# Appendix C – GPRA05 Building Technologies Program Documentation

## Introduction

**Table 1** outlines the activities characterized for the GPRA05 Building Technologies Program. Characterizations and inputs for these activities were provided to EERE as inputs to EERE's integrated modeling effort.

**Table 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: Controls |
| | | Solid State Lighting |
| | Space Conditioning & Refrigeration R&D | Refrigeration R&D: Res. HVAC Dist. System |
| | | Refrigeration R&D: Adv. Elec HPWH |
| | | Refrigeration R&D: Commercial Refrigeration |
| | | Refrigeration R&D: Refrigerant Meter |
| | Appliances & Emerging Technologies R&D | Appliances & Emerging Tech R&D: HPWH |
| | | Appliances & Emerging Tech R&D: Roof Top AC |
| | | Appliances & Emerging Tech R&D: Recessed Can Lights |
| | | Appliances & Emerging Tech R&D: R-Lamp |
| | Building Envelope R&D: Window Technologies | Window Technologies: Electrochromic Windows |
| | | Window Technologies: Superwindows |
| | | Window Technologies: Low-E Market Acceptance |
| | Analysis Tools and Design Strategies | Analysis Tools and Design Strategies |
| Equipment Standards and Analysis | Equipment Standards and Analysis | Standards: EPAct Standards |
| | | Standards: Distribution Transformers |

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

# 1.0 Residential Buildings Integration

The long-term goal of Residential Buildings Integration is to develop cost-effective designs for 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

### 1.1.1 Target Market

**Project Description.** The Residential Building Energy Codes project improves the minimum or baseline energy efficiency of new residential buildings requiring code permits. The project promulgates upgraded energy efficiency requirements for residential buildings. Similarly, the project works with model energy code groups to upgrade the energy efficiency requirements of their codes. Federal, state, and local jurisdictions then adopt and implement these upgraded federal and 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.

**Market Description.** The market includes new residential low-rise buildings three stories or less in height and all additions and renovations to buildings requiring code permits.

**Size of Market.** Each year, nearly 1.6 million residential building permits are issued, approximately 80% of which are single-family dwellings. Although not all jurisdictions currently have energy efficiency building codes in place, the Pacific Northwest National Laboratory (PNNL) estimates that about half of 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 could 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 FY05, the percentage of potential savings, in the first year 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 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, 37 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.

### 1.1.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.** Incremental investment costs were developed assuming a five-year payback period on investment (i.e., an annual energy cost savings of $1 implies an initial investment of $5). This corresponds to a total incremental cost of approximately $120 million in 2010, $285 million in 2020, and $300 million in 2030.

**Key Consumer Preferences/Values.** The following nonenergy characteristics were not considered.

- Improved environment and more comfortable buildings.
- Lower utility bills
- 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.

### 1.1.3 Methodology and Calculations

**Inputs to Base Case.** With respect to codes, it is indeterminate as to whether potential future code improvements are incorporated into the National Energy Modeling System GPRA 2005 (NEMS-GPRA05) base case. The NEMS-GPRA05 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 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-GPRA05 base case, but would not be included in the GPRA forecast of savings for that activity, because it no longer would be funded. Only an estimate of potential future codes is included in the GPRA estimates. Therefore, PNNL did not provide inputs to change the base case assumptions for the program markets.

**Technical Characteristics.** The FY 2005 GPRA estimates are based on increased compliance with existing codes, accelerated adoption of the 2000 editions of the International Energy Conservation Code (IECC) code (to comply with Section 304 of the Energy Conservation and Production Act), and 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 2000) with variations in climate by states (and differences among states) in their adoption and enforcement of building codes. This discussion uses national averages of some of the key assumptions related to adoption and compliance to help summarize the methodology.

The principal difference between the 1995 Model Energy Code and the IECC 2000 involves the solar heat gain requirements for windows and increased thermal resistance requirements for ducts in unconditioned spaces. Based on a series of simulations for various U.S. locations, the percentage reduction in cooling load was estimated to be about 15%. This requirement increases the heating load by a small amount, about 2% nationally. (The requirement itself is restricted to the southern tier of states). The GPRA estimates were partly based on states' accelerated schedule of adoption of the IECC 2000 and 2003 codes. Through the efforts of the Building

Energy Codes project, 31 states were assumed to have adopted the standard by the end of 2005. The project was assumed to accelerate the adoption of the standard by an average of three years nationwide.

The IECC's ongoing activities were assumed to lead to more stringent residential standards in the future. The Department of Energy (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 IECC standard assumed to become available in the latter part of the current decade. Based on discussions with Building Technologies (BT) staff, PNNL assumed that the results of these upgrades were to reduce heating and cooling loads in new residential structures by 10%. Without these activities, the analysis assumed that the same standard would be adopted, on average, three years later.

> *Relationship to WIP.* EERE's efforts to support building codes covers two aspects: 1) the development of new codes with greater stringency or ease of enforcement and 2) activities to improve the compliance with codes and to accelerate adoption of the most recent codes by states and localities. The development of new codes is supported by the Building Technologies Program and efforts to improve compliance and accelerate adoption are supported in the Weatherization and Intergovernmental Program (WIP). The methodology to develop the total effect from these two EERE programs is integrated. The documentation below discusses both aspects of EERE activities with regard to energy codes.
>
> More explicitly for modeling purposes, the GPRA energy savings estimates for BT (in regard to codes) is restricted to the development of a single new national residential code, expected to publish in the latter part of the current decade. However, with the ongoing efforts to promote adoption and compliance, the impact of the published code would be modest. However, without development of a new code, activities to promote adoption and compliance would be meaningless. Thus, the issue becomes assignment of savings from future code between the BT and WIP programs. In the GPRA estimates for 2005, 50% of the savings attributable to accelerated adoption and increased compliance of the new code were allocated to the BT program.

**Expected Market Uptake.** The project's activities also were assumed to improve compliance rates for codes currently adopted by states and localities, as well as future building codes. Compliance is increased through better familiarity with the codes, simplifications to the code while maintaining stringency, and the availability and increased use of compliance tools by builders and enforcement officials. Compliance rates, with and without the project, were estimated for various standards as discussed above. The compliance with the several key provisions in the IECC 2001 and 2003 (compared with the 1995 Model Energy Code) was expected to be higher from the outset. On average, the compliance was estimated to be 68% in the year of the adoption. By 2010, compliance rates were assumed to increase to 69% without the project and 74% with the project. For homes that do not comply with the standard, only half of the incremental energy savings were assumed to be achieved by adopting IECC 2001 or 2003.

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 going to the new standard is 85% at the time of adoption, increasing to 90% with the project after the first 10 years.

## 1.2 Research and Development: Building America

### 1.2.1 Target Market

**Project Description.** The project's long-term goal is to develop advanced systems to improve the energy performance of residential new homes by 70% relative to homes built under the Model Energy Code, 1995 edition (MEC95), and to reduce existing home energy use by 20% over current use. Ultimately, the goal for single-family homes is to achieve a cost-effective, marketable zero-net energy home design by integrating renewable energy (initially solar electric and solar thermal) into home designs.

**Market Description** [1,6]: The target market includes all new residential homes. Existing homes also would benefit from new technologies and improved construction practices developed for new homes. For the FY 2005 GPRA effort, potential impacts to the existing residential market were not explored.

**Size of Market**[7]**:** Each year about 1.2 million new housing units are built. In 2002, 976,000 new single-family homes were built. These units are primarily owner occupied.

**Market Introduction:** 1997[2]**;** Initial penetration of renewable energy designs began in the southwest in 2003[6]. The on-site renewable energy technology research is anticipated to expand into the northern climate zones beginning in 2008. While renewable technology currently exists (e.g., solar thermal, photovoltaics), penetration into the general market is expected to continue to be extremely low without DOE R&D funding, because the technology is currently unaffordable for production home builders. PNNL assumed that residential R&D activities would not occur in the absence of DOE R&D funding, therefore, this project was not assumed to accelerate the market acceptance of these practices.

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

### 1.2.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.**
**<u>Building America Whole House Energy Savings:</u>**
**Cost of BT Technology**:[5] 2% above conventional cost[4].
**Incremental Cost** (average price per household):

- Single Family: $2,500
- Multifamily: $1,500
- Manufactured Home: $800.

**<u>Renewable Portion:</u>**
**Incremental Cost** (average price per household):

- Single Family: $31,000 declining to $9,100 by 2020. [6]

**Key Consumer Preference/Values – Nonenergy Benefits**.[1] The cost and performance characteristics were used to model this project in NEMS-GPRA05/MARKAL-GPRA05. The following nonenergy characteristics were not considered in the model:

- Improved comfort, durability, and occupant health from better indoor air quality
- Reduced on-site generated waste
- Better sustainability
- Reduced maintenance.

### 1.2.3 Methodology and Calculations

**Inputs to Base Case.** The base case was developed based on an assortment of sources, including AEO 2003, CBECS 95, RECS 97, and several other sources, all of which are documented in the 2004 PNNL report, *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort* (Elliott, et. al).

**Technical Characteristics.** Reduce whole-house energy use by 40%, increasing to 70% in 2030. The renewable energy technologies also are credited with displacing energy supply with solar or other renewable technologies, such that an additional 10% in fossil fuel savings is achieved by 2010, increasing to 30% by 2020.

**Technical Potential.** The technical energy savings potential for this project includes all primary energy consumption in the residential sector, or 20 QBtu (Table 1.2.3, page 1-6 of *2003 Buildings Energy Databook*). Up to 70% of current residential building energy use would eventually (by 2030) be reduced through advanced building practices and technologies; with the remainder of the building load met using photovoltaic, solar thermal, and other on-site renewable technologies.

**Expected Market Uptake.** PNNL assumed that this activity would not occur in the absence of DOE funding, therefore, no acceleration of market acceptance was modeled. 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). **Table 2** displays the resulting estimated number of homes impacted based on the penetration curves developed.

### 1.2.4 Sources

(1) FY 2002 Budget – *Data Bucket Report for Residential Building Integration R&D Program* (internal BT document).
(2) *FY 2002 GPRA Program Characterization* (internal BT document).
(3) Based on Impacts spreadsheet developed by Ren Anderson, National Renewable Energy Laboratory, August 10, 2000, Confirmed by Ren Anderson in September, 2003.
(4) Average prices for single-family and multifamily homes are based on information from *MEANS Square Foot Cost 1995* and from Table 3.1b in "Residential Energy Consumption Survey." 1997. U.S. Department of Energy, Energy Information Administration. eia.doc.gov/emeu/recs/contents.html. Average prices for manufactured housing derived from data provided by the Manufactured Housing Institute, "Manufactured Home Shipments, Estimated Retail Sales and Average Sales Prices" (1997).
(5) *GPRA Metrics for the FY2000 Budget Request: Data Collection Survey*, August, 1998 (internal PNNL document).

(6) U.S. Department of Energy, Building Technologies Program. October 2003. *Final Draft: Zero Energy Homes' Opportunities for Energy Savings: Defining the Technology Pathways Through Optimization Analysis*.
(7) Based on Impacts spreadsheet developed by Ren Anderson, National Renewable Energy Laboratory, December 22, 2003, Confirmed by Ren Anderson in January, 2004.
(8) "The BUILDER 100 Database" at www.builderonline.com, accessed August 8, 2003.
(9) 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.
(10) BTS Core Databook (July 26, 2003), Table 5.1.1., "2001 Five Largest Residential Homebuilders."

**Table 2. FY 2005 Market Penetration for Residential Technology R&D Projects** (7)

| Year | BA Annual No. Homes | Annual Homes Impacted by Renewable Technologies Supported by Project |
|---|---|---|
| 2005 | 50,065 | 2,514 |
| 2006 | 78,420 | 5,667 |
| 2007 | 115,625 | 9,500 |
| 2008 | 157,704 | 16,238 |
| 2009 | 200,148 | 23,744 |
| 2010 | 250,888 | 33,048 |
| 2011 | 293,699 | 42,121 |
| 2012 | 317,715 | 48,992 |
| 2013 | 334,054 | 54,865 |
| 2014 | 355,265 | 61,637 |
| 2015 | 364,470 | 66,282 |
| 2016 | 375,111 | 70,983 |
| 2017 | 374,436 | 73,223 |
| 2018 | 377,371 | 75,792 |
| 2019 | 385,194 | 79,024 |
| 2020 | 383,500 | 80,000 |

## 2.0 Commercial Buildings Integration

The long-term goal of this subprogram is to develop cost effective designs for commercial buildings that produce as much energy as they use on an annual basis. Research will focus on reducing total energy use in a commercial building by 60% to 70%.

## 2.1 Commercial Building Energy Codes

### 2.1.1 Target Market

**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.

**Market Description.** The market includes new commercial and multifamily high-rise (above three stories) buildings and all additions and renovations to commercial buildings requiring code 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 FY05, the percentage of potential savings, in the first year of the single future code, was assumed to be approximately 20% for envelope measures and 30% for lighting measures without the project.

**Baseline Market Acceptance.** The FY 2005 GPRA estimates are based on increased compliance with existing codes, accelerated adoption of the 1999 and 2001 editions of ASHRAE 90.1-1999[4] standard (to comply with Section 304 of the Energy Conservation and Production Act), and the future development of more stringent building energy codes. Through the efforts of the Building Energy Codes project, 21 states were assumed to have adopted the standard by the end of 2005. The project was assumed to accelerate the adoption of the standard by an average of four years nationwide.

### 2.1.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.** Incremental investment costs were developed 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.

- Improved environment and more comfortable buildings.
- Lower utility bills
- 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.

### 2.1.3 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-GPRA05 base case. The NEMS-GPRA05 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, 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., IECC 2003) is included in the GPRA forecast of savings. The GPRA savings estimates for WIP also include a portion of the impact of changes in building codes that are anticipated within approximately the next 10 years. (A portion of the savings from increased stringency of future codes is also allocated to the Building Technologies Program). Therefore, PNNL did not provide inputs to change the base-case assumptions for the 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. This BT program works with the Training and Assistance for Codes project within the Office of Weatherization and Intergovernmental Programs, which funds the development of core materials (such as compliance tools and training materials) and provision of training and financial and technical assistance for states to update and implement their building energy codes. Benefits cannot be clearly allocated to either project, thus the benefits estimated are a function of both training and deployment as well as development of the commercial building energy codes and standards.

Savings estimates for commercial codes are based on increased stringency from the combined impact of the forthcoming ASHRAE 90.1-2004 code and the “next” code assumed to be published in 2007. For FY05, future codes (up through 2010) are assumed to achieve a total reduction of 18% in electricity and a 10% reduction in natural gas as compared to 90.1-1999, based on a series of simulations for various U.S. locations. Benefits for FY 2005 were assumed to be allocated according to the ratio of actual funding levels.

The project impacts energy consumption through two primary avenues: 1) developing and supporting code changes to improve the minimum energy efficiency requirements for commercial and multifamily high-rise buildings and 2) providing technical and financial assistance to states to update and implement their building energy codes. The latter includes developing tools that can ease the adoption of new codes and through their use, can support improvements in compliance and enforcement of code provisions. Tools take the form of code compliance software, computer-based training tools for building energy codes, and tools for implementing noncomputer-based codes.

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. Support 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 2005 GPRA estimates are based on increased compliance with existing codes, accelerated adoption of the 1999 and 2001 editions of ASHRAE 90.1[4] standard (to comply with Section 304 of the Energy Conservation and Production Act), and 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 principal differences between the ASHRAE 90.1-1989, 90.1-1999, and 90.1-2001[5] standards relate to requirements for better windows, reduced installed wattage for lighting, and more efficient heating and cooling equipment. The savings from improved equipment are not included in the project's savings estimates, because they are reflected in the Equipment Standards and Analysis decision unit in this appendix. Based on a series of simulations that include various U.S. locations and that were developed specifically to evaluate the two ASHRAE standards (often referred to as the "determination" study[6]), the average reduction in site energy use was estimated to be about 3.5% or 2 MMBtu/sq ft. The GPRA estimates were partly based on states' accelerated adoption schedule of the ASHRAE 90.1-1999 and 90.1-2001 standards. Through the efforts of the Building Energy Codes project, 21 states were assumed to have adopted the standard by the end of 2005. The project was assumed to accelerate the adoption of the standard by an average of four years nationwide.

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, assumed 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. Many states adopting this standard by 2010 also depends on the project's continuing activities to assist states in the adoption (and compliance) process. Without these activities, the analysis assumed that the same standard would be adopted, on average, six years later.

The project activities also were assumed to improve compliance rates for codes currently adopted by states and localities, as well as future building codes. Compliance is increased through increased familiarity with the codes, simplifications to the code while maintaining stringency, and the availability and increased use of compliance tools by builders and enforcement officials. Compliance is effectively measured as the percentage of potential savings moving from one code to the next. Compliance rates estimated between the existing code (assumed to be 90.1-1989) and a code based on ASHRAE 90.1-1999; and between 90.1-1999 and a new code discussed above.

Without the program, the percentage of potential savings is assumed to be modest, as the program is directed toward software tools and training that facilitate adherence to the code. In this case, on average, PNNL estimated the percentage of potential energy savings for envelope measures to be about 20% in the year of adoption. Ten years later, the percentage of potential energy savings is assumed to increase to approximately 50%. For lighting, these percentages were 30% and 55%, respectively. With the program, the percentage of potential energy savings is expected to be higher at the outset and increase more rapidly. For envelope measures, the initial potential savings is about 70%, increasing to about 95% 10 years later. For lighting measures, the initial percentage of savings is 80%, again increasing to about 95% years later.

**Expected Market Uptake.** As part of work for an unpublished analysis of the historical impacts of Building Energy Codes in August 2003, the assumptions regarding the acceleration effect of the program were modified (e.g., program activities leading to states adopting codes more rapidly than they would have otherwise). In general, the states were classified into groups that: 1) immediately adopted the ASHRAE 90.1-1989 code, 2) would have adopted within five years without the building codes project, or 3) would have adopted within 10 years without the building codes project. 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 three years for the forthcoming ASHRAE 90.1-2004 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. This modified set of assumptions increases the overall estimate of the future energy savings impact from the program.

### 2.1.4 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.
(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 Technology Research and Development

### 2.2.1 Target Market

**Project Description.** The Commercial Buildings Integration subprogram develops and demonstrates advanced technologies, controls, and equipment in collaboration with the design and construction community. The project focuses on advancing integrated technologies and practices to optimize whole-building energy performance. The project reduces energy use in commercial and multifamily buildings by promoting practices that help ensure the industry constructs buildings as designed and operates them at or near the optimum level of performance. The project's long-term goal is to improve the energy efficiency of the nation's new commercial buildings by 30% and existing buildings by 20% compared with buildings built in 1996.

**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 buildings with relatively higher energy use intensities such as assembly, education, health care, lodging, and office buildings.

**Market Introduction**(2): PNNL assumed that this project accelerates the adoption of relevant energy-savings products, technologies, and designs by 10 years.

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the 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)(5). The study suggested several generic penetration curves based on the type of equipment of interest. PNNL used the curve related to design products to model this project.

### 2.2.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.**
**Cost of Conventional Technology:**(3) Average of $101/ft$^2$ for the targeted new commercial and multifamily; $0 for existing buildings.
**Cost of BT Technology:** $103/ft$^2$ for new commercial and multifamily; $3/ft$^2$ (2001 to 2009), increasing to $4/ft$^2$ (2010 to 2030) for existing buildings.
**Incremental Cost:**(2) 2% above base for new buildings; $3/ft$^2$ (2005 to 2009), increasing to $4/ft$^2$ (2010 to 2030) for existing buildings.

**Key Consumer Preference/Values – Nonenergy Benefits**.(1) 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.

### 2.2.3 Methodology and Calculations

**Inputs to Base Case.** The base case was developed based on an assortment of sources including AEO 2003, CBECS 95, RECS 97, and several other sources, all of which are documented in the 2004 PNNL report, *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort* (Elliott, et. al).

**Technical Characteristics.** Together with the Analysis Tools and Design Strategies Project, this project has the following performance goals:

- By 2004, reduce heating and cooling loads by 30% in new construction and by 20% in existing units
- By 2010, reduce heating and cooling loads by 50% in new construction and by 30% in existing units.
- By 2020, reduce heating and cooling loads by 60% in new construction and 40% in existing units.

**Technical Potential.** Approximately 2 QBtu in 2005. The technical energy-savings potential for this project includes all heating, cooling, and water-heating primary energy consumption (5.3 QBtu) for about 70% of the commercial-building sector. Because the maximum performance goal for this program is a 60% reduction in these end uses, the technical potential is 5.3 QBtu * .60 * .70 = 2.2 QBtu. Table 1.3.3, page 1-10 of *2003 Buildings Energy Databook.*

**Expected Market Uptake.** The market-penetration goal is to accelerate the penetration of high-performance building designs, such that 60% of new commercial and multifamily construction – and 20% of existing construction—incorporates the products supported by this project 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). PNNL assumed that this project accelerates the adoption of relevant energy-savings products, technologies and designs by 10 years.

### 2.2.4 Sources


(1) Interview with the project manager, Dru Crawley, August, 2001.
(2) E-mail correspondence with project manager, Dru Crawley, June, 2003.
(3) RS Means Company, Inc. 2002. *"RS MEANS Square Foot Costs"*. 23rd Edition, Kingston, MA.
(4) RS Means Company, Inc. 2002. *"RS MEANS Square Foot Costs"*. 23rd Edition, Kingston, MA.
(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.


## 3.0 Equipment Standards and Analysis

This subprogram seeks to develop minimum energy efficiency standards that are technologically feasible and economically justified.

## 3.1 EPAct Standards

### 3.1.1 Target Market

**Project Description.** The EPAct standards were assumed to continue with the technologies having the potential for additional energy savings. These technologies include boilers, three phase residential size cooling equipment, packaged terminal air conditioning, packaged terminal heat pump equipment, and large rooftop air-conditioning equipment.

**Market Description:** The market includes all residential and commercial equipment covered by the appropriate legislation.[2,3]

**Size of Market:** The market size includes all applicable residential and commercial equipment in the market to which legislation applies (ovens/ranges and medical equipment, for example, are not covered).

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

### 3.1.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.** Incremental investment costs were developed assuming a nine-year payback period on investment (i.e., an annual energy cost savings of $1 implies an initial investment of $9). This corresponds with a total incremental investment cost of approximately $200 million in 2005, $1 billion in 2010, $1.4 billion 2020, and $600 million in 2030.

**Key Consumer Preferences/Values.** The following nonenergy characteristics were not considered in developing energy-output estimates:

- Reduced $CO_2$ and $SO_X$ emissions
- Reduced water consumption from plumbing equipment
- Increased life of equipment operating at cooler temperatures
- Reduced first costs that transform new technologies into commodities.

### 3.1.3 Methodology and Calculations

**Technical Characteristics.** For FY 2005, the energy savings from equipment standards activities were based primarily based on a PNNL screening analysis conducted in late 1999 and early 2000[4] to provide preliminary estimates of the potential energy savings from updated commercial equipment standards. PNNL used the spreadsheet developed for this study to estimate the energy savings from various levels of standards for nearly 40 types of equipment covered by EPAct. The spreadsheet results were used to identify technologies that could achieve significant energy savings beyond the efficiency levels set in the recent ASHRAE 90.1-1999 publication.[5]

Based on the spreadsheet EPACT_SA.XLS (essentially identical to the spreadsheet installed on the BT Web site for public comment subsequent to the EPAct screening analysis), the tables below summarize the efficiency assumptions and energy-savings results for technologies that DOE/BT will further analyze. The key assumptions and results were summarized for 12 cooling technologies in **Table 3** and for boilers and a high-capacity instantaneous water heater in **Table 4.** Cumulative savings, shown in the last column in both tables, were based on the savings from the effective date of the standards through 2030.

### Table 3. Key Assumptions and Results for Cooling Products

| Equipment Category | Efficiency (SEER and EER)* | | | Energy Savings by Year (TBtu) | | | |
|---|---|---|---|---|---|---|---|
| | EPAct | New Std | Eff. Date | 2010 | 2020 | 2030 | Cum. |
| 3-Phase Single Package, Air Source Air Conditioning, <65 kBtu/h | 9.7 | 12.0 | 2005 | 4.6 | 21.0 | 26.5 | 396.0 |
| 3-Phase Single Package, Air Source Heat Pump, <65 kBtu/h | 9.7 | 12.0 | 2005 | 1.2 | 3.1 | 3.4 | 60.2 |
| 3-Phase Split, Air Source Air Conditioning, <65 kBtu/h | 9.7 | 11.0 | 2005 | 0.9 | 4.1 | 5.2 | 78.1 |
| 3-Phase Split, Air Source Heat Pump, <65 kBtu/h | 9.7 | 12.0 | 2005 | 9.1 | 24.0 | 26.5 | 463.0 |
| Central, Water Source Heat Pump, >17 and <65 kBtu/h | 9.3 | 12.5 | 2008 | 1.5 | 7.1 | 11.1 | 146.9 |
| Central, Air Source Air Conditioning, >=65 and <135 kBtu/h | 8.9 | 11.0 | 2008 | 5.5 | 25.0 | 31.6 | 471.6 |
| Central, Air Source Air Conditioning, >=135 and <240 kBtu/h | 8.5 | 11.0 | 2008 | 5.4 | 24.6 | 31.0 | 463.1 |
| Packaged Terminal Air Conditioning, 7-10 kBtu/h | 8.6 | 10.8 | 2008 | 0.4 | 1.8 | 2.2 | 33.3 |
| Packaged Terminal Air Conditioning, 10-13 kBtu/h | 8.1 | 10.2 | 2008 | 0.6 | 2.6 | 3.3 | 49.5 |
| * SEER = seasonal energy efficiency ratio; EER = energy efficiency ratio. | | | | | | | |

### Table 4. Key Assumptions and Results for Boilers and a High-Capacity Instantaneous Water Heater

| Equipment Category | Efficiency (SEER and EER) | | | Energy Savings by Year (TBtu) | | | |
|---|---|---|---|---|---|---|---|
| | EPAct | New Std | Eff. Date | 2010 | 2020 | 2030 | Cum. |
| Pkg'd Boilers, Gas, 400 kBtu/h, Hot Water | 75% | 78% | 2008 | 0.2 | 0.9 | 1.7 | 19.7 |
| Pkg'd Boilers, Gas, 800 kBtu/h, Hot Water | 75% | 78% | 2008 | 0.4 | 2.0 | 3.7 | 43.0 |
| Pkg'd Boilers, Gas, 1500 kBtu/h, Hot Water | 75% | 78% | 2008 | 0.1 | 0.7 | 1.2 | 14.2 |
| Pkg'd Boilers, Gas, 3000 kBtu/h, HW | 75% | 80% | 2008 | 0.2 | 0.7 | 1.3 | 15.2 |
| Pkg'd Boilers, Gas, 400 kBtu/h, Steam | 72% | 76% | 2008 | 0.1 | 0.6 | 1.1 | 12.6 |
| Pkg'd Boilers, Gas, 800 kBtu/h, Steam | 72% | 76% | 2008 | 0.4 | 1.6 | 3.0 | 34.5 |
| Pkg'd Boilers, Gas, 1500 kBtu/h, Steam | 72% | 79% | 2008 | 0.3 | 1.2 | 2.3 | 26.7 |
| Pkg'd Boilers, Gas, 3000 kBtu/h, Steam | 72% | 80% | 2008 | 0.2 | 0.9 | 1.7 | 19.2 |
| Instantaneous Water Heaters, 1000 kBtu/h | 80% | 83% | 2008 | 1.0 | 4.4 | 5.6 | 83.3 |

## 3.2 Distribution Transformers [a]

### 3.2.1 Target Market

**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. Rules are being written to reduce the amount of heat loss during this conversion process.

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

### 3.2.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.** Incremental investment costs were developed assuming a 10-year payback period on investment (i.e., an annual energy cost savings of $1 implies an initial investment of $10). This corresponds to a total incremental investment of approximately $580 million in 2010, $780 million in 2020, and $230 million in 2030.

**Key Consumer Preferences/Values.** The following nonenergy characteristics were not considered in developing energy-output estimates:

- Reduced $CO_2$ and $SO_X$ emissions

### 3.2.3 Methodology and Calculations

**Inputs to Base Case.** The base case was developed based on an assortment of sources, including AEO 2003, CBECS 95, RECS 97, and several other sources, all of which are documented in the 2004 PNNL report, *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort* (Elliott, et. al).

**Technical Characteristics**
**Performance Target:** Savings estimates for a distribution transformer standard were based on a study conducted by Geller and Nadel.[7] The study assumed the following:

- Savings of 80 watts per unit
- 20% sales complying with the new level without the standard

**Lifetime:**

- 8,760 annual operating hours per unit
- 13-year life of equipment.

The savings estimate of 80 watts per unit installed was multiplied by the estimated hours of operation and then by the forecasted number of units installed.

[a] Updated information on the FY05 characterization of the Distribution Transformer Standard project became available too late to become incorporated in the official GPRA estimates for FY05. Therefore, the FY04 characterization was used as a proxy. This results in an unspecified under-reporting of benefits for the FY05 budget that will be addressed for the FY06.

**Expected Market Uptake**

**Table 5. Distribution Transformer Market Penetration**

| Year | Transformer Sales Forecast (8,9) |
|---|---|
| 2005 | 1,623,086 |
| 2006 | 1,654,225 |
| 2007 | 1,685,962 |
| 2008 | 1,718,307 |
| 2009 | 1,751,273 |
| 2010 | 1,784,871 |
| 2011 | 1,819,115 |
| 2012 | 1,854,015 |
| 2013 | 1,889,584 |
| 2014 | 1,925,836 |
| 2015 | 1,962,784 |
| 2016 | 2,000,440 |
| 2017 | 2,038,819 |
| 2018 | 2,077,934 |
| 2019 | 2,117,799 |
| 2020 | 2,158,429 |
| 2021 | 2,199,839 |
| 2022 | 2,242,044 |
| 2023 | 2,285,057 |
| 2024 | 2,328,057 |
| 2025 | 2,373,577 |
| 2026 | 2,419,114 |
| 2027 | 2,465,525 |
| 2028 | 2,512,827 |
| 2029 | 2,561,036 |
| 2030 | 2,610,170 |

## 3.3 Sources


(1) FY 2002 Budget Request - *Data Bucket Report for the Lighting and Appliance Standards Program* (internal BTS document).
(2) National Appliance Energy Conservation Act of 1987, Public Law 100-12.
(3) Energy Policy Act of 1992, Public Law 102-486.
(4) Somasundaran, S. et al. 2000. *Screening Analysis of EPAct-Covered Commercial HVAC and Water Heating Equipment*. PNNL-13232, Pacific Northwest National Laboratory, Richland, Washington.
(5) ASHRAE 90.1-1999, "Energy Standard for Buildings Except Low-Rise Residential Buildings," American Society of Heating, Refrigeration, and Air-Conditioning Engineers.
(6) *Annual Energy Outlook 2001*. 2001. Energy Information Administration, Washington, D.C.
(7) Geller, H., and S. Nadel. 1992. "Consensus National Efficiency Standards for Lamps, Motors, Showerheads and Faucets, and Commercial HVAC Equipment." In *American Council for an Energy Efficient Economy Proceedings*, pp. 6.71-6.82.
(8) Monthly Energy Review. May 2001. Table 7.1.
(9) *Annual Energy Outlook 2002*. 2002. Table 22. Energy Information Administration, Washington, D.C.

## 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

### 4.1.1 Target Market

**Project Description.** 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 nonsoftware solutions such as improved standards, guidelines, and performance measurements, all of which bring about excellence in designing new buildings.

**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**(2): 1996; PNNL assumed that this project accelerates the introduction and market penetration of the advanced building energy tools and design strategies by 10 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. PNNL assumes 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.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the 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)(5). The study suggested several generic penetration curves based on the type of equipment of interest. PNNL used the curve related to design products to model this project.

### 4.1.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.** 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, with the idea that the private sector can use these algorithms, codes, and modules and design a suitable user-friendly interface.

**Key Consumer Preference/Values – Nonenergy Benefits**.[(1)] 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).

### 4.1.3 Methodology and Calculations

**Inputs to Base Case.** The base case was developed based on an assortment of sources, including AEO 2003, CBECS 95, RECS 97, and several other sources, all of which are documented in the 2004 PNNL report, *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort* (Elliott, et. al).

**Technical Characteristics.** Working together with the Commercial Buildings R&D Project, this project has the following performance goals:

- By 2004, reduce heating and cooling loads by 30% in new construction and by 20% in existing units
- By 2010, reduce heating and cooling loads by 50% in new construction and by 30% in existing units.
- By 2020, reduce heating and cooling loads by 60% in new construction and 40% in existing units.

**Technical Potential.** Approximately 2 QBtu in 2005. The technical energy savings potential for this project includes all heating, cooling, and water-heating primary energy consumption (5.3 QBtu) for about 70% of the commercial building sector. Because the maximum performance goal for this program is a 60% reduction in these end uses, the technical potential is 5.3 QBtu * .60 * .70 = 2.2 QBtu[(4)].

**Expected Market Uptake.** The market penetration goal is to accelerate the penetration of high-performance building designs, such that 60% of new commercial and multifamily construction, and 20% of existing construction, incorporates the products supported by this project 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). PNNL assumes that this project accelerates the adoption of relevant energy-savings products, technologies, and designs by 10 years.

### 4.1.4 Sources

(1) FY 2002 Budget Request - *Data Bucket Report for Analysis Tools and Design Strategies Program* (internal BTS document).
(2) Interview with the project manager, Dru Crawley, August 22, 2001
(3) E-mail correspondence with project manager, Dru Crawley, June, 2003.
(4) Table 1.3.3, page 1-10 of 2003 Buildings Energy Databook.
(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

### 4.2.1 Target Market

**Project Description.** This project helps manufacturers and utilities commercialize highly efficient appliances and equipment by providing the following assistance:

- Technology procurement to bring new technologies to market (late developmental work), which can bridge the gap between traditional R&D and mainstream deployment.
- Independent third-party evaluation and verification of highly efficient technologies using field studies and demonstrations increase market share of emerging technologies and Energy Star technologies with very low market penetration.
- R&D on appliances not covered by other projects but offering significant energy-savings potential.

**Market Description:** The market includes residential and commercial building technologies, with emphasis on appliances, water heating, lighting, and building equipment.

**Size of Market:** The market size depends on the selected equipment:

- **Heat Pump Water Heaters:** 13.6 million existing homes of the potential 44 million homes with electric resistance water heaters and about 40% of new homes. Limited, but initial market, for light commercial.
- **Rooftop Air Conditioners:** One of the most widely used technologies with greatest commercial space-conditioning energy use; more than a million tons sold in 1998.
- **Residential Can Lights:** An estimated 22 million incandescent can fixtures sold in 2001.
- **Reflector CFLs (R-lamps):** Nearly 125 million parabolic/reflector lamps sold to the residential market.

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

### 4.2.2 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:

- Reduced carbon emissions
- Economic benefits to private sector.
- Dehumidification provided by heat-pump water heater.
- Reduced lamp replacement frequency with R-CFLs and CFL cans.

### 4.2.3 Methodology and Calculations

**Heat-Pump Water Heater**

The purpose of this project is to expand the market for heat-pump water heaters. Field testing, data collection, workshops, and potential volume purchasing are elements of this project. The Appliances and Emerging Technologies project is assumed to lead to a more rapid commercialization of a moderately priced heat-pump water heater, first available in 2003.

The input file used for *Annual Energy Outlook 2001*[(2)] included several categories of heat-pump water heaters, two having installed costs of >$1,000. With the discount rates used in *Annual Energy Outlook 2001* for electric water heaters, only a very small number of the $1,025 units are predicted to be sold (no higher-costs unit). A more moderately priced heat-pump unit is assumed to become available in 2005, with a cost of $900 and an energy factor of 2.0. By 2015, the cost of this unit is assumed to fall to $800 and the energy factor to increase to 2.2.

The original *Annual Energy Outlook 2001* input file does not reflect the pending water heater standards that are scheduled to take effect in 2004. Two modifications were made to account for these standards (shown at the top of Table 9.1):

1. Technology No. 1 (see Table 9.1) was assumed to be unavailable after 2003 and therefore was dropped from the list of technologies available to consumers in the FY 2005 time horizon.

2. The efficiency for Technology No. 2 was changed to 0.89 with an unchanged cost (see revised characteristics under technology labeled No. 2a in **Table 6**).

Table 6. Key NEMS-PNNL[b] Inputs for Electric Water Heaters

| Technology | Start Year | End Year | Energy Factor | Installed Cost | Type |
|---|---|---|---|---|---|
| 1 | 1997 | 2003 | 0.86 | $350 | Resistance |
| 2 | 1997 | 2003 | 0.88 | $350 | Resistance |
| 2a | 2003 | 2020 | 0.89 | $350 | Resistance |
| 3 | 1997 | 2020 | 0.95 | $575 | Resistance |
| 4 | 1997 | 2020 | 2.60 | $1,025 | Heat Pump* |
| 5 | 1997 | 2020 | 2.00 | $2,600 | Heat Pump |
| 6 | 1997 | 2020 | 0.90 | $360 | Resistance |
| 7 | 2005 | 2020 | 0.96 | $475 | Resistance |
| 8 | 2004 | 2009 | 2.47 | $700 | Heat Pump** |
| 9 | 2015 | 2020 | 0.90 | $400 | Resistance |
| 10 | 2015 | 2020 | 0.96 | $425 | Resistance |
| 11 | 2006 | 2020 | 2.47 | $650 | Heat Pump** |

* Inexplicably, the lower-cost unit is assumed to have a higher efficiency.
** Appliances and Emerging Technologies project.

The Appliances and Emerging Technologies project is assumed to lead to a more rapid commercialization of a moderately priced heat pump water heater, first available in 2003. However, the project's principal impact is to achieve a lower cost than the unit assumed to be introduced in 2005 in the *Annual Energy Outlook 2001* base case. As **Table 6** shows, the heat pump water heater units supported by emerging technologies are assumed initially to have energy efficiency rating of 2.47 and an installed cost of $700.[c] By 2006, further development will yield a unit with the same energy factor (2.47) at lower cost ($650).

One issue related to assessing impacts of this technology with the NEMS-PNNL model is the appropriate discount rate to use. The logit parameters in the NEMS-PNNL model related to the choice of electric water heaters are -0.0162 (Beta1) and -0.0195 (Beta2), implying a discount rate of about 83%.[d] At this discount rate, the high initial cost of the heat pump water heater, even with its much higher efficiency, discourages most consumers from choosing this technology. A more robust assessment of the project is obtained by assuming that the ongoing Energy Star project for water heaters provides impetus for increased market acceptance of the heat pump

[b] Any modification or alteration to the official EIA NEMS model must be called out as such; for PNNL's effort, the modified version used is referred to as NEMS-PNNL.
[c] The influence of emerging technologies research is assumed to reduce the unit from $900 (Annual Energy Outlook 2001 base case) to $700.
[d] Within NEMS-PNNL, the two modeling parameters determining the discount rate are labeled Beta1 and Beta2. Beta1 is used as a multiplicative factor with the initial cost of the appliance. Beta2 is used to multiply the annual energy cost. As a rough approximation, the ratio of Beta1/Beta2 can be interpreted as the consumer discount rate for the specific appliance.

water heater.[e] In this scenario, the changes in the discount rates assumed for Energy Star project are combined with the introduction of the (lower-cost) heat-pump water heater.

The *Annual Energy Outlook 2001* baseline parameters that determined the market share for electric water heaters are described as follows:

$$\frac{Beta_1}{Beta_2} = \frac{-0.0162}{-0.0195} \approx discount\ rate = 83\%$$

With the support of the Appliances and Emerging Technologies and the Energy Star projects, the parameters impacting market share were assumed to change in the following manner, based on project goals:

$$\frac{Beta_1^{E-Star}}{Beta_2^{E-Star}} = \frac{-0.0072}{-0.0195} \approx discount\ rate^{E-Star} = 37\%$$

As **Table 7** shows, the lower discount rates generate much higher penetrations of the heat pump water heater, ultimately reaching nearly 25% of sales by 2010. While Table 9.2 displays the shares for only new homes, the shares for the replacement market are similar.

**Table 7. NEMS-PNNL Results for Heat Pump Water Heaters (national market shares[f] for new single-family homes)**

| Year | Market Share with *Annual Energy Outlook 2001* Discount Rate | Market Share with Adjusted NEMS-PNNL Discount Rates |
|---|---|---|
| 2004 | 0.024 | 0.040 |
| 2005 | 0.012 | 0.031 |
| 2006 | 0.012 | 0.050 |
| 2007 | 0.012 | 0.077 |
| 2008 | 0.012 | 0.116 |
| 2010 | 0.028 | 0.239 |
| 2015 | 0.047 | 0.241 |
| 2020 | 0.048 | 0.243 |

[e] Market transformation projects, such as Energy Star, attempt to accelerate market penetration of existing high-efficiency technologies. From a modeling standpoint, these efforts translate into reducing the consumer's discount rate for these energy-efficient products. See the documentation specific to Energy Star project for more information.

[f] The market shares in this discussion pertain only to electric water heaters.

The project's energy savings were calculated as the difference between NEMS-PNNL model runs that do the following:

1. Include the heat pump water heaters assumed in the AEO base case.
2. Substitute the lower-cost units assumed to stem from the Emerging Technologies project.
3. Assume Energy Star influence on deploying technology such that discount rate is reduced for water heaters.[g]

In essence, the heat pump water heater savings were calculated as the difference between an Energy Star project with and without the units developed under the Appliances and Emerging Technologies project.

**Market Introduction:** 2003; PNNL assumed these projects would accelerate the introduction of these technologies into the marketplace by 10 years.

**Performance Target:** 2.47 energy factor.

**Installed Cost:** Initial installation cost of $700, decreasing to $650 in 2006.

**Lifetime:** 10 years.

**Rooftop Air Conditioning**

The intent of the rooftop air-conditioner project is to use competitive procurements of large numbers of units to stimulate the production of high-efficiency equipment. The immediate goal is to get high-efficiency equipment installed in buildings owned by the federal government and other state and local agencies. A long-term, key outcome of the project is to provide incentives for manufacturers to reduce the cost of this equipment to all potential and private sector buyers.

With this long-term goal in mind, PNNL adjusted the assumed costs of high efficiency roof top air conditioners in the NEMS-PNNL commercial model to reflect the principal influence of this project. In NEMS-PNNL, two air conditioners were specified in the rooftop category—a baseline unit (energy efficiency ratio of 8.5) and a high-efficiency unit (energy efficiency ratio of 11.6). No subgroups were distinguished by capacity (e.g., 65 to 135 kBtu/hr vs. 135 to 240 kBtu/hr).

For this analysis, the incremental cost was reduced by 40%, based on project goals. Given the proportion of the market assumed in the NEMS-PNNL to display high discount rates in the selection of equipment, this cost reduction yielded a 9% penetration of the high-efficiency unit in 2005. The penetration rate falls to 6% in 2010, possibly as a result of a greater efficiency in the baseline units and/or lower energy costs. By 2020, the proportion of the total stock using the high-efficiency unit is about 5%.

[g] In both runs, the adjustments to the discount rate (via the Beta1 coefficient) were the same as those used in evaluating the Energy Star project (within the Weatherization and Intergovernmental Program) for water heaters. The assumption of an ongoing Energy Star project raises the question of whether the Energy Star project should receive some of the credit for energy savings from this technology. No clear methodology exists for decomposing the benefits between applied R&D project and market conditioning activities. If such an attribution must be made for this process, 70% of the savings are proposed to be assigned to the Appliances and Emerging Technologies project and 30% to Energy Star.

**Market Introduction:** 2004; PNNL did not model any acceleration of market acceptance because the impact was determined to be negligible. Because the technology has only modest penetration (10%) by 2020 and only a few percent by 2010, assuming that this project accelerated market acceptance would not have a significant impact over the analysis period, therefore, no acceleration was assumed.

**Performance Target:** An efficiency increase from 10.3 to 11.0 energy efficiency ratio for 65 to 135 kBtu/hr and from 9.7 to 10.8 for 135 to 240 kBtu/hr.

**Lifetime:** 15 years.

**Residential Can Lights**

The intent of this project is to develop a recessed can light fixture that uses compact fluorescent lamps rather than incandescent.

**Market Introduction:** 2003; these projects were assumed to accelerate the introduction of these technologies into the marketplace by seven years.

**Performance Target:** Assumed efficacy of 37.5 lumens/watt[h]. Actual project requirements should be similar to other programs; here, efficacy is expected to improve by a factor of 2.5, while R-lamps are expecting an improvement factor of 3.33 and Energy Star CFLs are looking to an improvement factor of 3.42.

**Installed Cost**: Incremental cost above incandescent cans is $30/can in 2004 declining to $20/can by 2011.

**Lifetime:** 30 years.

**R-Lamps**

The intent of this project is to develop a floodlight or spotlight (lamps using reflector surfaces) that can utilize a screw-base compact fluorescent lamp rather than an incandescent lamp.

**Market Introduction:** 2004; these projects were assumed to accelerate the introduction of these technologies into the marketplace by five years.

**Performance Target:** Assumed efficacy of 50 lumen/watt[i]. Actual project requirements should be similar to Energy Star (within WIP), as **Table 8** shows.

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[h] Actual efficacy is lower than this value. The value of 37.5 assumes an existing technology value of 15 lumens/watt; actual incandescent can lights have efficacies significantly lower than this. However, BESET currently assume all incandescent lighting to have an efficacy of 15 lumens/watt. The proposed technology, which has the same lumen output as the current technology, is rated at 26W while the existing incandescent technology is rated at 65W. Hence 15 * 65 / 26 = 37.5.

[i] Actual efficacy is lower than this value. Weighting the Energy Star targets 58% for less than 20W and 42% for 20W or more (58% of incandescent lamps in homes have Wattages less than 75W and 42% of incandescent lamps in homes have Wattages 75W and greater[(1)]) yields an average lumens/watt of 36. The comparison incandescent lamp, EPACT 65W R-lamp, has approximately 700 lumens or 10.8 lumens/watt. Thus the proposed technology has an efficacy 3.33 times that of the incandescent lamp. However, because BESET currently assume all incandescent lighting to have an efficacy of 15 lumens/watt the actual 36 lumens/watt cannot and for the appropriate comparison 50 lumens/watt must be used (15 * 3.33 = 50 lumens/watt).

**Table 8. Performance Targets for R-Lamps**

| Lamp Power (watts) and Configuration | Minimum Efficacy: Lumens/watt* |
|---|---|
| **Reflector Lamp:** | |
| Lamp power <20 | 33 |
| Lamp power >=20 | 40 |
| * Based on initial lumen date. | |

**Installed Cost:** Initial cost is $7/compact fluorescent lamp reflector lamp; which represent an initial incremental cost of $5/unit in 2004, which declines to $1.50/unit by 2020.

**Lifetime:** 8,000 hours

### 4.2.4 Sources


(1) Estimated from http://enduse.lbl.gov/Info/LBNL-39102.pdf, p.19.
(2) Gordon, K.L., and M.R. Ledbetter. 2001. *Technology Procurement Screening Study*. Pacific Northwest National Laboratory, Richland, Washington.
(3) The Freedonia Group, Inc. 1999. *Lamps in the United States to 2003*. Cleveland, Ohio. (See the following sections: "Introduction," "Executive Summary," "Market Environment," "Supply and Demand," "Incandescent Lamps," "Electrical Discharge," and "Lamp Markets.")


## 4.3 Envelope Research and Development

### 4.3.1 Target Market

**Project Description.** The project's objective is to promote the research, development, and deployment of energy-efficient windows. Because the fenestration field is less suited to national standards and has a growing international market, significant investments are needed to establish a technical basis for performance standards recognized for scientific excellence. On this basis, the project helps develop the credible rating, certification projects, and design tools to develop and apply efficient windows. The project also conducts R&D on high-performance windows, including electrochromic technology and durable spectrally selective glazing.

The project's specific long-term goals are as follows:

- National: Change windows from net energy losers to net energy providers across the United States.
- Industry: Strengthen market position of U.S. industry in global markets.
- Owners: Provide cost-effective savings with comfort, productivity, and amenity.

**Market Description**(1)**:** The market includes new and existing commercial and residential buildings in all climate zones.

**Size of Market**(1)**:** 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.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

### 4.3.2 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:

- Reduced utility and building peak loads
- Reduced HVAC Requirements and first costs
- Improved indoor comfort and aesthetics.

### 4.3.3 Methodology and Calculations

**Inputs to Base Case.** The base case was developed based on an assortment of sources including AEO 2003, CBECS 95, RECS 97, and several other sources, all of which are documented in the 2004 PNNL report, *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort* (Elliott, et. al).

**Electrochromic Windows**

Electrochromic multilayer windows are windows that can be darkened by applying a low voltage. When the voltage is removed, the window lightens. This project develops commercially viable advanced electrochromic windows using competing producers. With a focus on electrochromic research, the project's objective is to reward the marketplace for industry's investments in researching, developing, and deploying energy-efficient windows.

**Market Introduction:** 2010; This project was assumed to accelerate the introduction of this technology into the marketplace by 10 years.

**Performance Parameters:** Performance parameters for Electrochromic Windows are presented in **Table 9**.

**Table 9. Performance Parameters for Electrochromic Windows**

| Parameter | Value | Units |
|---|---|---|
| Maximum Shading Coefficient | 0.4 (heating) | Dimensionless |
| Minimum Shading Coefficient | 0.1 (cooling) | Dimensionless |
| U-value | 0.25 | Btu/h • $ft^2$• $^oF$ |
| Lighting Reduction | 30 | % of lighting energy |

**Performance Target.** Performance characteristics vary by building type and climate zone. The estimated savings per building were determined by simulating residential buildings in all climate zones. National impacts were determined using BEAMS (see **Table 10**).

**Table 10. Performance Targets for Electrochromic Windows**

| | New Buildings | | Existing Buildings | |
|---|---|---|---|---|
| | HEAT | | HEAT | |
| | North | South | North | South |
| Assembly | 8.01% | 6.53% | 9.51% | 6.96% |
| Education | 4.97% | -1.25% | 5.37% | 2.48% |
| Food Sales | -71.9% | -94.83% | -35.01% | -67.56% |
| Food Services | .27% | 46.05% | 6.97% | 8.78% |
| Health Care | 81.33% | 93.42% | 79.47% | 67.56% |
| Lodging | 16.31% | 71.14% | 19.00% | 34.94% |
| Office-Large | 47.78% | 73.28% | 41.38% | 51.71% |
| Office-Small | 17.71% | 40.94% | 18.28% | 28.28% |
| Merc/Service | -52.26% | -84.53% | -31.01% | -51.24% |
| Warehouse | -71.9% | -40.11% | -10.89% | -12.7% |
| Other | -20.91% | -94.83% | -5.00% | -19.94% |

| | New Buildings | | Existing Buildings | |
|---|---|---|---|---|
| | COOL | | COOL | |
| | North | South | North | South |
| Assembly | 34.78% | 28.50% | 34.99% | 28.72% |
| Education | 38.54% | 32.24% | 38.25% | 32.47% |
| Food Sales | 28.43% | 22.85% | 28.64% | 23.69% |
| Food Services | 26.43% | 21.51% | 25.63% | 21.71% |
| Health Care | 29.40% | 21.01% | 30.26% | 22.34% |
| Lodging | 37.39% | 30.80% | 38.00% | 31.61% |
| Office-Large | 40.69% | 39.64% | 39.82% | 39.50% |
| Office-Small | 34.74% | 32.27% | 34.15% | 32.61% |
| Merc/Service | 41.46% | 35.31% | 41.70% | 35.61% |
| Warehouse | 94.90% | 58.18% | 79.65% | 43.26% |
| Other | 61.43% | 52.76% | 63.26% | 51.24% |

**Installed Cost:—**Incremental Cost Over Low-e Double-Pane Windows
2010: $50.00/ft^2$
2015: $20.00/ft^2$
2030: $5.00/ft^2$

**Lifetime:** 20 years.

**Expected Market Uptake.** The goal is to obtain 20% of window sales in new buildings and 17% in existing 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 electrochromic window sales with the DOE project; the "Net" penetration curve represents the percent of sales attributable to DOE, as PNNL assumed that the DOE project would accelerate market acceptance by 10 years. See penetration curves in **Figures 1 and 2**.

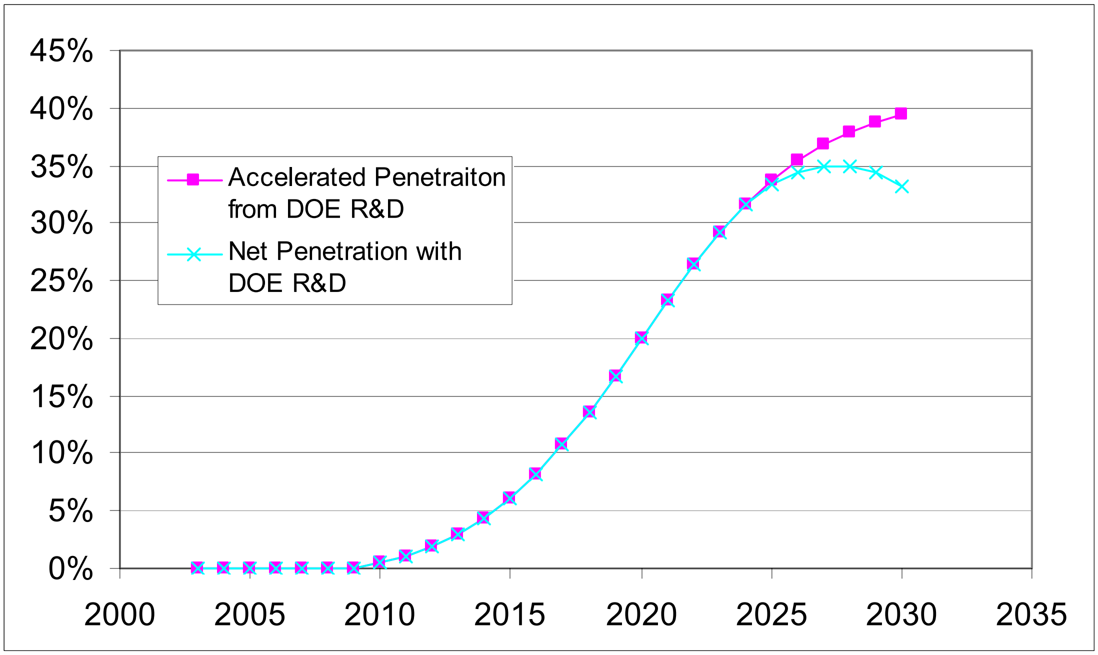


**Figure 1. Market Penetration of Electrochromic Windows in New Buildings**

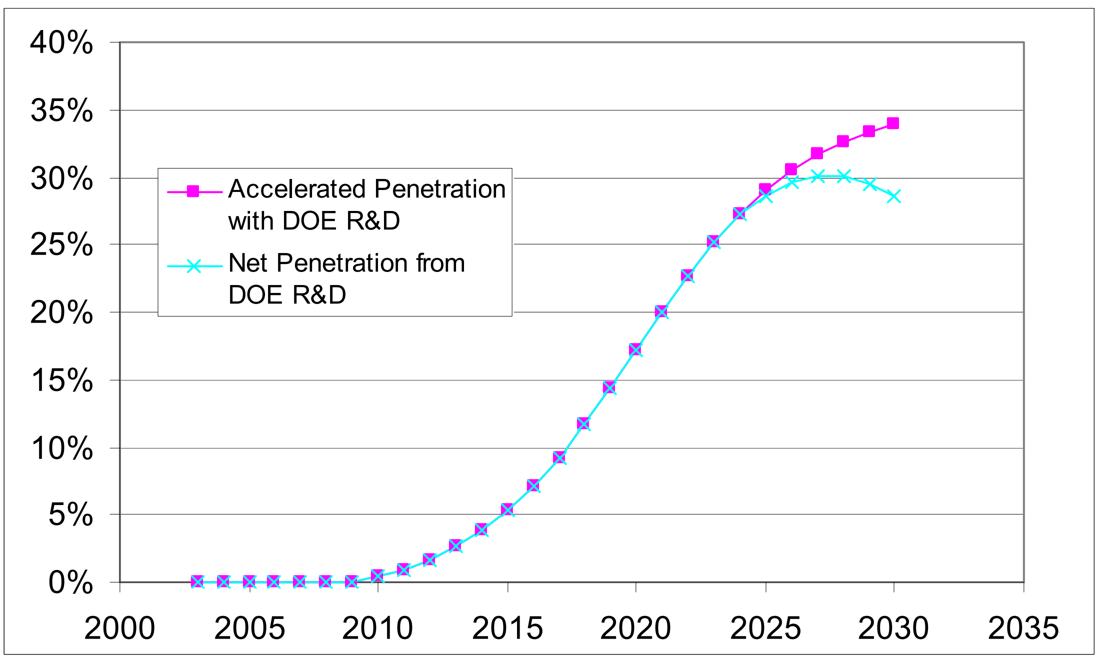


**Figure 2. Market Penetration of Electrochromic Windows for Existing Buildings**

## Superwindows

The project is developing commercially viable advanced technologies from competing producers and providing research support to Energy Star and Efficient Window Collaborative projects. One project objective is to double the average energy efficiency of windows sold and establish universal National Fenestration Rating Council ratings based on credible International Standards Organization standards.

**Technical Characteristics.**
**Market Introduction:** 2007; PNNL assumed that this project would accelerate the introduction of this technology into the marketplace by 10 years.

**Performance Parameters:** Two superwindow technologies were used: northern superwindows in heating-dominated climates (heating-degree days >4500) and southern superwindows in cooling dominated climates (heating-degree days <4500) (see **Table 11**).

**Table 11. Performance Parameters for Superwindows**

| Window | Parameter | Value | Units |
|---|---|---|---|
| Northern Superwindow | Shading Coefficient | 0.7 (heating season)<br>0.3 (cooling season) | Dimensionless |
| | U-value | 0.1 | Btu/h • ft$^2$ • $^o$F |
| Southern Superwindow | Shading Coefficient | 0.15 (all seasons) | Dimensionless |
| | U-value | 0.2 | Btu/h • ft$^2$ • $^o$F |

**Performance Target:** Performance characteristics vary by building type and climate zone. The estimated savings per building were determined by simulating residential buildings in all climate zones. National impacts were determined using BEAMS (see **Table 12**).

**Table 12. Performance Targets for Superwindows**

| | New Buildings | | Existing Buildings | |
|---|---|---|---|---|
| | HEAT | | HEAT | |
| | North | South | North | South |
| Single-Family | 38.76% | -63.79% | 27.97 | -10.66 |
| Multi-Family | 90.76% | 69.58% | 73.93 | 22.05 |
| Mobile Home | 21.42% | -18.24% | 20.19 | -5.36 |
| | COOL | | COOL | |
| Single-Family | 8.68% | 27.25% | 10.62 | 25.58 |
| Multi-Family | -5.97% | 23.79% | -.29 | 25.05 |
| Mobile Home | 15.09% | 29.05% | 15.03 | 26.20 |

**Installed Cost:—**Incremental Cost Over Low-e Double-Pane Windows

2007: \$6.00/ft$^2$
2020: \$4.00/ft$^2$
2030: \$3.00/ft$^2$

**Lifetime:** 30 years

**Expected Market Uptake.** The goal is to obtain 65% of window sales in new buildings and 33% in existing 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 sales attributable to DOE, as

PNNL assumed that the DOE project would accelerate market acceptance by 10 years. See penetration curves in **Figures 3 and 4**.

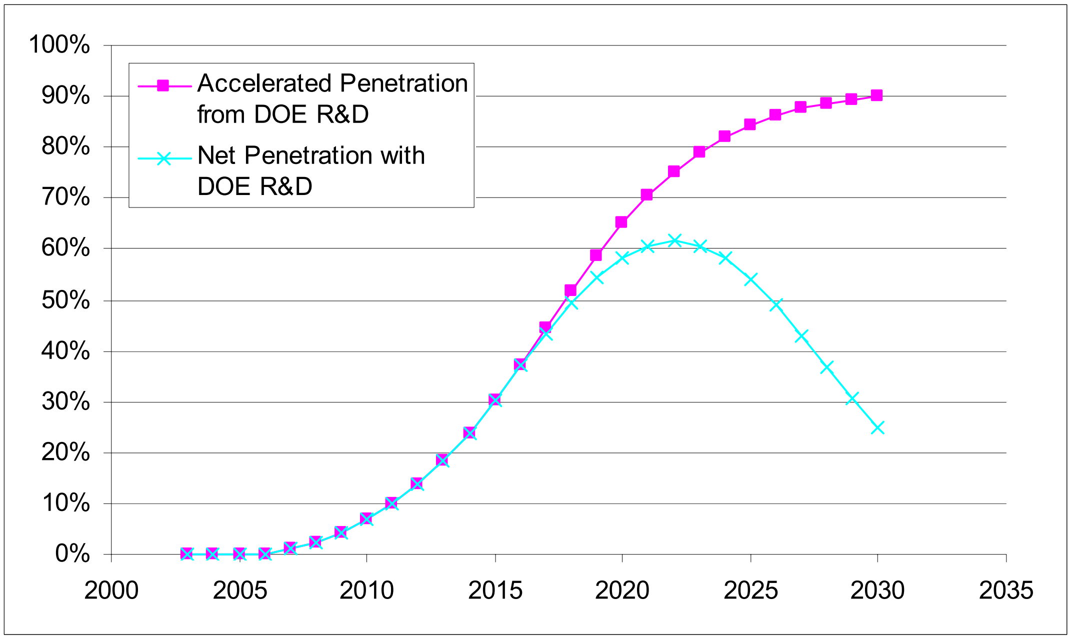


**Figure 3. Market Penetration of Superwindows in New Buildings**

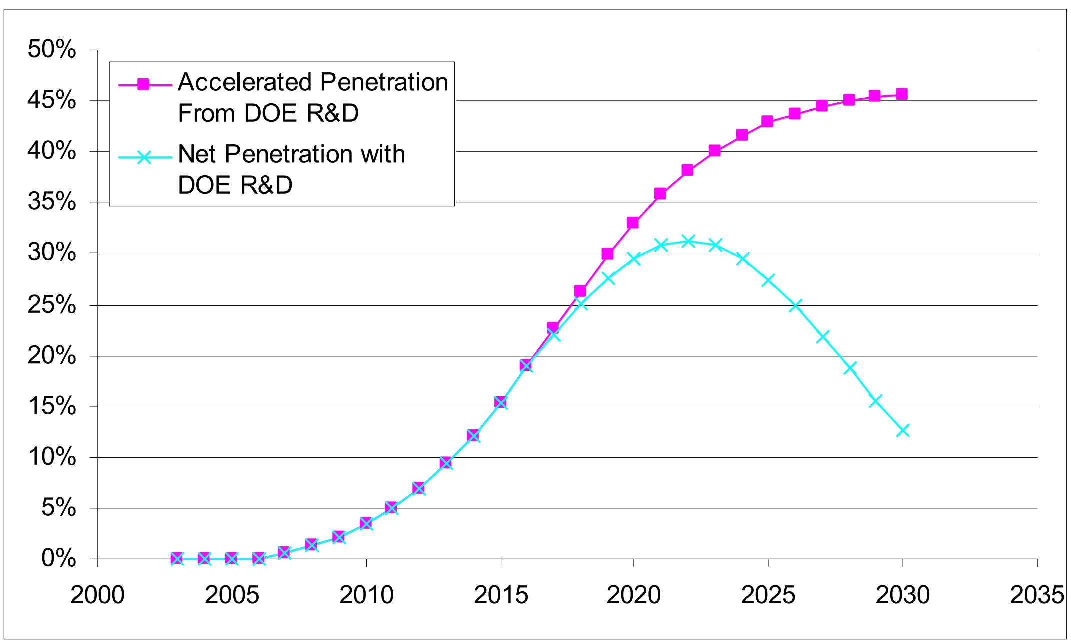


**Figure 4. Market Penetration of Superwindows for Existing Buildings**

## Low-Emissivity Glass Acceptance

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. This is a new program for FY05. 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 (BT) and Energy Star Windows (Office of Weatherization and Intergovernmental Programs), 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.

**Market Introduction:** The technology is commercially available. PNNL assumed that this project would accelerate the penetration in the marketplace by 10 years.

**Methodology and Calculations**

**Technical Characteristics.**
**Performance Parameters:** Performance parameters are listed in **Table 13**.

**Table 13. Performance Parameters for Low-e Windows**

| Parameter | Value | Units |
|---|---|---|
| Shading Coefficient | 0.52 | Dimensionless |
| U-value | 0.357 | Btu/h • ft$^2$ • $^o$F |

- **Performance Target:** Performance characteristics vary by building type and climate zone. The estimated savings per building were determined by simulating residential buildings in all climate zones. National impacts were determined using BEAMS (see **Table 14**).

**Installed Cost:**—Incremental Cost Over Conventional Double-Pane Windows

- 2005: \$1.00/ft$^2$
- 2010: \$0.50/ft$^2$
- 2015: \$0.00/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 both markets by 2020. Both programs, Low-e Market Acceptance and Energy Star Windows (Office of Weatherization and Intergovernmental Programs), 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 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 sales attributable to DOE, as PNNL assumed that the DOE project would accelerate market acceptance by 10 years. The penetration rates are shown in **Figures 5 and 6**. For Low-e Market Acceptance/Energy Star Windows, PNNL assumed that these projects would accelerate the acceptance of this technology in the marketplace by 10 years.

**Table 14. Performance Targets for Low-e Windows**

| New Buildings | | | Existing Buildings | |
|---|---|---|---|---|
| | Heat | | Btu/h • ft$^2$ • $^o$FHeat | |
| | North | South | North | South |
| SingleFamily | 39.73% | 66.19% | 28.22% | 42.54% |
| MultiFamily | 75.26% | 94.44% | 63.73% | 84.21% |
| MobileHome | 44.99% | 53.89% | 34.16% | 39.30% |
| Assembly | 44.88% | 76.06% | 38.32% | 64.07% |
| Education | 41.27% | 73.62% | 45.36% | 66.11% |
| Food Sales | 64.06% | 91.69% | 59.00% | 76.73% |
| Food Service | 66.17% | 90.08% | 56.17% | 80.10% |
| Health Care | 97.69% | 99.81% | 91.42% | 98.22% |
| Lodging | 63.34% | 95.42% | 55.83% | 88.91% |
| Office-Large | 65.00% | 85.55% | 59.44% | 82.17% |
| Office-Small | 50.17% | 73.83% | 43.72% | 72.34% |
| Merc/Service | 57.53% | 80.16% | 58.11% | 75.68% |
| Warehouse | 53.33% | 63.84% | 14.82% | 9.86% |
| Other | 55.83% | 86.76% | 44.19% | 59.20% |

| New Buildings | | | Existing Buildings | |
|---|---|---|---|---|
| | Cool | | Cool | |
| | North | South | North | South |
| SingleFamily | 13.95% | 16.59% | 16.30% | 17.38% |
| MultiFamily | 1.92% | 9.23% | 7.35% | 11.80% |
| MobileHome | 22.31% | 23.04% | 19.26% | 19.68% |
| Assembly | -11.69% | -8.47% | -4.85% | -4.18% |
| Education | -23.64% | -15.70% | -8.81% | -4.87% |
| Food Sales | -13.76% | -11.35% | -11.59% | -6.65% |
| Food Service | -15.38% | -10.65% | -8.14% | -6.10% |
| Health Care | -21.81% | -12.28% | -19.93% | -13.88% |
| Lodging | -38.61% | -29.58% | -18.52% | -19.56% |
| Office-Large | -40.67% | -31.12% | -33.71% | -27.50% |
| Office-Small | -25.43% | -23.59% | -7.03% | -10.92% |
| Merc/Service | -24.41% | -17.66% | -17.90% | -10.77% |
| Warehouse | 63.97% | 21.01% | 47.73% | 2.10% |

| | New Buildings | | Existing Buildings | |
|---|---|---|---|---|
| | Heat | | Heat | |
| | North | South | North | South |
| Single Family | 39.73% | 66.19% | 28.22% | 42.54% |
| Multi Family | 75.26% | 94.44% | 63.73% | 84.21% |
| Mobile Home | 44.99% | 53.89% | 34.16% | 39.30% |
| Assembly | 44.88% | 76.06% | 38.32% | 64.07% |
| Education | 41.27% | 73.62% | 45.36% | 66.11% |
| Food Sales | 64.06% | 91.69% | 59.00% | 76.73% |
| Food Service | 66.17% | 90.08% | 56.17% | 80.10% |

| | | | | |
|---|---|---|---|---|
| Health Care | 97.69% | 99.81% | 91.42% | 98.22% |
| Lodging | 63.34% | 95.42% | 55.83% | 88.91% |
| Office-Large | 65.00% | 85.55% | 59.44% | 82.17% |
| Office-Small | 50.17% | 73.83% | 43.72% | 72.34% |
| Merc/Service | 57.53% | 80.16% | 58.11% | 75.68% |
| Warehouse | 53.33% | 63.84% | 14.82% | 9.86% |
| Other | 55.83% | 86.76% | 44.19% | 59.20% |

| | New Buildings | | Existing Buildings | |
|---|---|---|---|---|
| | Cool | | Cool | |
| | North | South | North | South |
| Single Family | 13.95% | 16.59% | 16.30% | 17.38% |
| Multi Family | 1.92% | 9.23% | 7.35% | 11.80% |
| Mobile Home | 22.31% | 23.04% | 19.26% | 19.68% |
| Assembly | -11.69% | -8.47% | -4.85% | -4.18% |
| Education | -23.64% | -15.70% | -8.81% | -4.87% |
| Food Sales | -13.76% | -11.35% | -11.59% | -6.65% |
| Food Service | -15.38% | -10.65% | -8.14% | -6.10% |
| Health Care | -21.81% | -12.28% | -19.93% | -13.88% |
| Lodging | -38.61% | -29.58% | -18.52% | -19.56% |
| Office-Large | -40.67% | -31.12% | -33.71% | -27.50% |
| Office-Small | -25.43% | -23.59% | -7.03% | -10.92% |
| Merc/Service | -24.41% | -17.66% | -17.90% | -10.77% |
| Warehouse | 63.97% | 21.01% | 47.73% | 2.10% |

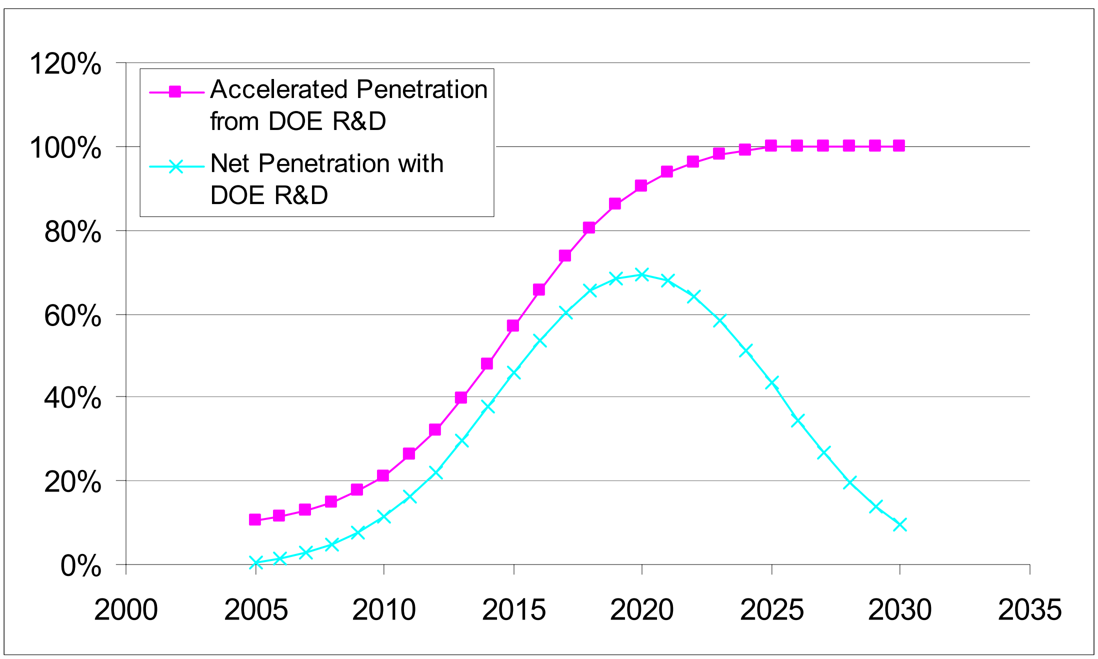


**Figure 5. Market Penetration of Low-e Windows in Commercial Buildings**

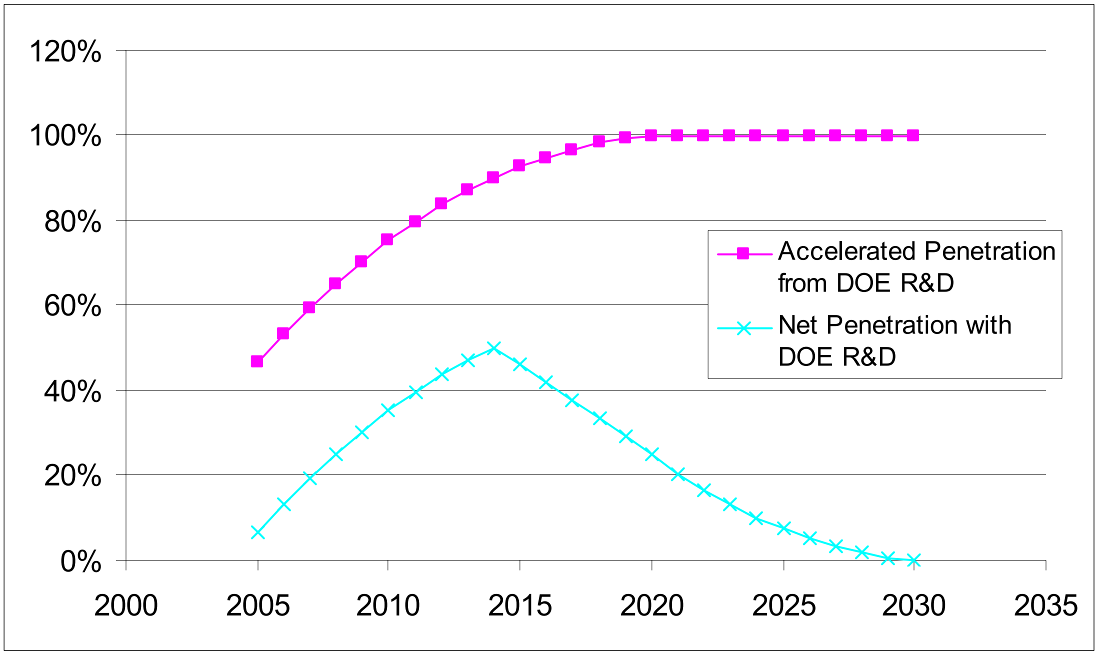


**Figure 6. Market Penetration of Low-E Windows in Residential Buildings**

### 4.3.4 Sources


(1) *FY 2002 Budget Request - Data Bucket Report for Building Envelope: Windows Program* (internal BT document).

(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 Lighting Research and Development

### 4.4.1 Lighting Controls

#### 4.4.1.1 Target Market

**Project Description.** The Lighting R&D project develops and accelerates the introduction of advanced lighting technologies.

**Market Description:** The market includes all commercial buildings, with some technologies being introduced into residential buildings.

**Size of Market:** Lighting consumes 26% (3.9 quad) of the primary energy used in commercial buildings, which had a building stock of about 69 billion sq ft in 2000[(1)].

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

#### 4.4.1.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.** Incremental investment costs were developed assuming a four-year payback period on investment (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
- Responds to an industry-initiated collaborative.

#### 4.4.1.3 Methodology and Calculations

**Inputs to Base Case.** The base case was developed based on an assortment of sources, including AEO 2003, CBECS 95, RECS 97, and several other sources, all of which are documented in the 2004 PNNL report, *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort* (Elliott, et. al).

**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 2005, 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.** PNNL 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).

#### 4.4.1.4 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

### 4.4.2 Solid-State Lighting

#### 4.4.2.1 Target Market

**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.

**Market Description:** The market includes all commercial buildings, with some technologies being introduced into residential buildings.

**Size of Market**(4): 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.[j]

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

#### 4.4.2.2 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
- Responds to industry-initiated collaborative.

#### 4.4.2.3 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 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) by A.D. Little for BT in early 2001; the study used some of the basic assumptions in the white paper(2) in developing some scenarios related to solid-state lighting.

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[j] According to a recent 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. This report, however, was distributed after the FY04 GPRA estimates were prepared, so PNNL's estimates are based on EIA's estimates.

The most recent work pertaining to the goals of the Next Generation Lighting Initiative, however, is a series of cost and performance projections prepared by Lincoln Technical Services (LTS) in the fall of 2002.[k] For the FY05 GPRA effort, the LTS estimates were used exclusively to drive the input assumptions.

The LTS estimates were predicated on a substantial ramp up of funding for this area of research by DOE. Within about five years, the funding for this activity was expected to increase to about $50 million per year, remaining at that level for a decade or longer.

The energy savings path essentially assumes that the technology would not be introduced without DOE support. In part, this assumption stems from the time horizon of the *Annual Energy Outlook 2002* version of NEMS that does not extend beyond 2020.

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 four major groups: 1) incandescent CFL (point source), 2) 4-foot fluorescent, 3) 8-foot fluorescent, and 4) high-intensity point source (outdoor lighting). Solid-state lighting was assumed to penetrate the first three market groupings.

Given the cost 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.

**Table 15** summarizes the cost inputs for some of the key lighting technologies used in NEMS-PNNL for FY 2005. The FY 2005 estimates were based on the efficacy of solid-state lighting reaching 160 lumens/watt in 2010, 180 lumens/watt by 2015, and 208 lumens/ watt by 2018.

### 4.4.2.4 Sources


(1) FY 2002 Budget Request – *Data Bucket Report for Lighting R&D Program* (internal BT document).
(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) A.D. Little. 2001. *Energy Savings Potential of Solid State Lighting in General Lighting Applications*. Prepared for DOE's Office of Building Technology, State and Community Programs by A.D. Little, Cambridge, Massachusetts.
(4) *Annual Energy Outlook 2002*. 2002. Energy Information Administration, Washington, D.C.


[k] Spreadsheet named Dave.data1.xls transmitted by Michael Scholand of Navigant Consulting, Inc. on October 30, 2002.

**Table 15. Solid-State Lighting Cost and Efficiency Assumptions – FY 2005 GPRA**

| | Efficacy (Lumen/ watt) | Light Source Cost ($/kLumen) (2010) | Light Source Cost ($/kLumen) (2017) | Light Source Cost ($/kLumen) (2019) | Light Source Cost ($/kLumen) (2020) | Ann. Oper. Cost ($/yr) |
|---|---|---|---|---|---|---|
| **Incandescent / CFL** | | | | | | |
| Incandescent A19 | 15 | 0.25 | 0.25 | 0.25 | 0.25 | 6.50 |
| CFL (pin-base, 20 watts) | 60 | 4.89 | 4.70 | 4.52 | 4.34 | 1.75 |
| CFL (integral, 20 watts) | 60 | 8.00 | 7.69 | 7.39 | 7.10 | 1.75 |
| Solid state (2017 intro) | 160 | NA | 12.00 | 12.00 | 12.00 | 0.87 |
| Solid state (2019 intro) | 164 | NA | NA | 11.20 | 11.20 | 0.87 |
| **4-foot Fluorescent** | | | | | | |
| Halogen reflector lamp | 14 | 5.84 | 5.84 | 5.84 | 5.84 | 15.77 |
| F32T8 Electronic | 80 | 1.01 | 0.97 | 0.93 | 0.90 | 2.80 |
| Solid state (2017 intro) | 160 | NA | 12.00 | 12.00 | 12.00 | 2.53 |
| Solid state (2019 intro) | 164 | NA | NA | 11.20 | 11.20 | 0.87 |
| **8-foot Fluorescent** | | | | | | |
| F96T12 - Electronic ES | 61 | 3.01 | 2.89 | 2.77 | 2.66 | 5.25 |
| F96T12 - Electronic HO | 52 | 1.88 | 1.81 | 1.74 | 1.67 | 9.64 |
| Solid state (2017 intro) | 160 | NA | 12.00 | 12.00 | 12.00 | 2.50 |
| Solid state (2019 intro) | 164 | NA | NA | 11.20 | 11.20 | 0.87 |
| NA = Not applicable. | | | | | | |

## 4.5 Space Conditioning and Refrigeration R&D

### 4.5.1 General Target Market

**Project Description.** This project develops and promotes the use of commercial food display and storage technologies that use less energy and less refrigerant. Water-heating activities are centered on developing low-cost, high-reliability heat pump water heater concepts. The project's HVAC delivery (e.g., duct work) technologies are intended to reduce the energy losses incurred in transferring heating or cooling from the conditioning units (e.g., heat pump, furnace, and air conditioner) to the conditioned space. The refrigerant pressure charge meter and coefficient of performance (COP) meter enables early warning of poor operation of HVAC equipment to keep installed equipment operating at design efficiencies during the service life.

**Market Description:**[(1)] The market includes commercial refrigeration, a broad classification of building equipment that collectively consumes about one quad of U.S. energy annually.[(2)] Supermarkets consume about one-third of the energy used in commercial refrigeration. Residential applications include air conditioners, heat pumps, heat-pump water heaters, and thermal distribution systems associated with forced air systems.

**Size of Market:** [(1)] Commercial refrigeration markets include about 30,000 large supermarkets and 100,000 convenience stores. Other markets include hospitals, large institutional buildings, and restaurants. Residential markets include new, single-family, and existing homes.

**Baseline Technology Improvements.** For this analysis, PNNL did not suggest any changes in technology improvements, apart from the EIA baseline.

## 4.5.2 Residential HVAC Distribution Systems

### 4.5.2.1 Target Market

**Project Description.** The Zero Cubic Feet per Meter (CFM) Loss Duct have the following characteristics:

- Shop-fabricated round ducts that are ready for installation. Installation consists of inflation of the double walled duct followed by connection to registers and supply. Then space between duct walls is filled with moisture resistant spray foam insulation (R-8) which resists vapor condensation on cold surfaces during cooling.
- Applicable to residential and light commercial (e.g., small commercial buildings where the chief energy efficiency issue regarding ventilation is thermal loss from the ducts).
- Applicable to new construction and retrofit.
- Applicable only to ducts in crawl space and attic.
- Result is CFM duct leakage approaching 0 CFM.
- Project includes market deployment element, specifically development of materials (CDs and brochures) designed to inform the home owner about the advantages of the technology

**Market Description.** The seasonal heating distribution includes conduction through duct walls, as well as air leakage through duct system holes and joints for ducts located in unconditioned spaces. The seasonal heating distribution efficiency of typical current ducts is about 56% and 72% for good conventionally designed ducts with R-4 duct insulation.[l] For this analysis, PNNL assumed that existing homes have “typical ducts” and new homes would have “good conventionally designed ducts.” The seasonal cooling distribution efficiency of typical current ducts is about 75% and 87% for good conventionally designed ducts with R-4 duct insulation.[m]

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[l] Brookhaven National Laboratory. 2001. *Better Duct Systems for Home Heating and Cooling*. BNL-68167, Vol. 4, Upton, New York, p.10.
[m] ibid.

Given the limited use of ducts in unconditioned spaces in light commercial buildings,[n] this analysis was limited to residential applications. Compensating for this is the assumption that all residential duct work is in unconditioned spaces.

#### 4.5.2.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.** This product is expected to have the following characteristics:

- Cost is less than current ductwork for new homes.
- Cost is $1,000 for materials, plus one person-day labor ($250) for installation in retrofit (include disconnection and moving aside of existing duct work)

#### 4.5.2.3 Methodology and Calculations

**Inputs to Base Case.** The base case was developed based on an assortment of sources, including AEO 2003, CBECS 95, RECS 97, and several other sources, all of which are documented in the 2004 PNNL report, *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort* (Elliott, et. al).

**Technical Characteristics.** Zero CFM Loss Ducts (a.k.a. push button ducts) have the following characteristics:

- Shop fabricated round ducts that are ready for installation. Installation consists of inflation of the double-walled duct followed by connection to registers and supply. Then space between duct walls is filled with moisture-resistant spray foam insulation (R-8)—resists vapor and condensate on cold surfaces during cooling.
- Applicable to residential and light commercial.
- Applicable to new construction and retrofit.
- Applicable only to ducts in crawl space and attic.
- Result is ~0 CFM duct leakage.
- Project is going to include development of materials (CDs and brochures) designed to "sell" the home owner on the concept

The estimated improvement in heating and cooling system seasonal distribution efficiency is shown in **Table 16**.

**Table 16. Assumed Reductions in Energy Use for Residential HVAC Distribution Systems**

| *System* | *Heating* | *Cooling* |
|---|---|---|
| Current Technology Existing Buildings | 56 | 75 |
| Current Technology New Buildings | 72 | 87 |
| R-8 Ducts with 5% Leakage[o] | 80 | 90 |
| BT Technology[p] | 87 | 95 |

[n] Light commercial, a.k.a. small commercial are buildings where the chief energy efficiency issue regarding ventilation is thermal loss from the ducts whereas for large commercial the chief ventilation energy efficiency issue is fan power. (Andrews, John W, and Mark P Modera. July 1991. *Energy Savings Potential for Advanced Thermal Distribution Technology in Residential and Small Commercial Buildings.*)

[o] ibid.

**Expected Market Uptake.** This product is intended to be used in both new construction and retrofit applications. 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 sales attributable to DOE, as PNNL assumed that the DOE project would accelerate market acceptance by 10 years.

- Penetration (fraction of sales in ducted residences) for new buildings is 2008 introduction, 50% in 2020, and 80% in 2030. With about 90% of new residential construction using ducts,[q] the penetration across all new residential construction (percentage of residential buildings constructed that year) is 45% (50% * 90%) in 2020, and 72% (80% * 90%) in 2030 (**Figure 7**).
- Penetration (fraction of sales) for existing buildings is 2008 introduction, 25% in 2020, and 40% in 2030, assuming this only occurs when making an HVAC equipment change (i.e., once every 20 years). With 50% of existing homes having ducts[r], and only 1/20 of the homes receiving new HVAC equipment each year, the penetration across all existing residential building (percentage of buildings receiving the technology that year) is 0.625% (25% * 50% * 1/20) in 2020, and 1.25% (50% * 50% * 1/20) in 2030 (**Figure 8**).

[p] Heat system performance improves from 56% to 72% (a 16 percentage point improvement) by reducing typical duct leakage loss of 17% to 5%; hence, reducing from 5% to 0% can be expected to save an addition 6.66 (5/12 * 16) percentage points. Cooling system performance improves from 75% to 87% (a 12 percentage point improvement) by reducing typical duct leakage loss of 17% to 5%; hence, reducing from 5% to 0% can be expected to save an addition 5 (5/12 * 12) percentage points. These savings are added to the benefit of going from the current designs shown in the table to a design with 5% leakage and R-8 insulation.

[q] Brookhaven National Laboratory. 2001. Better Duct Systems for Home Heating and Cooling. BNL-68167, Vol. 3, Upton, New York, p.1.

[r] ibid.

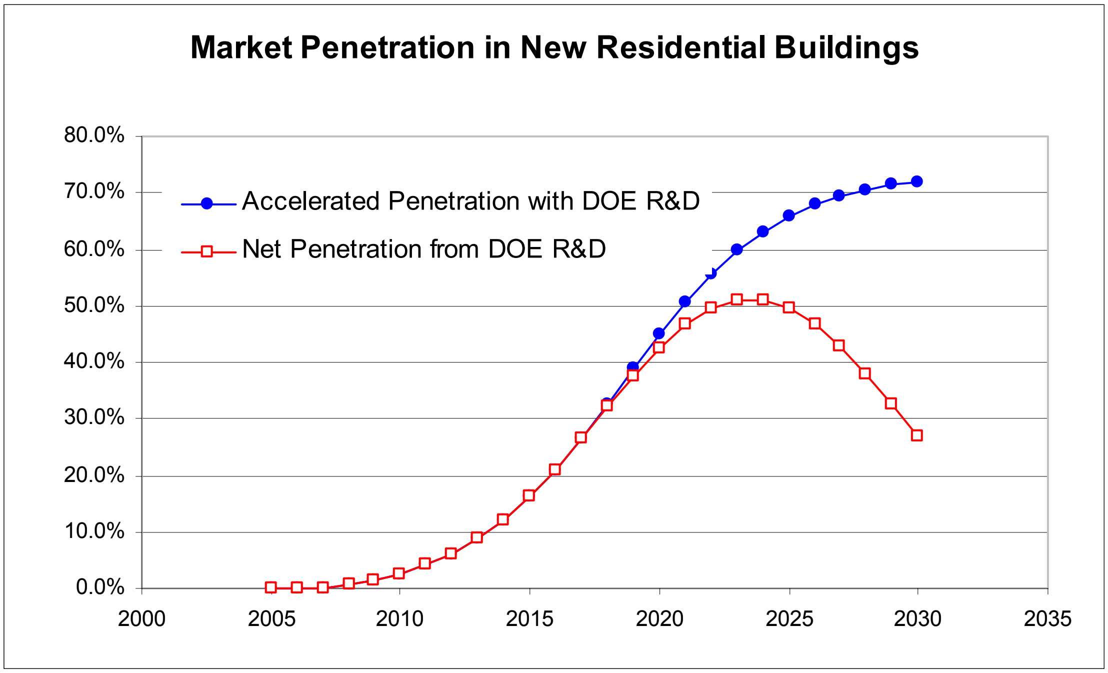


**Figure 7. Market Penetration of HVAC Distribution in New Residential**

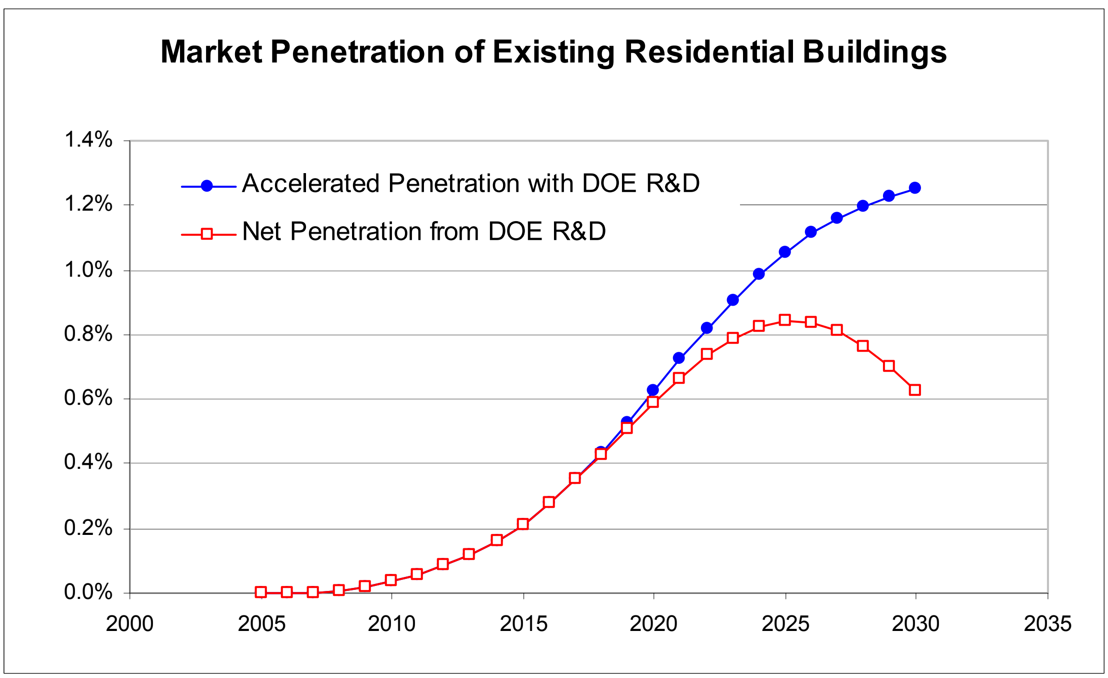


**Figure 8. Market Penetration of HVAC Distribution in Existing Residential**

### 4.5.3 Advanced Electric Heat Pump Water Heater

#### 4.5.3.1 Target Market

**Project Description.** The goal of this technology is to increase the efficiency of residential and commercial electric water heating equipment and reduce peak energy use. The purpose of this project is to improve the cost effectiveness of heat pump water heaters mainly through lower capital costs.

**Market Description:** Residential and commercial.

**Market Introduction:** 2005; this project was assumed to accelerate the introduction of this technology into the marketplace by 10 years.

**Performance Target:** 1.8 energy factor.

#### 4.5.3.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.**

- Cost of Conventional Technology: $350
- Cost of BT Technology: $1025
- Incremental Cost: $675/unit.

### 4.5.4 Commercial Refrigeration

#### 4.5.4.1 Target Market

**Project Description.** DOE is working to improve the efficiency of refrigerated display cases and developing methods of recovering reject heat for space conditioning. This project was modeled as an advanced supermarket refrigeration system that would target heating, cooling, and refrigeration end-use loads in the commercial food sales sector. The heating and cooling reductions occur because commercial refrigeration equipment draws a large amount of heat from the conditioned space, which must be made up by the heating equipment. In addition, heat energy can be recovered and used by the heating equipment, thus reducing the heating energy consumption and cost. These end uses comprise about 66% of total building, 67% of electric, and 61% of total natural gas end-use energy consumption.[(3)]

**Displaced Technology:** Conventional refrigeration equipment in food-sales buildings.

**Performance Target:** Reduced energy for building HVAC and refrigeration equipment during the next 15 to 20 years, specifically at least 15% for supermarket refrigeration and HVAC while reducing refrigerant needed. For FY 2005, PNNL assumed an overall 22.5% reduction in HVAC end-use energy consumption.

**Market Description:** All commercial food-sales buildings.

**Market Introduction:** 2004; PNNL assumed this project would accelerate the introduction of this technology into the marketplace by 10 years.

### 4.5.5 Refrigerant Meter

#### 4.5.5.1 Target Market

**Project Description.** This technology will increase the efficiency of residential and commercial space conditioning equipment and reduce peak energy use. Most air-conditioning units and heat pumps have an improper refrigerant charge level or other issue resulting in a COP that is lower than the rated design. These meters will inform the homeowner or business owner of the current state of charge or performance of their space conditioning equipment and ultimately the increased cost. PNNL determined this project's energy savings by using BEAMS and applying overall percentage reductions in vapor compression heating and cooling energy consumption.

**Market Description.** Residential and commercial space-conditioning equipment.

#### 4.5.5.2 Key Factors in Shaping Market Adoption of EERE Technologies

**Price.** This product is expected to have the following characteristics:

- Cost of Conventional Technology: $0.
- Cost of BT Technology: $100.
- Incremental Cost: $100.

#### 4.5.5.3 Methodology and Calculations

**Inputs to Base Case.** The base case was developed based on an assortment of sources, including AEO 2003, CBECS 95, RECS 97, and several other sources, all of which are documented in the 2004 PNNL report, *Methodological Framework for Analysis of Buildings-Related Programs: The GPRA Metrics Effort* (Elliott, et. al).

**Technical Characteristics.** This technology will increase the efficiency of residential and commercial space conditioning equipment and reduce peak energy use. Most air-conditioning units and heat pumps have an improper refrigerant charge level or other issue resulting in a COP that is lower than design. These meters will inform the homeowner or business owner of the current state of charge or performance of their space conditioning equipment and ultimately the increased cost. Given this information, that is not readily available, it is expected that prudent owners will get the situation corrected. PNNL determined this project's energy savings by using BESET and applying overall percentage reductions in vapor compression heating and cooling energy consumption.

**Table 17. Assumed Reductions in Energy Use for Refrigerant Pressure Charge Meters and COP Meters**

| End Use | Percentage Reduction in Energy Consumption |
|---|---|
| Residential Heat Pump Heating | 23.9* |
| All Residential Cooling (includes heat pumps) | 23.9 |
| Commercial Heat Pump Heating | 12.0** |
| Commercial Vapor Compression Cooling (includes heat pumps and excludes chillers) | 12.0 |

* This value is based on a frequency distribution of undercharging and overcharging and on an efficiency impact associated with each level of undercharging and overcharging. http://www.proctoreng.com/checkme/technical.html.
** While the impact of undercharging and overcharging in commercial equipment is roughly the same as residential equipment, the frequency of undercharging and overcharging is believed to be about half that in residential equipment.

**Expected Market Uptake.** The market penetration goal is to impact 50% of all applicable residential units by 2020 and 90% of all applicable commercial units by 2020 (see **Figure 9** and **Figure 10**). 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 sales attributable to DOE, as PNNL assumed that the DOE project would accelerate market acceptance by 10 years.

### 4.5.6 Sources

(1) FY 2002 Budget Request - *Data Bucket Report for Space Conditioning and Refrigeration: Refrigeration Program* (internal BT document).
(2) Arthur D. Little, Inc. 1996 *Energy Savings Potential for Commercial Refrigeration Equipment.* Reference 46230-00. Cambridge, Massachusetts.
(3) Belzer, D.B and L.E. Wrench. 1997. *End-Use Consumption Estimates for U.S. Commercial Buildings, 1992*. PNNL-11514, Pacific Northwest National Laboratory, Richland, Washington.
(4) Brookhaven National Laboratory. 2001. *Better Duct Systems for Home Heating and Cooling*. BNL-68167, Vol. 4, Upton, New York, p.10.
(5) Brookhaven National Laboratory. 2001. *Better Duct Systems for Home Heating and Cooling*. BNL-68167, Vol. 3, Upton, New York, p.1.

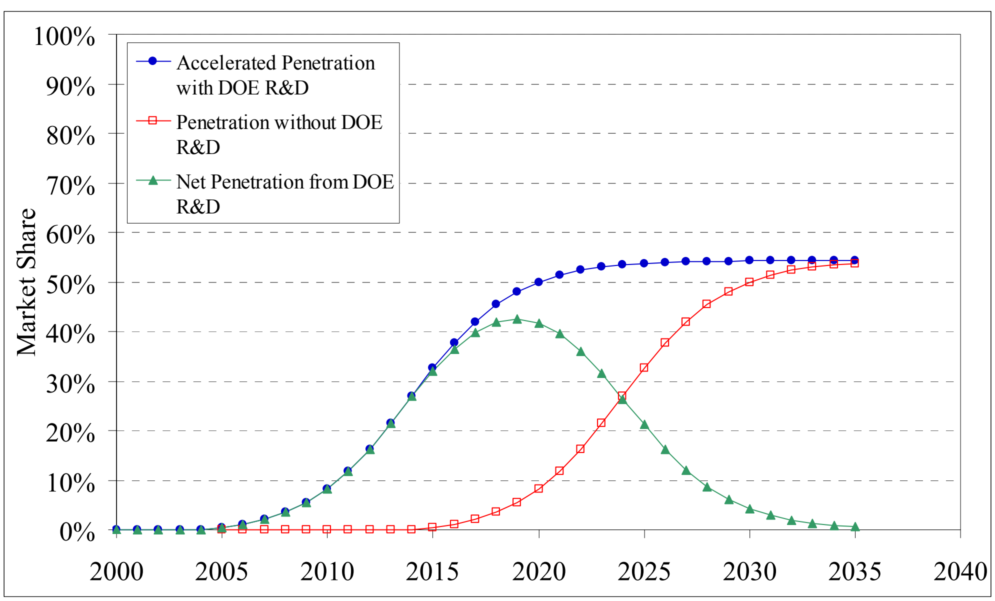

**Figure 9. Residential Market Penetration Curves for COP and Refrigerant Pressure Change Meters**

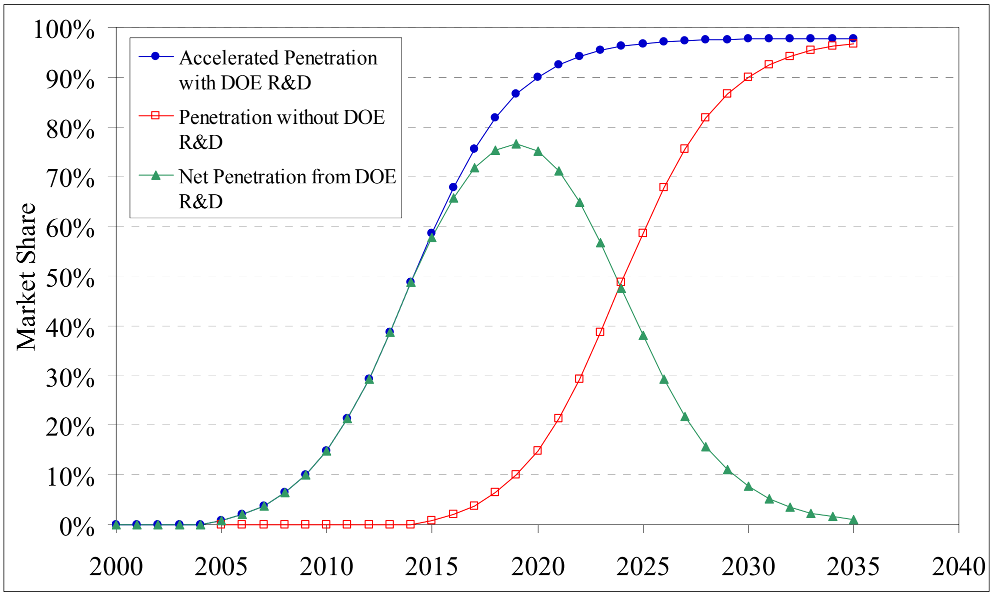


**Figure 10. Commercial Market Penetration Curves for COP and Refrigerant Pressure Change Meters**