for GPRA benefits prior to the FY07 budget. The WIP program has not characterized this program in the past, because when viewed in the context of national-level energy supply or consumption, the Tribal Energy Program (TEP) would not be expected to either generate or save an amount of energy that would appear in the significant digits of a national number. However, for the sake of completeness, the WIP program characterized this program for the FY07 budget.

3.1.2 Target Market

Target market description. DOE provides enabling funding for tribes to conduct renewables feasibility studies and energy plans, which may lead to actual supply development projects—also funded in part by DOE. The program has the goal of 1 GW of renewables capacity development in Indian Country by 2012 (TEP 2004). The program also funds the development of off-grid solar electrification of reservation households.

Baseline technology improvements. The stated (TEP 2005a) goal of the program is to promote tribal energy sufficiency, economic development and employment on tribal lands through the use of renewable energy and energy efficiency technologies. The TEP offers financial and technical assistance to tribes through government-to-government partnerships that:

1) Allow tribal leaders to make informed decisions;
2) Bring renewable energy and energy efficiency options to Indian Country;
3) Enhance human capacity through education and training;
4) Improve local tribal economies and the environment; and
5) Make a difference in the quality of life of Native Americans.

The program seeks to increase development of renewable energy supply. In 2003, the National Renewable Energy Laboratory (NREL) collaborated with the Bureau of Land Management to assess the public lands renewable resource potential (DOE/DOE 2003).

This information informs the planning of the Tribal Energy Program. The program will proceed with central station development of wind resources, followed by biomass resources. Biomass was found to show the most potential for central station development on tribal lands; and, thus, would be expected to reach an assumed parity with wind development in terms of capacity additions (TEP 2005b).

Baseline market acceptance. The WIP program attributed the estimated outcome entirely to the success of this program. However, in many cases, the program funds are leveraged with many other sources such as tribal, State, other Federal, and local grants. The basis for this attribution is that were DOE not leading this activity, these development projects would never occur. There are no standard leverage formulas to apply uniformly. The WIP program did not analyze whether success of this program would eventually lead to the private-sector involvement in developing the new renewables capacity on tribal lands in later years, but such an outcome would be possible under the right pricing conditions.

3.1.3 Key Factors in Shaping Market Adoption of EERE Technologies

Price. To enable analysis, the WIP program assumed the cost of leased solar arrays and battery storage of electricity to be less than the consumer costs of extending electrical transmission from the nearest electrical utility. For central station development, the WIP program assumed the electricity resource produced from renewable resources would cost less than utility-supplied electricity provided to the immediate tribal land with jurisdiction.

Nonprice factors.

- **Key consumer preferences/values:** This program seeks to establish electrical service for households currently without electricity on tribal lands. This is not a comparison of alternative electrical services or of using renewable fuels to provide electrical service, but rather a characterization of providing electrical service where none currently exists, using fuels and facilities that are within the control of tribal organizations.
- **Manufacturing factors:** Based on program materials and TEP program Web site documents (TEP 2004, 2005a, 2005b), most current activities are focused on development of wind resources. EIA (2000) suggests that biomass provides the greatest potential for central station power at competitive prices; therefore, the WIP program assumed that an even mix of technology will develop over time.
- **Policy factors:** Having renewable resources in the resource stack for utilities continues to increase in popularity with all customer classes, even at cost premiums. Central station facilities on tribal lands utilizing renewable fuels may generate value streams from off-reservation utility interests.

3.1.4 Methodology and Calculations

To permit analysis of program success, the WIP program made several enabling assumptions in consultation with the Tribal Energy Program:

- Achieving the program goal of 1,000 MW in new renewables capacity on tribal lands by 2012 would represent approximately 20% of the total potential capacity, or 5,000 MW.
- Current development efforts are almost all wind projects, but the mix will likely shift over time to an even split between wind capacity and biomass capacity for central station development over the next 20 years.
- New biomass plants would operate at a capacity factor of 80%, on average.
- For solar electrification, EIA (2000) states that roughly 16,000 reservation households are without electricity access. As a reasonable assumption, the efforts of the program lead to a potential to electrify 10,000 of those households in 20 years.

Table J-10 provides the inputs needed to develop the benefit metrics in the integrated models. Based on the enabling assumption presented above, the viability of biomass versus wind as a renewable fuel on tribal lands will cause the biomass share of new capacity additions to overtake that of new wind resources over the next 20 years. Also, the WIP program assumed the capacity factor of new wind resources would increase from 15% currently to 30% within 20 years, while the new biomass capacity factor would increase from 80% to 90% over the same period.

Table J-11 provides the development of the off-grid PV electrification of tribal households in the Desert Southwest. The WIP program assumed a capacity factor of 20% for new PV systems deployed in that region, and also assumed the average system would be rated for 1.2 kW capacity. The Navajo tribe and other program material indicate that there are at least 18,000 Navajo reservation households without electricity access. An arbitrary assumption was made to facilitate analysis—that the actions of the program could lead to providing distributed solar/PV to 10,000 households. The default system was assumed to be 1.2 kW.

Table J-10. Development of Tribal Renewable Energy Capacity resulting from the FY2007 Budget Assumptions

Year	Fraction of Potential	MW capacity (cumulative)	Added MW	Share Assumptions		Added MW			Cumulative MW		Capacity factor	
				Wind Fraction	Biomass Fraction	Wind	Biomass	Total	Wind	Biomass	Wind	Biomass
2007	0.011	45	45	1.00	0.00	45	0	45	45	0	0.150	0.750
2008	0.020	100	55	1.00	0.00	55	0	55	100	0	0.158	0.758
2009	0.037	185	85	0.95	0.05	81	4	85	181	4	0.167	0.767
2010	0.067	335	150	0.95	0.05	143	8	150	323	12	0.175	0.775
2011	0.118	590	255	0.95	0.05	242	13	255	566	25	0.183	0.783
2012	0.200	1000	410	0.50	0.50	205	205	410	771	230	0.200	0.792
2013	0.319	1595	595	0.50	0.50	298	298	595	1,068	527	0.206	0.800
2014	0.468	2340	745	0.50	0.50	373	373	745	1,441	900	0.211	0.806
2015	0.622	3110	770	0.50	0.50	385	385	770	1,826	1,285	0.217	0.811
2016	0.755	3775	665	0.50	0.50	333	333	665	2,158	1,617	0.222	0.817
2017	0.852	4260	485	0.50	0.50	243	243	485	2,401	1,860	0.228	0.822
2018	0.900	4500	240	0.25	0.75	60	180	240	2,461	2,040	0.233	0.828
2019	0.911	4556	56	0.25	0.75	14	42	56	2,475	2,082	0.239	0.833
2020	0.922	4611	55	0.25	0.75	14	41	55	2,488	2,123	0.244	0.839
2021	0.933	4667	56	0.25	0.75	14	42	56	2,502	2,165	0.250	0.844
2022	0.944	4722	55	0.25	0.75	14	41	55	2,516	2,206	0.260	0.850
2023	0.956	4778	56	0.25	0.75	14	42	56	2,530	2,248	0.268	0.868
2024	0.967	4833	55	0.25	0.75	14	41	55	2,544	2,289	0.276	0.876
2025	0.978	4889	56	0.25	0.75	14	42	56	2,558	2,331	0.284	0.884
2026	0.989	4944	55	0.25	0.75	14	41	55	2,572	2,373	0.292	0.892
2027	1.000	5000	56	0.25	0.75	14	42	56	2,586	2,415	0.300	0.900

Note: Based on enabling assumptions indicated in the text.

Table J-11. Development of Off-Grid Solar PV Capacity resulting from FY2007 Budget Assumptions

Year	Cumulative Households	MW Capacity	MWh
2007	110	0.13	231
2008	200	0.24	420
2009	370	0.44	778
2010	670	0.80	1,409
2011	1,180	1.42	2,481
2012	2,000	2.40	4,205
2013	2,533	3.04	5,326
2014	3,067	3.68	6,447
2015	3,600	4.32	7,569
2016	4,133	4.96	8,690
2017	4,667	5.60	9,811
2018	5,200	6.24	10,932
2019	5,733	6.88	12,054
2020	6,267	7.52	13,175
2021	6,800	8.16	14,296
2022	7,333	8.80	15,418
2023	7,867	9.44	16,539
2024	8,400	10.08	17,660
2025	8,933	10.72	18,781
2026	9,467	11.36	19,903
2027	10,000	12.00	21,024

3.1.5 Sources

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4) Tribal Energy Program (TEP 2005a). DOE's Tribal Energy Program, Program Review, October 17, 2005. Available at: http://www.eere.energy.gov/tribalenergy/pdfs/0510review_tep.pdf
5) Tribal Energy Program (TEP 2005b). Email communication (6/28/2005) with Thom Sacco, Native American and International Programs Office of Weatherization and Intergovernmental Programs.

3.2 International Renewable Energy Program

The International Renewable Energy Program promotes market transformation in international energy markets to increase the installation of U.S.-developed technologies.

The program states the goal of developing 1,000 MW of new renewables capacity worldwide by 2010. Even if all of this new generation displaced fossil generation, the savings are insignificant—especially on a world scale. In many instances, the new generation that would be created would serve to electrify currently unelectrified regions of the world—adding to world energy consumption. About 1,000 MW each five years would be equivalent to replacing one moderate-sized coal or oil-fired power plant each five years.

The activities of the program are more consistent with information programs and other outreach activities. The difference being that these activities occur with foreign governments. These activities could have the effect of placing U.S. technologies in foreign countries for demonstration or deployment, which may lead to potential adoption in the United States as a result, but this linkage is tenuous at best.

Based on these observations, analysis effort has been focused elsewhere.

Appendix K – GPRA07 Alternative Scenarios

Background

There is inherently considerable uncertainty in long term energy projections such as those underlying the EERE GPRA benefits analysis. In fact, uncertainty about future energy demand, supplies and prices is one of the motivations for Federal investment in R&D, so that the nation might be better prepared in the face of potentially adverse world energy markets. As a result, the benefits of some of EERE programs may be greater under other conditions than the reference or business-as-usual (BAU) projections used in the main report. The prospective benefits framework developed by the National Research Council (NRC)[1] recognizes this in their recommendation of assessing benefits for several "global scenarios."

The Office of Fossil Energy (FE) and EERE have jointly developed alternative scenarios to capture two of the key uncertainties impacting future energy: energy prices and climate policy. The scenarios were used on a pilot basis, internally within EERE, with respect to its FY06 GPRA analysis, and were more fully implemented for FY07. As all of the R&D offices within DOE's Office of Energy Science and Environment (ESE) work toward developing a common GPRA benefits analysis methodology, it is anticipated that these alternative scenarios, as well as potentially other scenarios, will be used.

The use of alternative scenarios that project other possible futures address just one type of uncertainty; and, in this case, along two dimensions of market uncertainty. Model risk is still embedded in the scenarios in that energy models are abstractions of reality and may contain biases in their abstractions.

Programmatic success is another major area of risk that is not addressed through these scenarios. All the EERE Portfolio cases assume that the programs meet their goals. Work is ongoing within EERE and other DOE R&D offices to account for technological and programmatic risk in the GPRA benefits process.

The two alternative market scenarios that were developed for GPRA07 are a high fuel price case and a case with a constraint on national energy-related carbon emissions. Baseline cases, without EERE programs, and portfolio cases, with representation of all the EERE programs, were created for these alternative cases. The benefits of the programs are then evaluated as the difference between each pair of portfolio and base cases, using a similar methodology as for the BAU GPRA07 benefits. However, the resulting benefits are not always comparable to the BAU benefits. For one, the alternative scenarios have different underlying macroeconomic assumptions and demands for energy services (such as light, travel, industrial steam, etc.) due to the higher energy prices. In other words, the energy system is smaller; and, therefore all else equal, the benefits (of reduced energy or avoided emissions) in absolute terms would be smaller. In addition the definition of the climate policy as a cap on energy related carbon emissions leads

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[1] National Research Council, Prospective Evaluation of Applied Energy Research and Development at DOE (Phase One), 2005

to reduced emissions to the cap level in both the baseline and EERE portfolio cases. Hence there are no carbon emission reductions attributable to the EERE portfolio of programs. The primary benefit is that the EERE programs help reach that cap at lower cost.[2]

The off-line analyses that support the benefits analysis were not revised for the alternative scenarios. Thus for programs whose inputs to the integrating models are "outcomes" (such as market penetration rates or energy savings), this potentially leads to an overstatement of benefits, especially in the carbon constraint scenario, because there would likely be greater efficiency investments in the Base case and therefore reduced savings resulting from the EERE technologies. For all programs, the baseline was not revisited, except to the extent that the models will endogenously project reactions to the scenarios. The program analysts were not asked to consider how the sectors in which their programs' technologies have an effect would react in absence of DOE research, development, and deployment (RD3) and in the presence of the scenario constraints. In other words, the baseline technology characteristics for EERE technologies for the most part remain the same under all the scenarios.

As in the benefits analysis shown in the main body of the report, two integrated energy models were used for the scenarios analysis: NEMS-GPRA07 and MARKAL-GPRA07. The former provides the mid-term projections (to 2025), while the latter is used to extend them out to 2050. In most cases, the two models show similar results in the mid-term period, so both sets are not shown. However, there are inter-temporal dynamics in the carbon constraint scenario that necessitate showing the full projection period for MARKAL-GPRA07.

High Fuel Price Scenario Definition

The High Fuel Price scenario is predicated on a future in which the supply of natural gas and oil are more limited, and as a result significantly higher fuel prices occur.[3] The world oil price follows the trajectory of the AEO2005 High B price case (the higher of the two high oil price cases). As seen in Figure 1, oil prices start off higher than the reference case in 2005 and rises to \$48 (2003 dollars[4]) per barrel by 2025 and then to \$70 by 2050. Natural gas supply in the GPRA High Fuel Price case was restricted in order to cause natural gas prices to reach and remain above \$5 by 2015. They continue to rise and reach \$8.25 by 2050. The restrictions on gas supply included limiting the ability of new LNG terminals to be constructed, delaying the Canadian and Alaska gas pipelines until after 2025, and reducing assumed Canadian resources. Coal price assumptions were not explicitly changed, but coal prices rise by up to 12 percent due to the increases in other prices.

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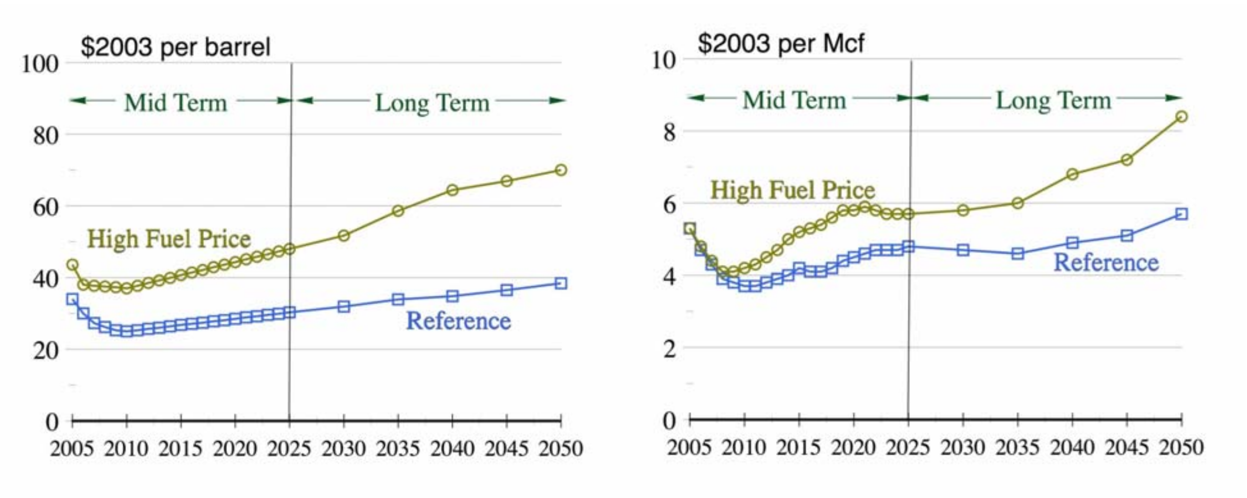
[2] One might argue that the presence of EERE technologies that allows for more rapid adoption of technologies that reduce carbon emissions might influence climate policy, however carbon caps, including the one modeled here, usually specify a time-path for reductions. The level of emissions reductions and the timing of the reductions are thus dictated by the scenario, and not influenced by the technologies in this construct.

[3] In hindsight the oil price path turns out to be very similar to the more current view of prices as represented by the *Annual Energy Outlook 2006*.

[4] Unless otherwise stated, all prices are given in 2003 dollars.



a) World Oil Price ($2003 per barrel)

b) U.S. Wellhead Gas Price ($2003 per Mcf)

Figure 1. Projected World Oil and Wellhead Natural Gas Price

Carbon Constraint Scenario Definition

A second scenario was designed to examine the implications of EERE benefits under a cap on energy-related carbon emissions. The cap is imposed beginning in 2008 and drops to 1,580 million metric tons of carbon equivalent (MMTCE) by 2017, which is roughly the level of emissions in 2003. After 2017, the cap is assumed to remain constant at that level. An economy-wide trading system is assumed where the lowest cost reductions will occur first. The price of the carbon allowances indicates the marginal cost of compliance.

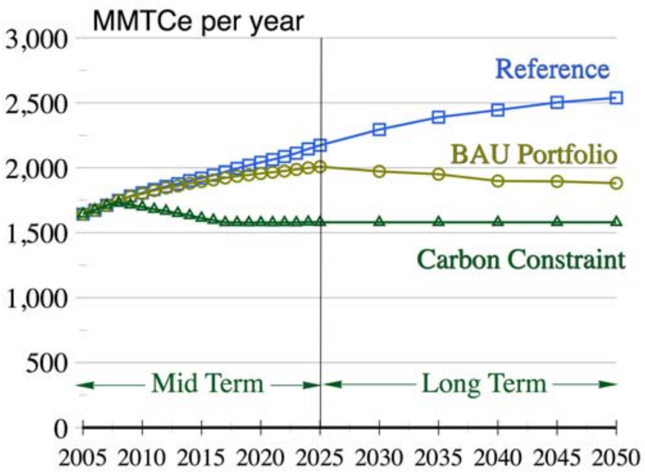
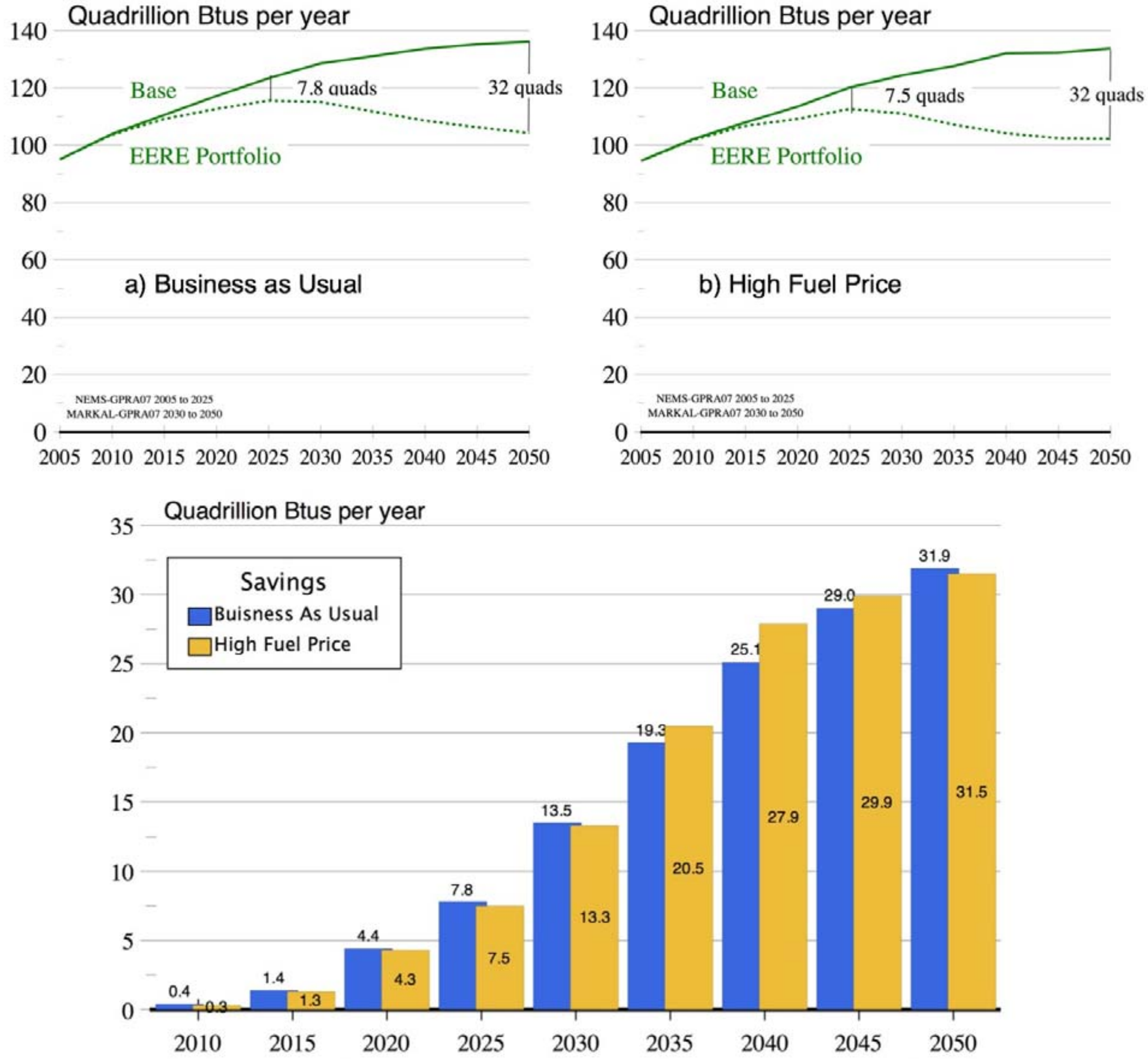


Figure 2. Carbon Emissions

Benefits Under High Fuel Prices

Changes in Primary Non-Renewable Energy Consumption

Figure shows the impacts of EERE's technology portfolio under business-as-usual and high fuel price scenarios.



c) Primary Non Renewable Energy Savings for EERE Technology Portfolio: Business-as-Usual and High Fuel Price Scenarios

Figure 3. Primary Nonrenewable Energy Use Under Alternative Fuel Price Scenarios

The benefits of EERE's portfolio of programs, as measured by the traditional GPRA metrics, are generally lower under the high fuel price conditions than under the reference conditions. One of the key determinants of how the benefits change under high fuel price conditions is the baseline projection, given that benefits are defined as the difference between the baseline and the portfolio cases. Higher prices shrink the demand for energy. In part, this is due to lower demand for energy services as a result of slightly lower incomes and economic output, and behavioral responses to higher prices such as turning down thermostats and driving less. Higher energy prices also stimulate greater investment in energy efficient and renewable technologies even in the absence of technology improvements resulting from the EERE R&D and deployment programs. In the Portfolio case, with advanced technologies available, greater adoption of these technologies is expected. The net result is somewhat smaller primary non-renewable energy savings resulting from the EERE portfolio in most years as shown in Figure 3.

Sector- Specific Effects

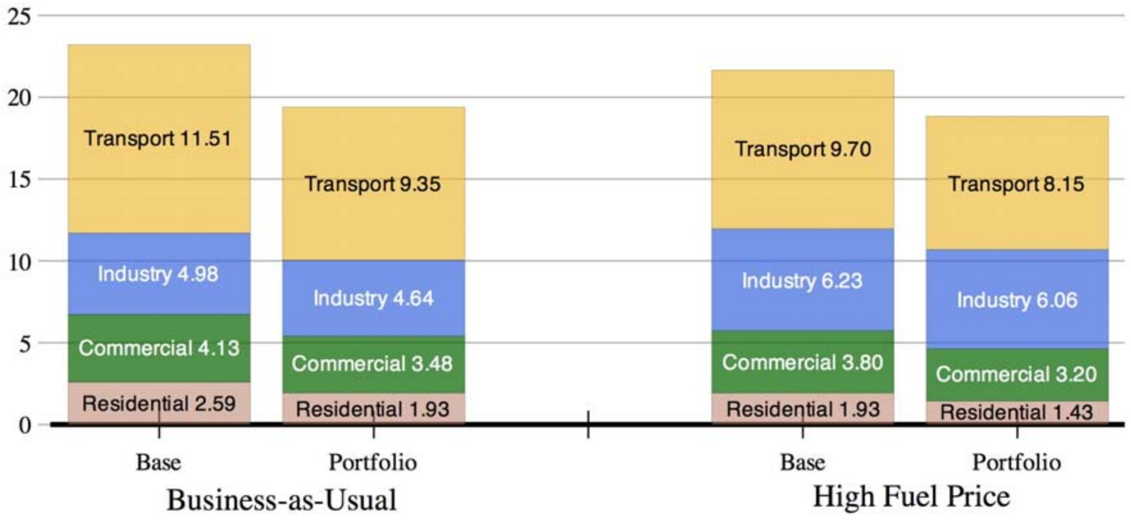


Figure 4. Growth in End-Use Energy Consumption from 2005 to 2025: Business-as-Usual and High Fuel Price Scenarios

The most significant reduction in energy consumption with high prices occurs in the transportation sector (see Figure 4), where higher gasoline and diesel prices lead to reduced vehicle miles traveled and higher vehicle efficiencies. Both of these factors reduce the opportunity for savings from the FreedomCar and hydrogen fuel cell vehicles, even though higher prices make these vehicles more attractive.

Similarly, in the residential and commercial sectors, higher prices reduce energy consumption, primarily oil but also natural gas and electricity to a less extent, through behavioral changes as well as equipment efficiencies. Overall, the buildings energy demand reduction resulting from the EERE Portfolio is roughly 15 percent smaller with higher fuel prices in 2025. The industrial sector’s energy use actually increases in the high price case, due to increased consumption of coal for coal-to-liquids production.

The base case reduction in service demands and increased efficiency in the High Fuel Price scenario relative to the BAU scenario leads to a reduction in incremental delivered energy consumption in the buildings sector of 9 percent and 4 percent in 2030 and 2050 respectively.

The addition of EERE technologies in the Portfolio Case reduces delivered energy consumption in the buildings sector for both the BAU and high fuel price scenarios. This reduction in delivered energy consumption in the EERE Portfolio Cases is attributable to improved buildings shell packages, highly efficient space conditioning technologies and improved and highly efficient solid state lighting technologies. Figure 5 shows the incremental buildings delivered energy consumption for the Base and EERE Portfolio cases in the long term in both the BAU and High Fuel Price scenarios.

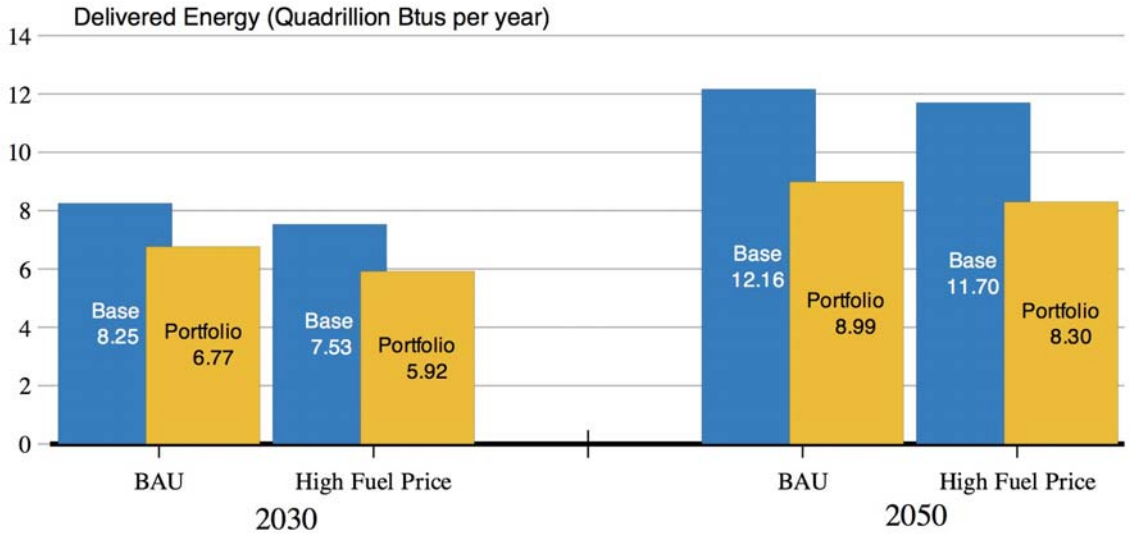


Figure 5: Buildings-Sector Delivered Energy Consumption: 2030 and 2050

In the transportation sector, service demands are lower and efficiency is increased. Light duty vehicle (LDV) vehicle miles traveled (VMT) fall by about 5 percent between the BAU and high fuel price scenario. Furthermore, the Base case average LDV stock efficiency increases by 9 percent and 30 percent in 2030 and 2050 in the high fuels scenario relative to the BAU scenario. Over the long run, the increase in LDV stock efficiency is due to a dramatic increase in hybrid vehicle penetration in the High Fuel Price Base case. Also, with the higher oil prices coal-to-liquids (CTL) technologies become cost-effective and ethanol consumption increases in the High Fuel Price Base case relative to the BAU Base case. The increased uses of these substitute fuels further reduce base case oil consumption in the High Fuel Price scenario.

By 2050, both the BAU and High Fuel Price EERE Portfolio cases, the LDV fleet is comprised entirely of EERE hybrids and fuel cell vehicles, although the proportion of fuel cell vehicles increases in the high fuels scenario. The EERE Portfolio cases lead to reduced petroleum consumption due to the increased market share of highly efficient EERE hybrid and fuel cell vehicles. Also, increased production of cellulosic ethanol further displaces petroleum consumption. Figure 6 shows the LDV stock market shares.

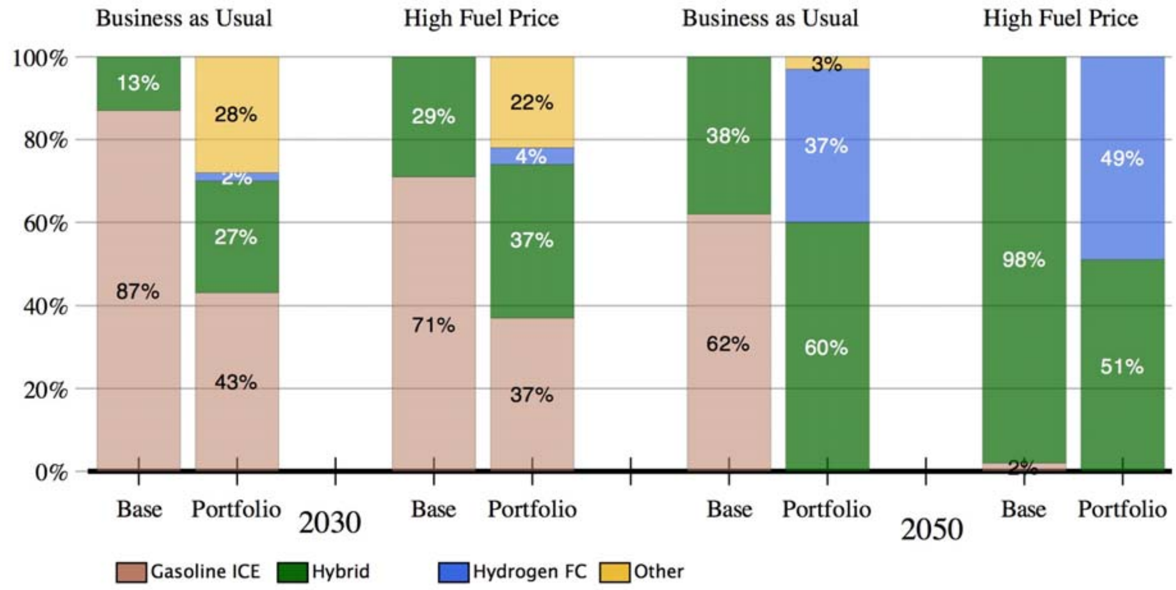


Figure 6: Light Duty Vehicle Stock Market Shares, 2030 and 2050

Electricity Generation and Capacity Effects

The mix of electric generation capacity shifts away from natural gas fired technologies (combustion turbines and combined cycles) and toward coal (steam coal and integrated gasification (IGCC)) and renewable capacity in the High Fuel Price Base relative to the BAU Base. The EERE Portfolio stimulates a greater amount of renewable capacity in the High Fuel Price scenario and displaces a greater proportion of coal than occurs with the BAU scenario.

The shifts become even more pronounced over the long term. By 2050, coal-fired capacity is 40 percent higher in the high fuels base case than in the BAU base case, while renewable generation capacity shows a more modest 8 percent increase. With the inclusion of the EERE portfolio technologies, by 2050 IGCC and natural gas combined-cycle capacity decrease 63 percent and 41 percent, respectively, relative to the High Fuel Price Base case. The decreases are attributable to both improved renewable generation technologies and end-use efficiency. The impacts for the mid and long-term are shown in

There is a corresponding shift in the fuels used for electric generation with generally more coal and less oil and gas when fuel prices are higher. Total generation decreases in the EERE Portfolio Case due to greater adoption of energy efficient equipment. (Figure 8)

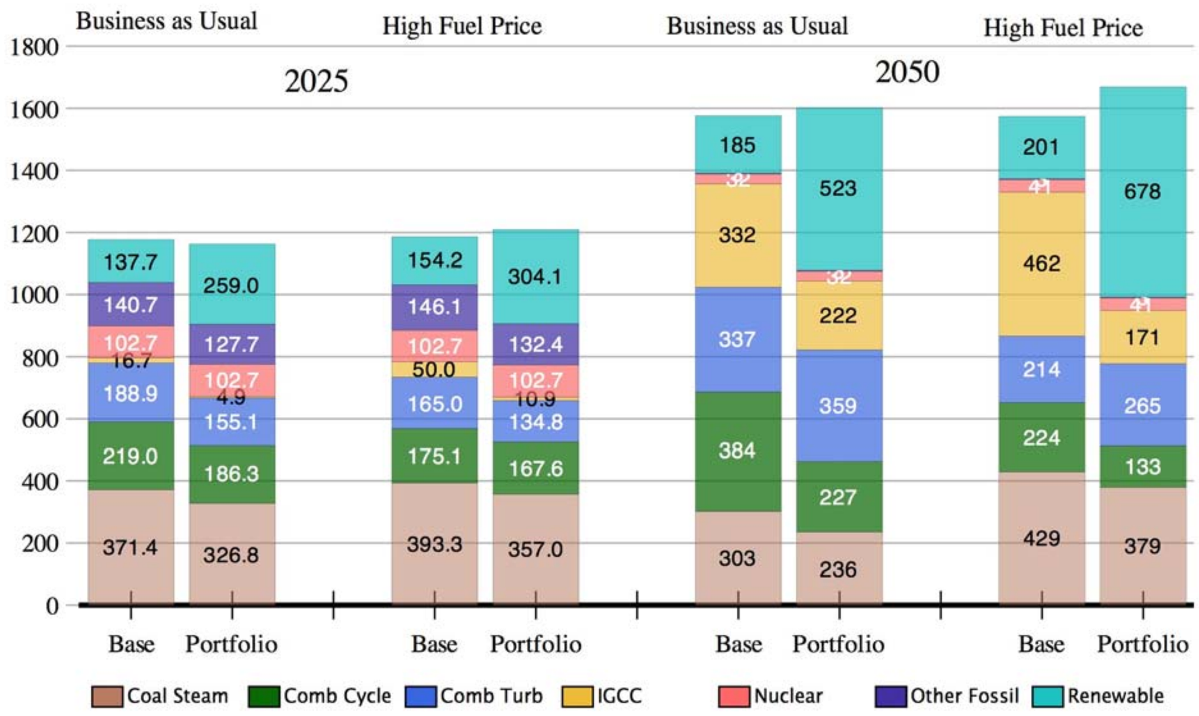


Figure 7. Gigawatts of Electric Generation Capacity in 2025 and 2050
Business-as-Usual and High Fuel Price Cases

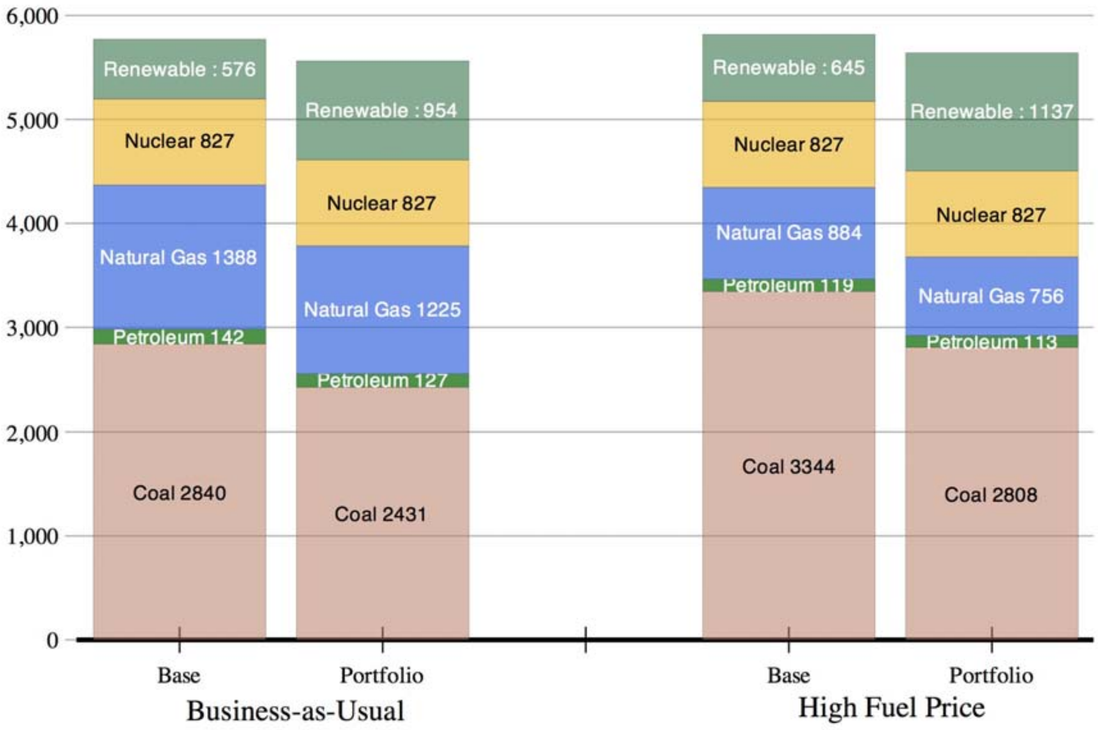


Figure 8. TWh of Electricity Generation in 2025:
Business-as-Usual and High Fuel Price Cases

As in the BAU scenario, wind and solar PV technologies increase substantially in the High Fuel Price Portfolio case, reflecting the R&D success in lowering costs and improving performance. The effect is magnified with higher fuel prices, even though more is adopted in the base (no R&D) case as well. The mix of generation is similar, although PV and wind are intermittent technologies and therefore provide less generation than other technologies that can be operated all the time.

In the long run, the most significant increase in both renewable capacity and generation in the High Fuel Price Portfolio case relative to the High Fuel Price Base case is for central solar thermal generation and distributed photovoltaics. These generation sources provide power during periods of peak electric demands and thus reduce the need for gas-fired combustion turbines. Figures 9 and 10 show non-hydro renewable generation and capacity for the mid and long-term.

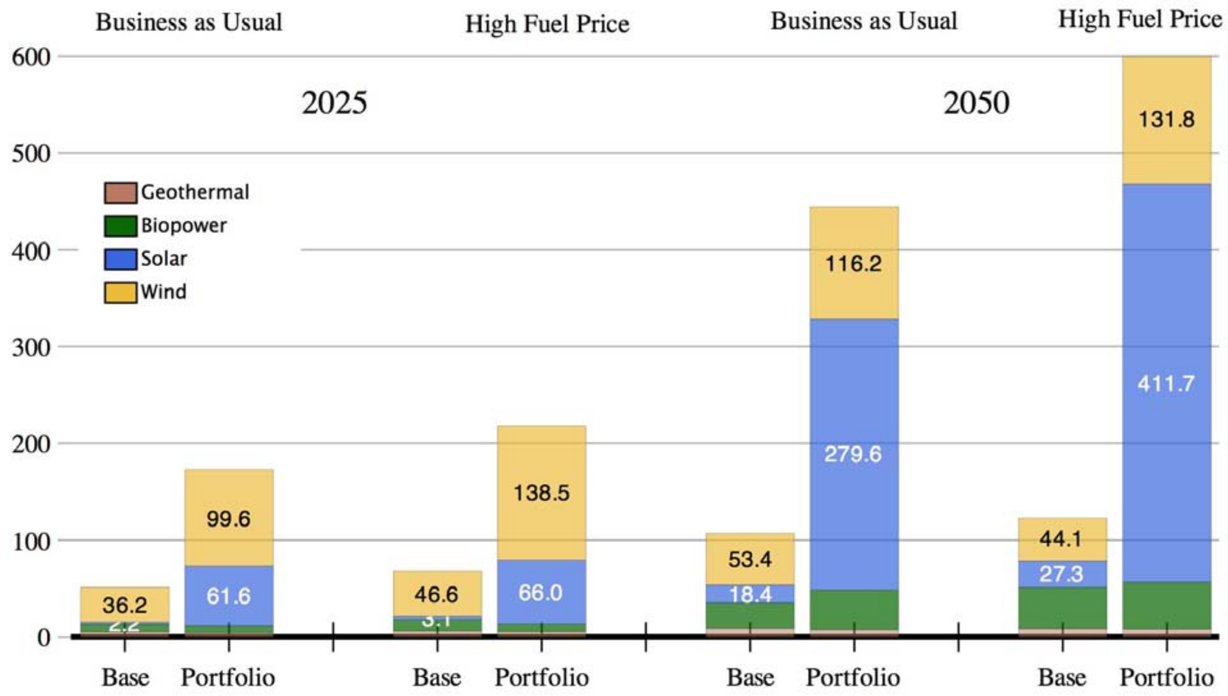


Figure 9. Gigawatts of Non-Hydro Renewable Generation Capacity, 2030 and 2050, Business-as-Usual and High Fuel Price Cases

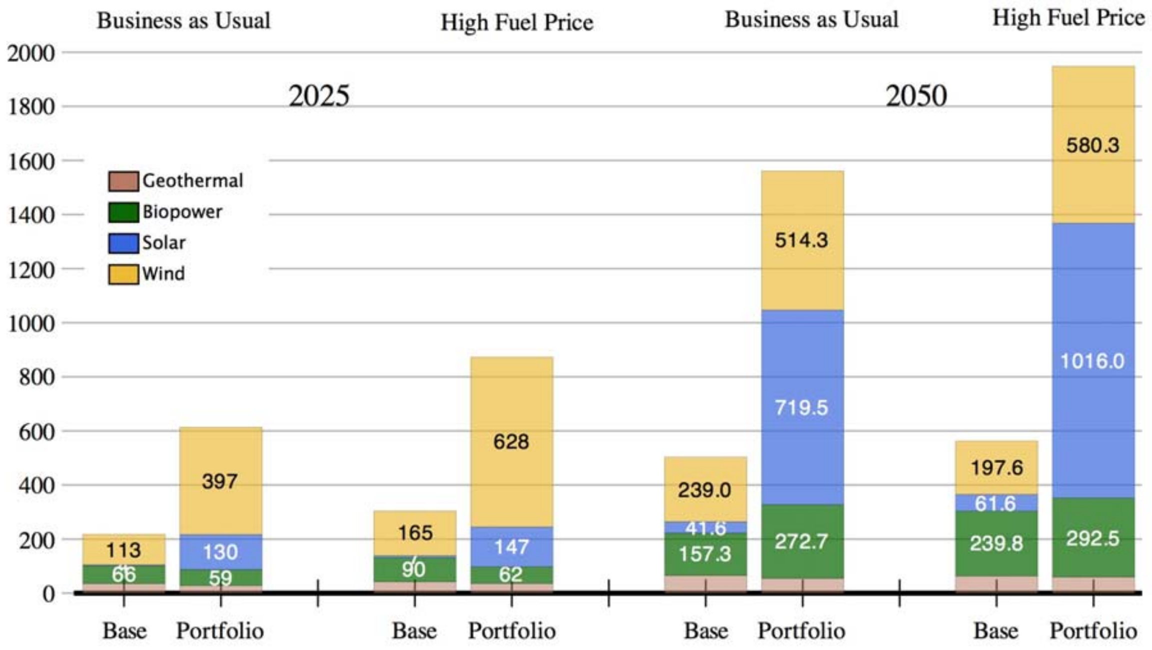


Figure 10. TWh of Non-Hydro Renewable Electric Generation in 2025 and 2050 in the Business-as-Usual and High Fuel Price cases

Carbon Emission Reductions

In the mid-term, carbon emission reductions resulting from the EERE Portfolio under high prices are higher in some years and lower than others relative to the BAU. Because the baseline projects a greater reliance on coal-fired generation, electricity generation displaced by efficiency and renewable generation in the portfolio case is more carbon intensive. On the other hand, energy savings are slightly lower. In the long-term, the coal displacement effect dominates and results in greater carbon emission reductions. Thus, as increased buildings efficiency and improved and less costly renewable generation technologies penetrate the market, a higher proportion of carbon intensive coal-fired power generation being displaced in the high fuels EERE scenario.

Economic Benefits

Energy expenditure savings, as measured in the mid-term projections, are greater due to higher fuel prices. Each unit of energy saved has a higher value. In addition, the impact of reduced consumption has a greater impact of reducing prices, especially natural gas, in the high price case. Energy system cost savings, as measured in the long-term projections, also increase due to the reduction in increasingly more expensive fossil fuels.

Benefits Summary

Table 1. FY07 Annual Benefits Estimates for the EERE Portfolio Under High Fuel Prices (NEMS-GPRA07)

Benefits	2010	2015	2020	2025
Energy Displaced				
Non-Renewable Energy Savings (quadrillion Btu/year)	0.3	1.2	4.3	7.5
Economic				
Energy Expenditure Savings (billion 2003 dollars/year)*	1	26	89	152
Environmental				
Carbon Savings (million metric tons carbon equivalent/year)	7	24	89	167
Security				
Oil Savings (million barrels per day)	0.03	0.2	0.7	1.3
Natural Gas Savings (quadrillion Btu/year)	0.1	0.4	0.9	0.7
Program-Specific Electric Capacity (gigawatts)	2	14	95	155
Program-Specific Generation (terawatt-hours/year)	2	39	314	515

Table 2. FY07 Annual Benefits Estimates for the EERE Portfolio Under High Fuel Prices (MARKAL-GPRA07)

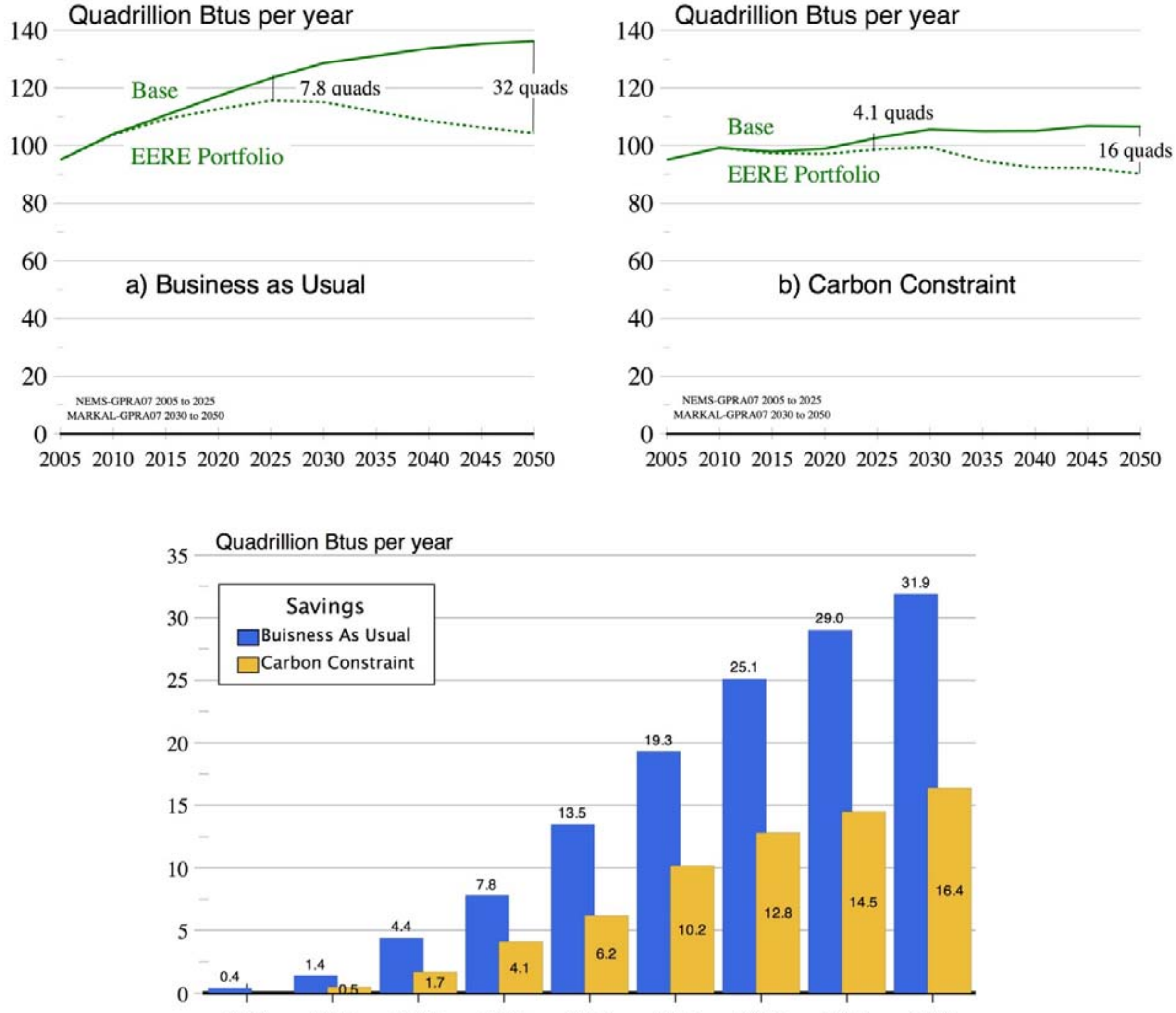
Benefits	2030	2040	2050
Energy Displaced			
Non-Renewable Energy Savings (quadrillion Btu/year)	13	28	31
Economic			
Energy-system net cost savings (billion 2003 dollars/year)*	89	203	307
Environmental			
Carbon Savings (million metric tons carbon equivalent/year)	286	626	698
Security			
Oil Savings (million barrels per day)	6	9	13
Natural Gas Savings (quadrillion Btu/year)	1	1	2
Program-Specific Electric Capacity (gigawatts)	160	337	479
Program Specific Generation (terawatt-hours/year)	525	1,066	1,396

* Midterm energy-expenditure savings only include reductions in consumer energy bills, while long-term energy-system net cost savings also include the incremental cost of the advanced energy technology purchased by the consumer.

Benefits Under a Carbon Emissions Constraint

Changes in Primary Nonrenewable Energy Consumption

Figure 11 shows the primary nonrenewable energy consumption for the base and EERE cases under both the BAU and Carbon Constraint scenarios as projected by NEMS-GPRA07 and MARKAL-GPRA07. The imposition of the carbon cap has a profound impact on the energy system. By 2025, the cap requires a 27 percent reduction in emissions from the BAU Baseline and a 21 percent reduction from the BAU Portfolio case.



c) Primary Non Renewable Energy Savings for EERE Technology Portfolio:
Business-as-Usual and Carbon Constraint Scenarios

Figure 11. Primary Nonrenewable Consumption in the BAU and Carbon Constraint Cases, through 2050

These emission reductions are achieved through a combination of energy service demand reductions, increased efficiency, and fuel switching to less carbon intensive energy sources. In the Carbon Constraint Base case, without EERE R&D, primary fossil energy use drops in 2025 by 21 percent relative to the BAU, and primary nonrenewable energy is reduced by 17 percent. Because meeting the cap requires such a significant shift in consumption, only slightly greater reductions occur in the EERE Portfolio case.

The most dramatic changes occur during the transition period between 2010 and 2020 when the carbon cap is being phased-in, before it reached the cap level of 1580 MMTCE that is then held constant. During the transition period, a large amount of carbon-intensive steam coal electric generation capacity is replaced with carbon free nuclear and renewable generation. At the same time, lower service demands and increased end-use sector efficiency result in lower demands for electricity

Carbon Reductions and Carbon Allowance Prices

By definition, carbon emissions are at the specified cap in the carbon cases, and take place on a specified schedule, with or without EERE technologies.[5] Therefore no carbon emission reductions are expected that would be attributable to the EERE programs, unless the cap becomes non-binding as occurs in the very long term. Nevertheless, there is a significant reduction in the cost required to meet that cap when the EERE advanced technologies are available.

In the midterm, the carbon allowance price that is necessary to reduce emissions to the cap level falls from a maximum of $200 per metric ton of carbon equivalent in the Base to $165 per ton in the Portfolio case. From 2015 to 2015, NEMS-GPRA07 projects an average price drop of $35 per ton with the EERE portfolio relative to the Base case without the R&D.

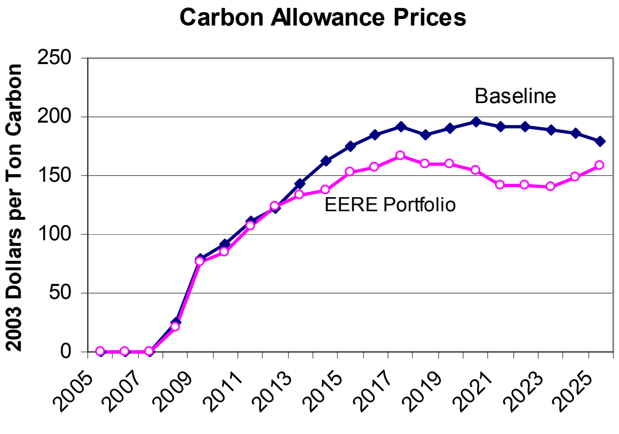


Figure 12. Carbon Allowance Prices through 2025 in the Base and EERE Portfolio Cases

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[5] No banking of allowances was included in the scenario.

The expenditures that consumers pay for energy are higher due to the carbon allowances that are embedded in energy prices. The reduction in the carbon allowance price in the EERE portfolio case, along with a reduction in energy consumption due to greater energy efficiency opportunities, leads to greater energy expenditure savings from the EERE portfolio than in the BAU case – 85 percent higher in 2020 and 51 percent greater in 2025.

The longer term effects are driven in large part by the energy system's reaction during the transition period. Specifically, the introduction of a large stock of highly efficient and/or carbon free capital stock during the transition period frees the energy system to make only incremental investments in additional efficiency and carbon free capital stock in future periods in order stay under the carbon cap while meeting increased demand for energy services. Thus, in the Carbon Constraint Base case, the marginal value of carbon falls dramatically from about $250 per metric ton of carbon in 2015 to stabilize at roughly $100 per metric ton after 2030.

The differences between model projections for carbon allowance prices are attributable to at least three fundamental factors:

- MARKAL's design includes perfect foresight and thus "optimizes" over the entire model horizon, while different NEMS-GPRA07 modules have different foresight formulations (myopic and simulation-based for the demand sectors; close to perfect foresight and optimizing for the electric generation sector). Because the carbon cap is instituted in 2012, MARKAL makes an optimal decision early, but with respect to the shape of the energy system through 2050. NEMS-GPRA07 only "sees" through 2025, and only its supply modules optimize over the time frame.
- The version of MARKAL employed for GPRA07 does not include elastic service demands. As relative prices change, the demand sectors continue to demand the same amount of energy services as under the original prices.[6] In NEMS-GPRA07, the demand sectors can lower their energy demands in the short-term in response to higher real energy prices; in MARKAL the only mechanism is through adoption of new technologies[7].
- MARKAL runs in five-year time steps, while NEMS runs in one-year time steps. While this distinction is usually not very significant for long-term models, the timing of the carbon cap in our scenario makes the time-step issue quite important. The carbon cap starts in 2008 and becomes more stringent in 2017. In MARKAL, this translates into 2010 and 2015, and the change occurs in one time step. In NEMS, the additional resolution of annual time periods allows the energy system to respond more gradually; in MARKAL, the new stringency is a one-period shock to the system.

With the addition of the EERE technologies in the Carbon Constraint Portfolio Case, the energy system carbon emissions fall below the cap after 2030, and the value of carbon (expressed as the allowance price) drops to zero. There are several reasons for this result. As noted above, the

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[6] Energy demand is generally quite inelastic in the short term, reflecting the existing capital stock, but more elastic in the long-term as fuel switching and capital retirements and replacements become more economic and have time to occur. EERE expects to implement an elastic service demand version of MARKAL in future GPRA reports.
[7] For these scenarios, some of the service demands, such as VMT, were adjusted to reflect the response from NEMS-GPRA07.

version of MARKAL being used has fixed service demands, thus consumers are not responding to a drop in the value of carbon (and the resulting decrease in fuel prices) by demanding more energy services. The introduction of more efficient and low/no carbon capital stock during the transition period has a lasting effect on carbon emissions throughout the projection period. Finally, the introduction of EERE technologies further reduces the cost of reducing carbon emissions. In fact, in the BAU scenario without any climate policy, the EERE portfolio emissions drop to about 1890 MMT of carbon by 2050. This is about two-thirds of the required savings from the BAU baseline needed to meet the carbon cap. The marginal value of carbon (allowance prices) and total carbon emissions as projected by MARKAL-GPRA07 are shown in Figures 13 and 14.

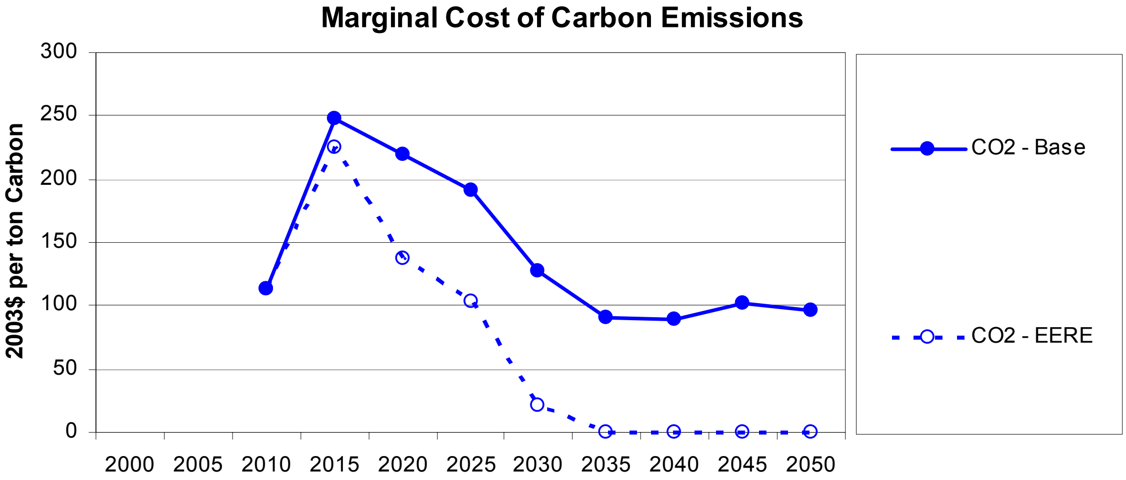

Figure 13. Carbon Allowance Prices through 2050 in the Base and EERE Portfolio Cases

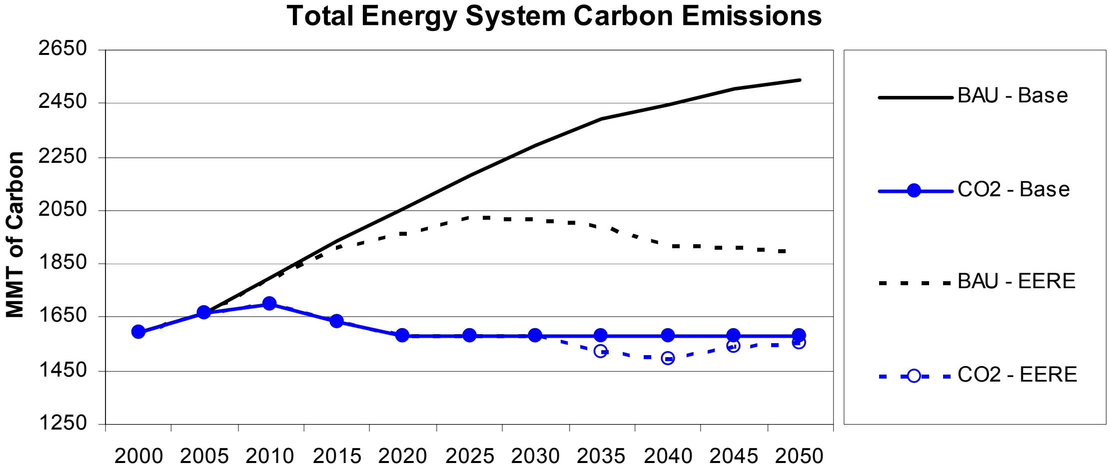

Figure 14. Carbon Emissions through 2050 in the BAU and Carbon Constraint Base and EERE Portfolio Cases

Generation and Capacity Effects

In both time periods and models, the greatest shifts in energy use patterns occur in the electric power sector. A significant portion of existing coal-fired power plants retire, and nuclear, sequestered coal, and renewable capacities increase. With the EERE Portfolio, an additional 121 GW of renewable capacity is added by 2025 compared to the carbon constraint baseline. This is very similar to the incremental amount that was added in the BAU Portfolio relative to the BAU Base although the mix of renewable types is different, as will be shown later. In the BAU scenario, the additional renewable capacity displaces a mix of gas and coal capacity. In the Carbon Constraint scenario, the displaced capacity includes nuclear and sequestered coal, as well as conventional gas and coal capacity. In 2025, total capacity is projected to be higher in the Carbon Constraint case despite lower electricity demand due to the increasing share of intermittent wind capacity that leads to greater capacity reserve requirements.

In the long-term projections, the inclusion of the EERE Portfolio technologies lowers the total generation capacity. Here the impact of reduced electricity demand due to increased efficiency in the end-use sectors leads to lower capacity overall. There is a shift away from existing coal and towards carbon free generation capacity, such as nuclear or IGCC with sequestration. However, with the EERE Portfolio of technologies, there are more cost-effective opportunities for reducing carbon emissions and the carbon allowance price declines significantly (shown in Figure 13). Therefore, the system's use of carbon-free generation sources declines and more unsequestered IGCC capacity is added at the end of the forecast period. The decline in the carbon allowance price also reduces the economic incentive to build large amounts biomass-fired and wind-powered generation capacity. However, the wind turbines built in the Portfolio Case have higher capacity factors than those built in the Base Case, and the decrease in wind generation between the Carbon Constraint Base case and EERE portfolio case is lower than the reduction in capacity. The decline in nuclear capacity occurs as no new nuclear plants are built after 2025 due to both the decline in the carbon allowance price, the reduction in electricity demand, and improvements in renewable generation technologies relative to the base case. Total electric generation capacity is shown in Figure 15 and nuclear generation capacity is shown in Figure 16.

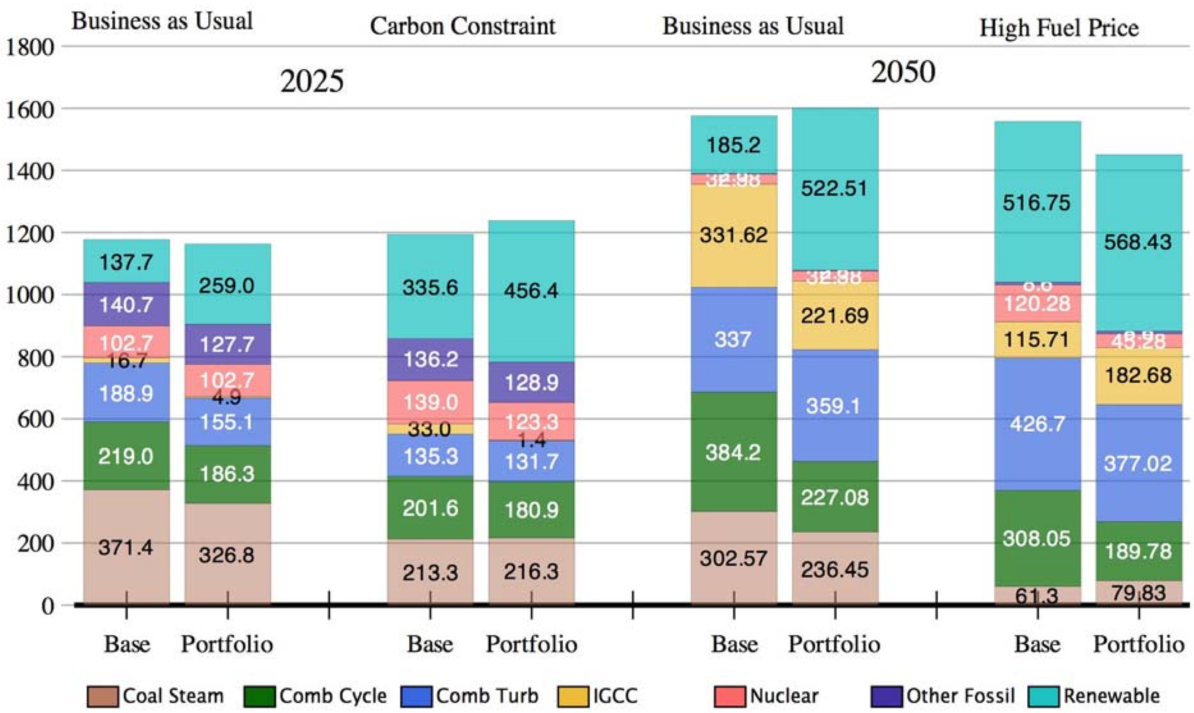

Figure 15. Electric Generation Capacity in 2025 and 2050 Business-as-Usual and Carbon Constraint Cases

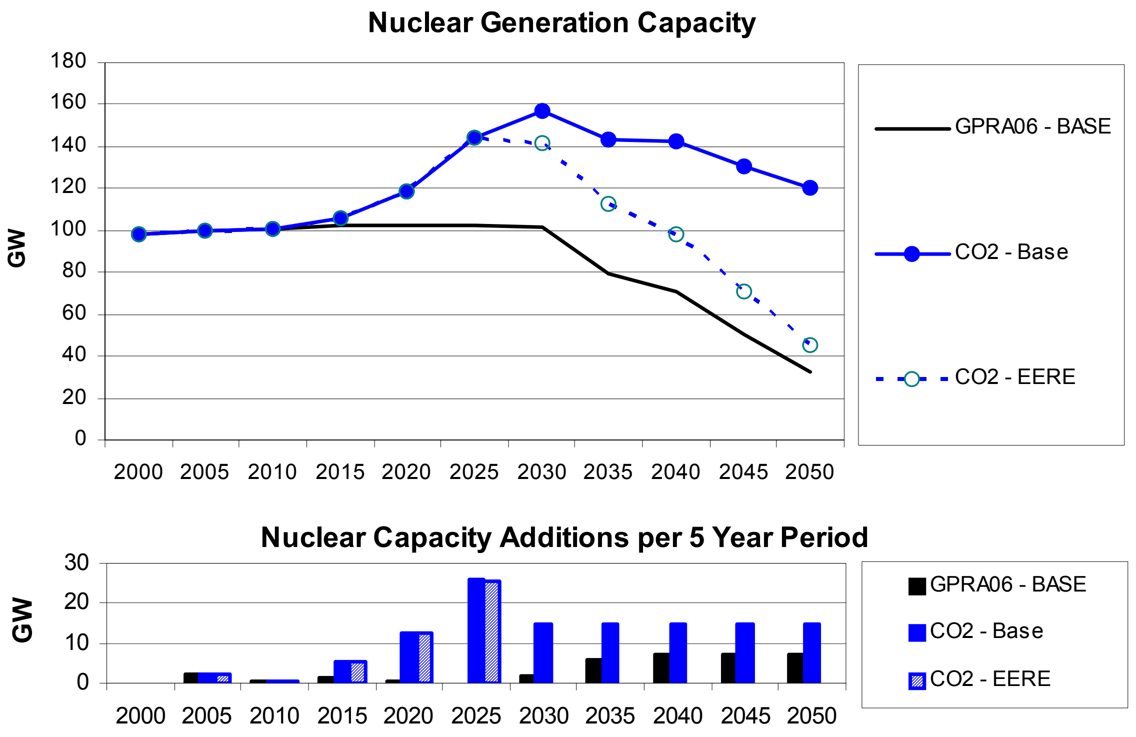

Figure 16: Nuclear Generation Capacity

In the Carbon Constraint case, the drop in coal generation is even greater than the decrease in capacity as existing coal plants become more expensive to operate. The EERE portfolio provides more cost-effective renewable generation, and nuclear and natural gas generation decline relative to the base. Total generation is slightly lower as well due to greater adoption of energy-efficient technologies.

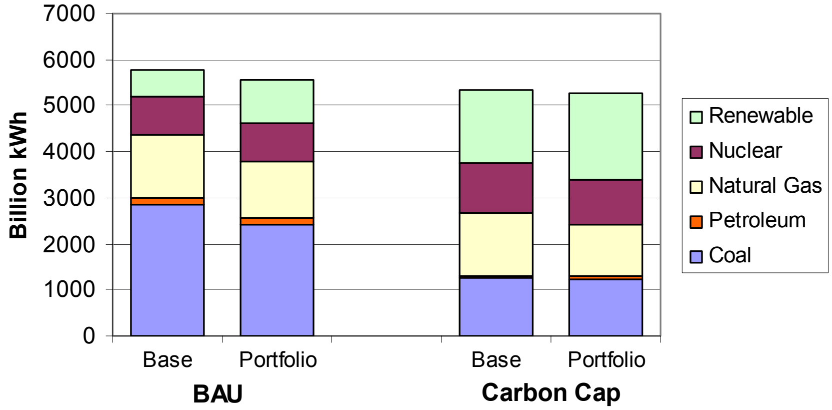

Figure 17. Electricity Generation in 2025 in the BAU and Carbon Constraint cases

With the EERE portfolio technologies, non-hydro renewable generation capacity increases in both the BAU and Carbon Constraint scenarios. However, the composition of this capacity changes dramatically in the Carbon Constraint scenario. In the Carbon Base case, the largest increase is in biomass and wind generation and capacity. In the EERE portfolio case, wind and solar technologies make significant additional contributions to carbon emission reductions in the midterm period. Dedicated biomass power, which is not in the EERE R&D portfolio, is greater in the Carbon Base case, but shrinks as the wind and solar technologies improve in the EERE Portfolio case.

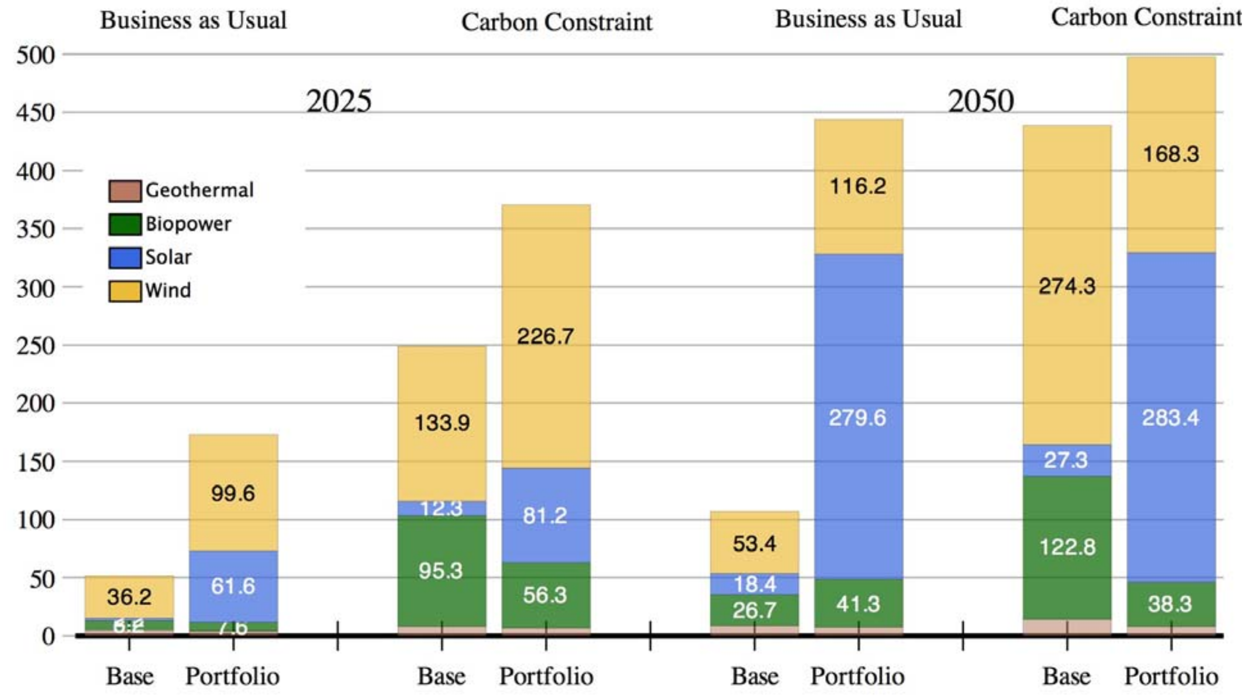

Figure 18. Non-Hydro Renewable Electric Generation Capacity in 2025 and 2050 Business-as-Usual and Carbon-Constraint cases

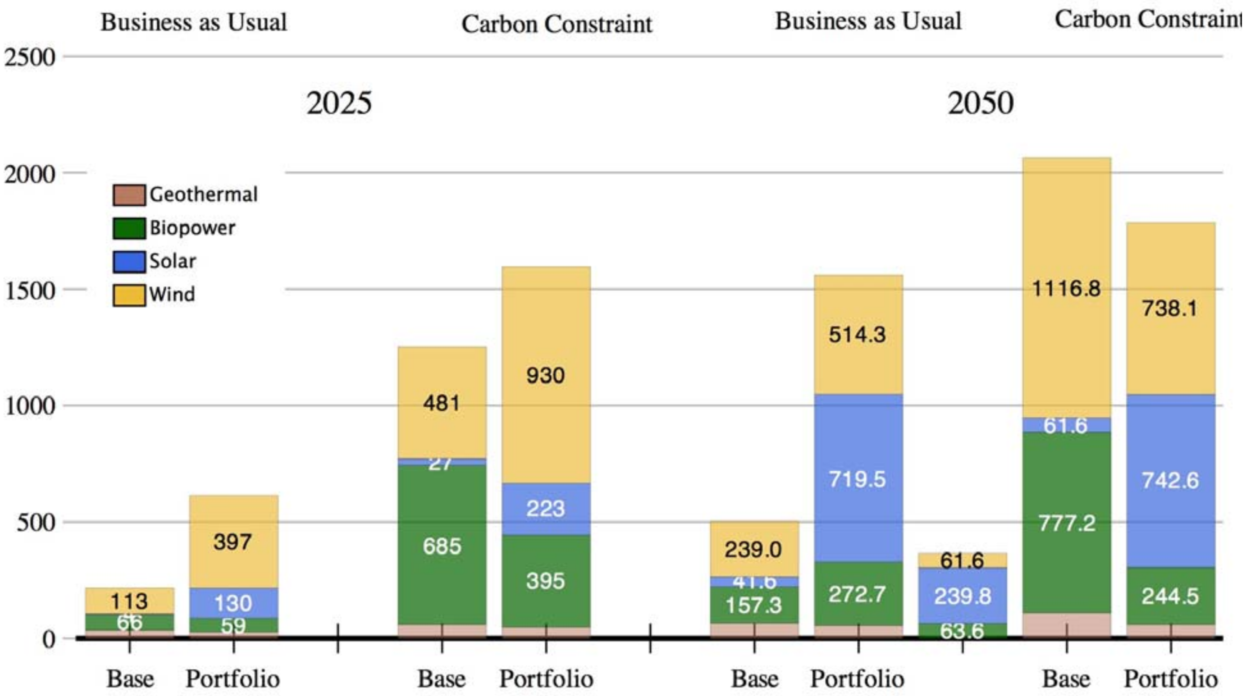

Figure 19. Non-Hydro Renewable Electric Generation in 2025 and 2050 Business-as-Usual and Carbon Constraint cases

In the long run, the largest increase is in solar generation relative to the carbon base case. In the carbon base case, biomass and wind generation were among the most cost effective options in reducing carbon emissions. However, with the introduction of the EERE technologies, end-use efficiency in both the buildings and transportation sectors are very cost effective in reducing carbon emissions. Furthermore, the EERE solar technologies show relatively higher cost and performance improvement over their base case levels.

Sector- Specific Effects

The growth in end-use consumption is reduced considerably in the Carbon Constraint base case even without the advanced EERE technologies. Part of the drop is due to lower demands for energy services, such as vehicle miles traveled or home heating and cooling, and partly due to greater efficiency. With the inclusion of EERE technologies, energy efficiency improves further, and energy consumption drops a bit more. The incremental reduction due to EERE is smaller in the carbon constraint case, because of overall reduced demand for services and greater efficiency in the base.

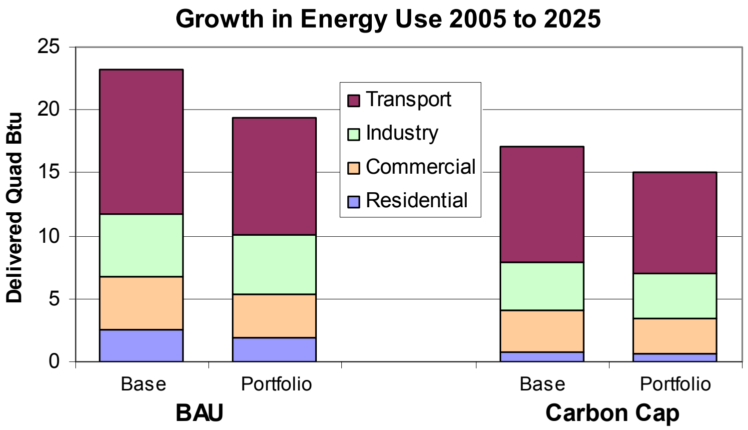

Figure 20. Growth in Energy Consumption from 2005 to 2025 in the BAU and Carbon Constraint cases

In the long term, the carbon constraint continues to reduce delivered buildings energy consumption in the Carbon Constraint Base case relative to the BAU Base. Incremental delivered energy consumption in the buildings sector is roughly 40 percent lower in 2030 and 2050. The inclusion of EERE portfolio technologies further reduces delivered energy consumption in the buildings sector in both the BAU and Carbon Constraint scenarios. The reduction in delivered energy consumption in the EERE Portfolio cases are attributable to improved buildings shell packages, highly efficient space conditioning technologies and improved and highly efficient solid state lighting technologies. Figure 21 shows the incremental buildings delivered energy consumption for the base and EERE portfolio cases in both the BAU and High Fuel Price scenarios.

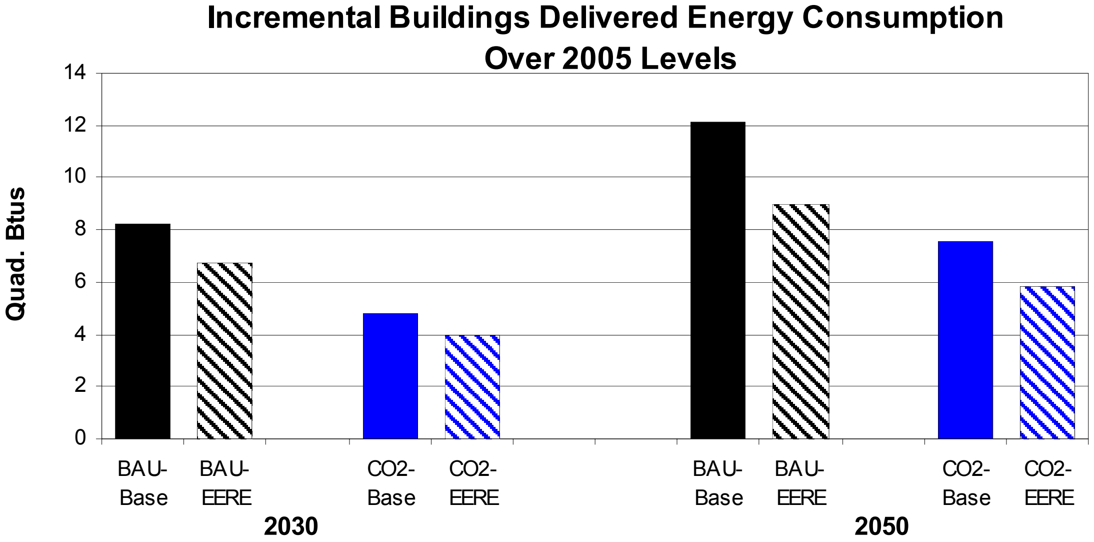

Figure 21. Buildings-Sector Delivered Energy Consumption: 2030 and 2050

The transportation sector reacts to the carbon constraint by reducing service demands and by increasing efficiency. LDV VMTs fall by about 6 percent between the BAU and Carbon Constraint scenario. Furthermore, in the Carbon Constraint scenario the Base case average LDV stock efficiency increases by 8 percent in 2030 and 18 percent in 2050 relative to the BAU scenario. The increase in LDV stock efficiency is due to an increase in hybrid vehicle penetration in the carbon constraint base case. Also, ethanol consumption increases in the Carbon Constraint Base case relative to the BAU Base. The increased use of ethanol further reduces Base case oil consumption in the Carbon Constraint scenario.

By 2050, both the BAU and Carbon Constraint EERE Portfolio cases, the LDV fleet is comprised entirely of EERE hybrids and fuel cell vehicles. The EERE Portfolio cases lead to reduced petroleum consumption due to the increased market share of highly efficient EERE hybrid and fuel cell vehicles. Also, increased production of cellulosic ethanol further displaces petroleum consumption. Figure 22 shows the LDV stock market shares.

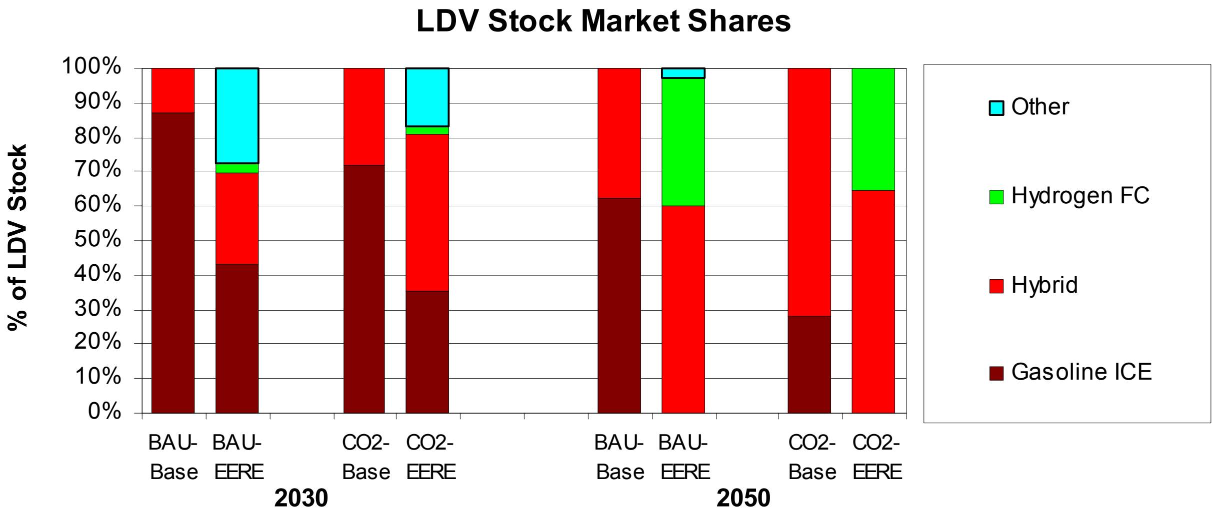

Figure 22: Light Duty Vehicle Stock Market Shares, 2030 and 2050

As noted earlier, many of the benefits estimates for the Carbon Constraint scenario are lower than in the BAU scenario due to the massive changes in the energy system in the Base case that result from the imposition of a carbon cap. Furthermore, the reduction in service demands means that the energy system cost savings are not comparable to those in the BAU scenario. However, the increased buildings and transportation efficiency, as well as improved cost and performance of renewable technologies still lead to significant benefits relative to the base case.

Benefits Summary

Table 3. FY07 Annual Benefits Estimates Through 2025 for the EERE Portfolio Under a Carbon Constraint (NEMS-GPRA07)

Benefits	2010	2015	2020	2025
Energy Displaced				
Non-Renewable Energy Savings (quadrillion Btu/year)	0.01	0.4	1.6	3.9
Economic				
Energy Expenditure Savings (billion 2003 dollars/year)*	13	55	129	162
Environmental				
Carbon Savings (million metric tons carbon equivalent/year)	ns	ns	ns	ns
Security				
Oil Savings (million barrels per day)	0.1	0.2	0.5	0.9
Natural Gas Savings (quadrillion Btu/year)	0.2	0.6	1.5	1.0
Program-Specific Electric Capacity (gigawatts)	ns	25	116	163
Program-Specific Generation (terawatt-hours/year)	ns	94	423	575

Table 4. FY07 Annual Benefits Estimates Through 2050 for the EERE Portfolio Under a Carbon Constraint (MARKAL-GPRA07)

Benefits	**2030**	**2040**	**2050**
Energy Displaced			
Non-Renewable Energy Savings (quadrillion Btu/year)	6	13	16
Economic			
Energy-system net cost savings (billion 2003 dollars/year)*	67	130	185
Environmental			
Carbon Savings (million metric tons carbon equivalent/year)	ns	83	29
Security			
Oil Savings (million barrels per day)	3	6	8
Natural Gas Savings (quadrillion Btu/year)	3	3	4
Program-Specific Electric Capacity (gigawatts)	62	85	139
Program Specific Generation (terawatt-hours/year)	269	291	260

* Midterm energy-expenditure savings only include reductions in consumer energy bills, while long-term energy-system net cost savings also include the incremental cost of the advanced energy technology purchased by the consumer.

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13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 Words)*

This document summarizes the results of the benefits analysis of EERE's programs, as described in the FY 2007 Budget Request. EERE has adopted a benefits framework developed by the National Research Council (NRC) to represent the various types of benefits resulting from the energy efficiency technology improvements and renewable energy technology development prompted by EERE programs. EERE's benefits analysis focuses on three main categories of energy-linked benefits—economic, environmental, and security.

15. SUBJECT TERMS

Government Performance and Results Act; GPRA 07; benefits estimates; portfolio benefits; program benefits; benefits analysis; biomass program; building technologies program; distributed energy resources program; federal energy management program; hydrogen, fuel cells, and infrastructure technologies program; industrial technologies program; solar energy technologies program; vehicle technologies program; weatherization and intergovernmental program; wind and hydropower technologies program.

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